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Study of Roost Selection and Habits of a Bat, *Hipposideros armiger* in Mainland China

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Abstract.- Roost selection, perching activity habits and the degree of human disturbance of a bat, *Hipposideros armiger* were studied from December 2010 to September 2013 in mainland China. Sixty-nine potential roosts were investigated. Among those, 54 roosts were occupied by bats, of which 20 roosts were used by *H. armiger*. The differences of various roosts were compared by measuring the structural characteristics of these roosts, the microenvironment and the degree of human disturbance. Comparing the 54 roosts used by bats with the 15 roosts not used by bats, it was found that the former had fewer entrances, larger volumes, longer cave lengths, higher temperatures and lower illuminance. Fifteen hibernation roosts of *H. armiger* had relatively lower illuminance and fewer entrances. Eleven breeding roosts of *H. armiger* had relatively longer cave lengths and lower illuminance, whereas the temperature and humidity were relatively high. *H. armiger* do not often co-inhabit roosts with other species. However, sometimes they co-inhabit roosts with *Hipposideros pratti*. Pregnant females give birth to a single young each year between May and early June. During the breeding and young rearing periods, the males and females usually live in different roosts, except for a few males that remain with the females in the breeding place.

Key words: Roost selection, *Hipposideros armiger*, conservation, degree of human disturbance.

INTRODUCTION

Bats spend over half of their lives in roosts, which provide them with protection and sites for resting, mating, hibernation, rearing young, and social interactions (Kunz, 1982). Although many bat species use caves only as an alternate refuge, some species rely completely on caves for day roosting. In Mexico, for example, 45% (60 of 134) of bat species are cave dwellers, with 27 using caves as the main roost and 33 additional species using caves occasionally (Arita, 1993). In Europe, caves are used regularly or occasionally by 46 bat species (Nagy and Postawa, 2011).

Roost selection by bats depends on many factors, including temperature, humidity, air flow, light intensity, safety from predators, proximity to foraging areas, and take-off height (Morrison, 1980; Tuttle and Stevenson, 1981; Kunz, 1982; Hill and Smith, 1984; McCracken, 1989). Occupation of roost sites with an appropriate microclimate can minimize the energetic costs related to thermoregulation, food digestion and assimilation, maintenance of a permanent state of alertness (which allow bats to avoid predation and to interact socially), gestation, embryonic development, parental care, lactation, and spermatogenesis (Kunz, 1973; Humphrey, 1975; Tuttle and Stevenson, 1981; McNab, 1982; Hill and Smith, 1984; Bonaccorso *et al*., 1992; Hamilton and Barclay, 1994).

The microclimate of a cave is dependent on latitude, longitude, and altitude as well as the length of the caves, the number of entrances, and the average temperature (Kowalski and Archeologiczne, 1954). The number of bat species using a cave is correlated with the length of the cave (Arita, 1996), the density of underground sites in each area (Brunet and Medellin, 2001) and environmental factors, such as geographical location and temperature range (Řehák, 2006; Ulrich *et al*., 2007).

Most bats use a variety of roosts, including man-made structures (Kunz, 1982; Fenton, 2001). Many species can endure a wide range of roost conditions. The roosting ecology of bats has been well studied for species in the temperate zone. Bats may use different roosts according to different requirements for environmental conditions in different seasons. In the winter, most temperate

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zone bats hibernate in cooler roosts so they can survive through the period of cold and food shortages (Kurta, 1986). In the summer or the breeding season, maternity colonies usually exist in roosts with higher ambient temperatures (Henshaw, 1960; Betts, 1997; Entwistle *et al*., 1997; Williams and Brittingham, 1997). Reproductive females, which need to maintain a higher body temperature to facilitate fetal growth, may take advantage of higher ambient temperatures in roosts to reduce metabolic energy expenditure (McNab, 1982). In contrast, males or non-breeding females, which do not have the pressure of maintaining a higher body temperature for fetal growth, choose roosting sites with lower ambient temperatures and frequently use torpor to reduce metabolic energy expenditure (Hamilton and Barclay, 1994).

Bats are sensitive to climate change and roost deterioration and have been recognized as valuable bio-indicators (Jones *et al*., 2009). The suitability and availability of roosts may influence the survival, reproduction, and distribution of bats (Humphrey, 1975). Because of cave exploitation for tourism, the extensive use of pesticides, the demolition of many old buildings and the inclusion of bats in the diet, bat populations in China appear to have decreased considerably in the last 30 years (Zhang *et al*., 2009).

The great leaf-nosed bat *Hipposideros armiger* (Hipposideridae, Chiroptera), one of the largest species within the genus *Hipposideros*, typically roosts in caves and feeds in open spaces in woodlands, gardens and around trees (Bates and Harrison, 1997). It is characterized by high wing loading, low aspect ratio, and average wing tip shape index (Wei *et al*., 2011). The wing loading is a measure of the surface area of the wings compared to the body weight. The aspect ratio describes the shape of the wings, and a low aspect ratio corresponds with shorter wings and less efficient flight. The wing tip shape index quantifies the pointedness of the wing tips (Jennings *et al*., 2004). The flight behavior of bats is correlation with wing loading, aspect ratio and wing tip shape index (Norberg and Rayner, 1987). *H. armiger* has a wide Asian geographical distribution that includes India, Nepal, Myanmar, Vietnam, Laos, Cambodia, Thailand, China and the Malay Peninsula (Simmons *et al*., 2005; Bates *et al*., 2007). In mainland China, it is widely distributed in 13 provinces of South China (Wang, 2003).

Studies on *H. armiger* have been conducted on the relationships between eco-morphology and prey selection (wang *et al*., 2005), echolocation calls (Bogdanowicz *et al*., 1999; Zhao *et al*., 2003), karyology analysis (Gu, 2001; Wu *et al*., 2003), some mitochondrial DNA sequences (Li *et al*., 2006), characterization of microsatellite loci (Guo *et al*., 2008), phylogeography (Lin *et al*., 2013), evolutionary analysis (Chen *et al*., 2014), and roost selection in Taiwan (Ho and Lee, 2003). However, in mainland China, the conservation state of their roosts, the habits of the species, the role of cave microclimate and other environmental factors influencing the distribution of this species are poorly known.

South China is characterized by numerous high mountains, deep valleys, large rivers, and environmental heterogeneity and harbors many species (Li and Fang, 1999). To understand the microclimate and structure of caves, the surrounding habitat, disturbance by humans, and relative abundance of *H. armiger* and to examine the differences in the environmental conditions of caves used by the species in different seasons, 69 underground sites in nine provinces in south China were investigated in a 3-year study (from December 2010 to September 2013). Such information is critical for improving the conservation management of this species and for determining whether economic development and biological conservation are indeed compatible.

MATERIALS AND METHODS

Study sites

This research was conducted in nine provinces in south China (N18°30'21"-30°26'12", E98°49'31"-118°15'10"). Among these provinces, Hainan is located in a tropical zone. Jiangxi, Fujian, Hunan, Guizhou and Sichuan Provinces are situated in a subtropical zone. Yunnan, Guangdong and Guangxi Provinces stretch across tropical and subtropical zones (Fig. 1).

Roost characteristics

Sixty-nine potential roosts were found using

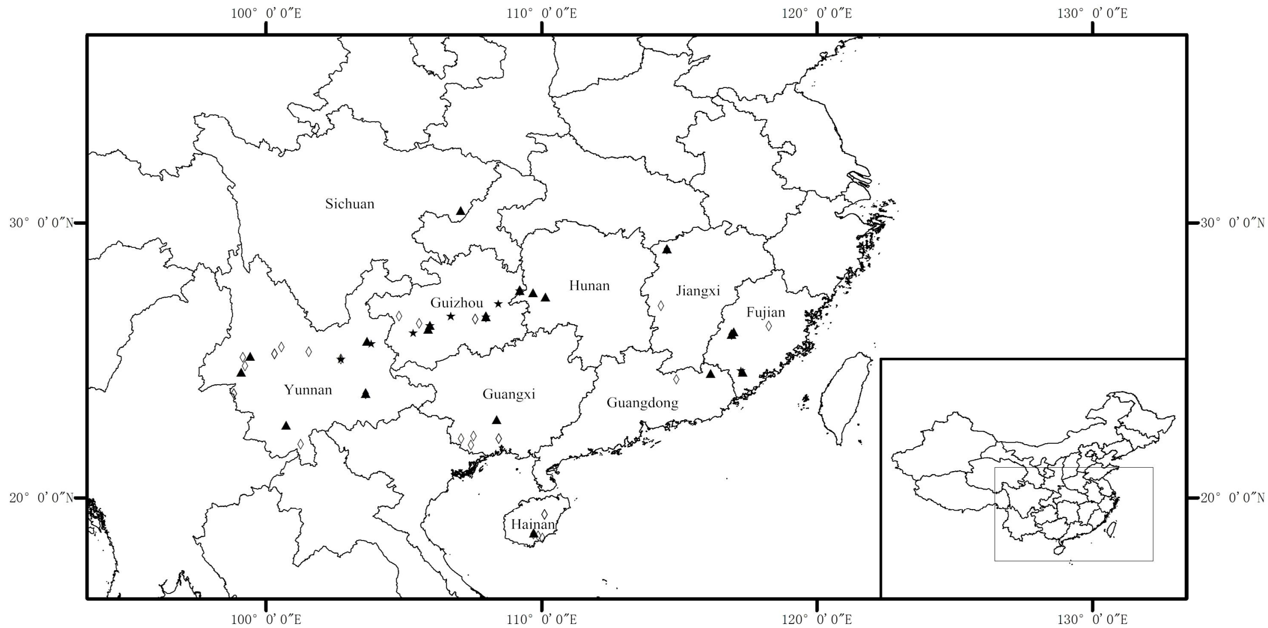

Fig. 1. Map of the research area and locations of surveyed roosts. Triangle symbols (▲): roosts used by *H. armiger*; Diamond symbols (◇): roosts used by other bat species; Star symbols (★): roosts not used by any bat species.

previous records and field survey. Fifty-four of these roosts are currently being used by various species of bats, including *H. armiger*. All of the roosts in natural caves and other man-made underground structures, such as abandoned mines and tunnels, are located in a mountainous area and are nearby natural forests or secondary forests. All fieldwork abided by the Law of the People's Republic of China on the Protection of Wildlife. The fieldwork was conducted during four periods: December 2010–March 2011, June–September 2011, December 2011–March 2012 and July–September 2013. Each cave was visited at least twice (once in the summer period when the bats are active and once during their hibernation period).

Nineteen structural variables were recorded for each of the 69 potential roosts. These include the elevation of the roost, the maximal height and width of the passage, the number of entrances and the number of chambers, the orientation of the entrances, the height and width of the entrances, the total lengths of all tunnels, the average height and width of all tunnels, the volume of the roost, the distance to the nearest water source, the total floor area covered by water inside the roost, the air temperature and relative humidity in the tunnels, the longitude and latitude of the entrances and the light intensity.

At each visit, we measured the air temperature and relative humidity using a digital thermo-hygrometer (Guangdong Benetech, GM1360; precision ± 1%, and relative humidity: ± 3°C). Light intensity was measured with a light meter (precision: 0.1 lux, Hong Kong Smart sensor, AR823) at sites where bats were present or at equivalent sites within roosts that were not being used by bats. The light intensity was divided into three levels: (1) > 10 lux, (2) 0.1 lux–10 lux, and (3) < 0.1 lux. The area covered by water was classified into four levels: (1) > 85%, (2) 50%–85%, (3) 15%–50%, and (4) < 15%.

For the caves that are used for tourism, the frequency of human activities in the caves and the degree of disturbance to the underground roosts are categorized into three levels: (1) serious disturbance (exploited for tourism, burning incense, fireworks, and firecrackers), (2) light disturbance (burning incense, and occasional visiting by people), and (3) no disturbance (no human activities in the caves). We also measured the distance of each roost to both the nearest road and the nearest building as an index of disturbance.

Roosts used by *H. armiger* were categorized into hibernacula and summer roosts. Summer roosts were further divided into breeding roosts consisting mainly of reproductive females and non-breeding roosts consisting mainly of males.

Biological data

Bats were captured nightly and daily at entrances or inside caves by using mist nets and hand nets. Calipers and a digital electronic scale (Guangdong Weiheng WH-DS01, accuracy = 0.01 g) were used to take measurements of the length of the forearm, the body size, the body mass, the length of some fingers, and the length of the hind foot. We obtained information about sex, age (juvenile or adult) and reproductive status (only for females: inactive, pregnant, or lactating) partly to determine roost use: hibernacula, maternity roost, or non-breeding male and/or female roosts. Bat species were identified based on their morphological characteristics following the method of Smith *et al.* (2009). All captured bats were released as soon as possible after being measured.

For measuring the population sizes of *H. armiger* and other bat species, the number of bats in a colony < 50 individuals were directly counted. For larger clusters and mixed species groups, the colony was photographed using a digital camera and the bats were counted from the photos.

Statistical analysis

Data analysis was performed in SPSS 13.0 for Windows. The independent- samples T test was used to determine significant differences in the characteristics of the different roosts. In addition, the characteristic data of the roosts were also processed using the principal component analysis method. The Chi-square test was used to determine significant difference in the orientation of the entrances and in the selection of the cave types. Moreover, the Chi-square test was also used to evaluate the degree of human disturbance on the roosts.

RESULTS

Roost characteristics and microclimate

Among the 69 roosts, 54 were occupied by bats, and *H. armiger* occupied 20 of the roosts. Among these 20 roosts, 11 roosts were breeding roosts and nine roosts were non-breeding roosts. Moreover, ten roosts had more than 200 *H. armiger,* seven roosts contained between 100 and 200 bats, and three roosts contained less than 100 bats. All 20 of these roosts were summer roosts and 15 of them were also used by *H. armiger* in the winter. Eighteen of the 20 roosts were also occupied by other bat species, including *Hipposideros pratti, Hipposideros larvatus, Hipposideros pomona, Aselliscus stoliczkanus, Rhinolophus rex, Rhinolophus ferrumequintum, Rhinolophus cornutus, Rhinolophus thomasi, Rhinolophus pusillus, Rhinolophus affinis, Myotis ricketti, Myotis frater, Myotis chinensis, Myotis altarium, Miniopterus schreibersii, Nyctalus noctula, Nyctalus velutinus, Ia io, Pipistrellus abramus* and *Taphozous melanopogon*.

All of the 69 roosts were located at elevations between 41 m and 2098 m. The elevations of the 54 roosts occupied by bats were between 41 and 2098 m. Fifteen hibernacula of *H. armiger* were between 89 m and 2042 m. Five roosts used by *H. armiger* only in the summer had elevations between 201 m and 1130 m. Eleven breeding roosts had elevations from 109 to 2042 m, and nine non-breeding roosts were between 89 m and 1130 m. The data indicate that the roost selection of *H. armiger* is unrelated to altitude (Table I). Forty-seven potential roosts had only one entrance, 13 had two entrances, four had three entrances, and five had four entrances. The distances from 35 of these roosts to the nearest permanent water source were within 100 m. Thirty-one roost-water distances were between 100 m and 500 m, and three were greater than 500 m (Table I).

Compared the 54 roosts used by bats with 15 roosts without bats, it was found that the former had fewer entrances, larger volumes, longer cave lengths, higher temperatures and lower illuminance. When the 20 roosts occupied by *H. armiger* were compared with the other 34 roosts without this species, no significant difference was detected in the physical structure of the roosts, light intensity, relative humidity and roost temperature ($p > 0.05$). When the 15 hibernation roosts of *H. armiger* were compared with non-hibernacula roosts, there was a significant difference in light intensity ($p<0.05$), and

Table I.- Characteristics of the different types of bat roosts investigated in mainland China. Variables are expressed as the means ± standard deviation (SD).

Variables	Roost type					
	HR	OR	HRW	HRS	HB	HNB
Sample size	20	34	15	5	11	9
Elevation of the roost (m)	754.55± 614.45	928.06± 730.0	850.53± 656.94	466.60± 380.40	1058.09± 648.35	392.25± 318.99
Number of entrances	1.75± 1.11	1.62± 0.88	1.27± 0.45	2.40± 1.14	1.91± 1.22	1.56± 1.01
Distance to nearest permanent water (m)	131.00± 130.25	251.47± 306.71	101.33± 105.75	220.00± 168.07	120.00± 117.47	144.44± 150.59
Height of entrances (m)	4.03± 2.35	9.01± 17.87	3.64± 1.53	5.22± 3.96	4.02± 1.55	4.04± 3.18
Width of entrances (m)	4.53± 5.06	6.69± 12.55	4.31± 5.24	5.20± 4.99	4.91± 6.06	4.07± 3.79
Maximal height of the roost (m)	11.31± 6.99	13.95± 19.84	11.18± 7.62	11.71± 5.39	13.70± 7.27	8.39± 5.72
Maximal width of the roost (m)	10.03± 7.02	12.92± 17.23	9.18± 7.41	12.56± 5.57	11.30± 7.58	8.46± 6.35
Average height of all roosts (m)	7.16± 3.66	11.63± 18.38	6.77± 3.38	8.35± 4.63	8.04± 2.939	6.10± 4.33
Average weigh of all roosts (m)	6.76± 3.89	9.26± 12.52	5.86± 3.350	9.46± 4.55	6.91± 3.23	6.56± 4.78
Total length of all roosts (m)	511.85± 544.26	394.06± 539.09	599.33± 526.12	166.00± 72.66	639.09± 472.30	311.67± 221.58
Air temperature (°C)	20.54± 3.59	21.89± 3.24	20.15± 3.12	21.72± 4.99	21.11± 1.85	18.74± 1.97
Relative humidity in roost (%)	84.47± 5.12	78.38± 12.23	84.06± 5.40	85.70± 4.48	87.35± 3.08	81.47± 4.26
Total floor area covered by water (m^2)	26.10± 28.14	31.147± 31.11	29.00± 31.04	17.40± 16.21	23.09± 25.96	30.33± 31.24
Volume of the roost (m^3)	21503.42± 28312.65	189014.35± 842229.52	24613.53± 31255.79	12869.07± 7193.27	31661.32± 35280.00	8639.61± 8639.08
Light intensity (lux)	6.08± 16.95	6.70± 21.74	0.10± 0.00	24.04± 28.76	0.10±. 00	13.94± 23.65

HR represents roosts occupied by *H. armiger*; OR represents roosts occupied by other bat species but without *H. armiger*; HRW represents hibernacula of *H. armiger*; HRS represents non-hibernacula of *H. armiger*; HB represents breeding roosts of *H. armiger*; HNB represents non-breeding roosts of *H. armiger*.

the hibernacula had a lower light intensity. Moreover, in a comparison of the 11 breeding roosts of *H. armiger* with the nine non-breeding roosts, the results indicate that there was a significant difference in relative humidity and temperature between the roosts ($p<0.05$). Breeding roosts had higher air temperature and relative humidity (Table Π).

For the 20 roosts used by *H. armiger*, cave entrances facing north and northeast account for 20% each, and cave entrances facing south, northwest and southwest account for 13.3% each. Finally, cave entrances facing east, west and southeast account for 6.7% each. Among the 34 roosts inhabited by other species, cave entrances facing north account for 20%. Cave entrances facing south, west, and northeast account for 16% each. Cave entrances facing east and northwest account for 4% each. Cave entrances facing southeast and southwest account for 12% each (Fig. 2a). According to the Chi-square test, there was no significant difference in the orientation of the entrances between the 20 roosts inhabited by *H. armiger* and the 34 roosts not inhabited by this species ($\bar{x}$ = 2.870, df = 3, p = 0.412).

A survey of all of the caves revealed that

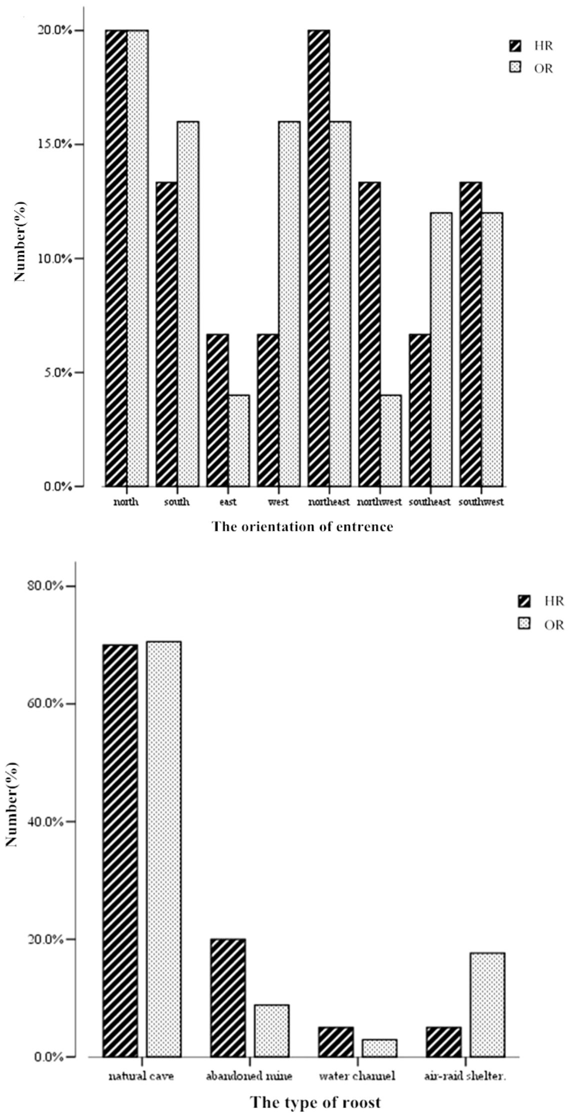

Fig. 2. A, The orientation of the entrance; B, The type of roost. HR, roosts occupied by *H. armiger*; OR, roosts occupied by other bat species but without *H. armiger*.

there are four different types of caves: 51 (73.9%) natural caves, 8 (11.6%) abandoned mines, 2 (2.9%) water channels and 8 (11.6%) air-raid shelters. For the 20 roosts used by *H. armiger*, natural caves accounted for 70%, abandoned mines accounted for 20%, and water channels and air-raid shelters accounted for 5% each. Among the 34 roosts used by other species, 70.6% were natural caves, 8.8% were abandoned mines, 2.9% were water channels, and the remaining 17.7% were air-raid shelters (Fig. 2 b). According to the Chi-square test, there was no significant difference in the number of the cave types between the 20 roosts inhabited by *H. armiger* and the 34 roosts inhabited by other species and not *H. armiger* ($\bar{x}$ = 2.912, df = 3, p = 0.405).

Degree of disturbance

When the roosts used by *H. armiger*, including both the hibernation and breeding roosts, were compared with non-hibernacula and non-breeding roosts, there was no significant difference in the distance to the nearest road or building (Table П), but this distance was related to the degree of disturbance. The distance to the roosts under serious disturbance was smallest, whereas roosts in the nature state had a longer distance to areas of human disturbance. Among the 54 roosts inhabited by bats, 14 roosts were under serious disturbance, 18 roosts were under light disturbance and 22 roosts were in natural state. When the 20 roosts inhabited by *H. armiger* were compared with 34 roosts not occupied by this species, a significant difference was found in the degree of disturbance ($p < 0.05$). Roosts inhabited by *H. armiger* had relatively less disturbance (Table Ш). Many *H. armiger* in 7 roosts were hunted by people, leading to a sharp reduction in the number of them. Other species were also hunted by people as food.

Principal component analyses were performed on the variables of the 20 roosts inhabited by *H. armiger.* The first four principal components account for 80.58% of the total variation, which best reflects the roost selection of *H. armiger.* The largest absolute load values of the first principal components are observed for the maximal height of the roost and the maximal width of the roost. The largest absolute load values of the second principal components are the total lengths of the roost and the volume of the roost. The largest absolute load value of the third principal components is the relative humidity in the roost. The largest absolute load value of the fourth principal components is the distance to the nearest permanent water source (Table IV).

Habits

Different species of bats generally occupy different positions within the roosting caves. For natural caves and abandoned mines, *H. armiger* always perched on the highest point of their roosts, 30 to 150 m from the entrances in summer. In winter, they usually inhabited deeper and lower parts of the roost. For human made air-raid shelters and water channels, the roost sites of *H. armiger* were close to the entrances in summer. Nevertheless, in winter, *H. armiger* usually inhabited the middle of channels, 200 m away from the entrances (Fig. 3). They usually form a colony and perch together on the inner recesses of the smooth ceiling where there is less light. *H. armiger* do not typically co-inhabit roosts with other species. However, sometimes they co-inhabit roosts with *Hipposideros pratti*. The colony size of *H. armiger* usually ranges from several to hundreds of individuals, and bats assemble with individual distances of approximately 100-150 mm from each other.

Table II.- The comparison of the characteristics and distance to the human disturbances of roosts used by *H. armiger*.

	Number of entrances	Relative humidity in roosts	Temperature in roosts	Total lengths of all tunnels	Volume of roosts	Light intensity	Disturbance distance of roosts
HR & OR							
T value	0.480	2.55	-1.415	0.773	-0.886	-0.109	0.072
P	0.633	0.014	0.163	0.443	0.380	0.914	0.943
HRW & HRS							
T value	-2.165	-0.610	-0.836	1.804	0.819	-3.418	2.087
P	0.09	0.550	0.414	0.088	0.424	0.03*	0.055
HB & HNB							
T value	0.694	3.574	2.774	1.908	2.116	-1.756	1.761
P	0.497	0.002*	0.013*	0.072	0.048	0.117	0.096

*Significantly different ($p < 0.05$) according to the independent-samples T test.
The labels correspond to the keys used in Table I

Table III.- The comparison of the degree of human disturbance between roosts used by *H. armiger* and roosts not used by this species.

Degree of disturbance	HR		OR	
	Count	Percentage	Count	Percentage
SI	3	15.0	11	32.4
LI	4	20.0	14	41.2
NS	13	65.0	9	26.5

$\overline{x}$=7.745, df=2, p=0.021*
*Significantly difference ($p < 0.05$) according to the Chi-square test; SI, represents serious disturbance; LI, represents light disturbance; NS represents no disturbance. HR and OR correspond to the same meanings as listed in the keys of Tables I and II.

Table IV.- Rotated component matrix on the loading coefficients of morphometric data for the roosts.

	Components			
	1	2	3	4
Number of entrances	0.276	0.678	-0.002	-0.362
Distance to nearest permanent water (m)	0.366	0.152	-0.440	0.638
Maximal height of the roost (m)	0.847	0.054	0.013	-0.408
Maximal width of the roost (m)	0.903	0.030	0.169	-0.057
Total length of all roosts (m)	-0.416	0.740	0.434	0.190
Air temperature (°C)	0.154	-0.219	0.632	0.478
Relative humidity in roost (%)	0.310	0.119	-0.722	0.381
Volume of the roost (m^3)	0.239	0.839	0.280	0.235
Light intensity (lux)	0.433	-0.488	0.550	0.218

Pregnant females give birth to a single young each year between May and early June. A multitude of male and female *H. armiger* roost in separate caves during parturition and the nursing period, and only a minority of males stay within maternity colonies during the breeding season.

H. armiger is less sensitive to light stimulation than other small bat species. In the caves

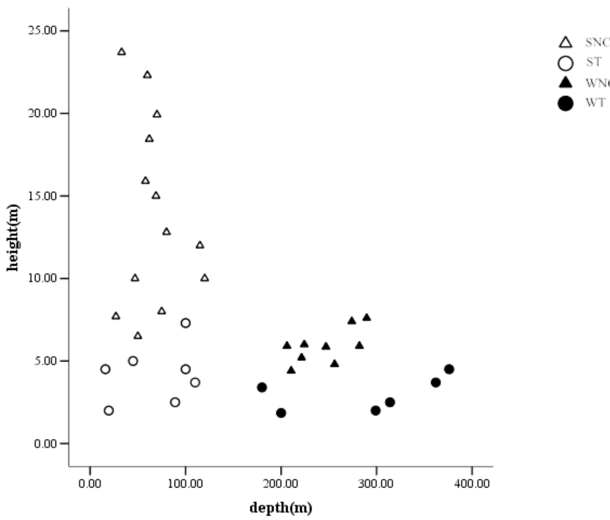

Fig. 3. The location of *H. armiger* in roosts. SNC, natural caves and abandoned mines in summer; WNC, natural caves and abandoned mines in winter; ST, water channels and air-raid shelters in summer; WT: water channels and air-raid shelters in winter.

with a light intensity of 0 < 0.1 lux, when bat species were stimulated by a torch light, small bat species flew away within 4 s, but *H. armiger* scattered after 10 s. If the height of the site used by *H. armiger* was more than 25 m high, only a few bats flew away, the rest did not leave.

H. armiger inhabited caves during the day in the summer and autumn months. Sometimes they flew around in the caves and did not fly out of the caves. They started cross-flying in caves at approximately 19:30, and a few started flying out of the cave 5 to 10 min later. After half an hour, a flock of *H. armiger,* together with other species, flew out. All individuals had flown out by approximately 22:00. The first bat returned to roost at approximately 4:00. Then, the bats flew back constantly until daybreak. All individuals returned to the roost site at approximately 6:00. After cross-flying for 5 to 10 min, they started perching on suitable sites in different flock sizes. *H. armiger* leave the roost to forage in light rain but would not fly out in heavy rain.

H. armiger begin to hibernate in caves from early November until April of the following year. The period of hibernation is approximately five months. When the temperature fell to 13°C in early November, a portion of the *H. armiger* moved from the original roost, which had several entrances, short tunnels and unstable temperatures, to a more suitable roost. *H. armiger* occupying roosts with single holes, long tunnels and stable temperatures will moved deeper into the cave to hibernate.

DISCUSSION

In mainland China, *H. armiger* lives in tropical and subtropical areas. These areas have higher temperatures and humidity, which may be the main conditions required for the survival of *H. armiger*. They inhabit areas with elevation less than 2100 m above sea level.

Vonhof and Barclay (1996) suggested that some forest-dwelling bats prefer to roost on taller trees to avoid potential terrestrial predators, *e.g.* weasels. Thus, roosting on a higher ceiling may also help reduce the energy cost of staying alert or responding to the occasional disturbances and it may be beneficial for avoiding terrestrial predators. Larger spaces may provide more space and various microclimates in which bats can roost, but they may also create a problem with dissipating heat and providing less total insulation for bats (Kurta, 1985). In our study, the roost caves used by bats have a larger volume and length than those that are unused. There were no significant differences in the total lengths and the maximal heights of the roosts between the roosts occupied by *H. armiger* and those used by other bat species. These results are inconsistent with those of Ho and Lee (2003). However, similar to the findings of Ho and Lee (2003), *H. armiger* always roost at the highest and widest positions of the cave and use deeper caves for breeding and hibernating.

The average body weight and body length of an adult *H. armiger* are approximately 55-70 g and 90-110 mm, respectively. Because of their larger body size and presumably lower basal metabolic rate, they generally maintain individual distances of 150 mm when roosting instead of clustering together. The problem of heat loss in large caves may not be as critical for this species.

Furthermore, during the breeding and young rearing periods, the males and females of *H. armiger* usually live in different roosts, except for a few males that remain with the females in the breeding place, which indicates that potential variations may exist in the population structure and life cycles among different colonies.

Bats usually have a higher rate of heat and evaporative water loss due to their relatively high surface area-to-volume ratio. *Plecofus auritus* can lose 20% to 30% of its body mass via evaporative water loss (Webb *et al*., 1995). Replenishing water after daily torpor is thus important for bats. *Eptesicus fuscus* and *P. auritus* select roosts that are closer to water (Entwistle *et al*., 1997; Williams and Brittingham, 1997). In our study, the roosts used by bats had higher temperatures and humidity than the unused roosts. However, there was no significant difference in the distance to the nearest permanent water source between the roosts occupied by *H. armiger* and those used by other bat species. For the 20 roosts occupied by *H. armiger*, the distance to the nearest permanent water was within 500 m. Because of the strong flying ability of *H. armiger*, this distance is insignificant. A similar scenario was also proposed by Jenkins *et al*. (1998).

Another factor relevant to evaporative water loss is the humidity in the roosts. Bats tend to select roosts with high relative humidity (Herreid, 1963; Clawson *et al*., 1980; Churchill, 1991; Clark *et al*., 1996). Webb *et al*. (1995) found that high ambient temperatures and relative humidity would reduce the rate of the evaporative water loss of active bats. However, in our study, obvious differences in the humidity and temperature only exist between the breeding and non-breeding roosts of *H. armiger*, and the breeding roosts had a higher relative humidity and temperature. Thus, the humidity and temperature requirements of lactating *H. armiger* are higher.

Human disturbance is a major threat to the survival of many bat species, and it may influence the bats' roosting behavior and roost site selection (Speakman *et al*., 1991). In conclusion, *H. armiger* is selective regarding its roosts. It prefers roosts with higher ceilings, larger spaces, high relative humidity and little human disturbance.

H. armiger and other bat species are threatened, and their populations are decreasing sharply (Zhang *et al*., 2009). We recommend the following measures for protecting these species: (1) develop good education programs to educate all levels of society and to raise their awareness about wildlife protection. (2) strengthen the legal protection of bats and their roosts, and (3) because the best way to save a species is to protect their habitats, the establishment of nature reserves should be strengthened.

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