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Diversity and pattern of nest preference of bat species at bat-dwelling caves in Gombong Karst, Central Java, Indonesia

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Abstract. *Wijayanti F, Maryanto I. 2017 Diversity and pattern of nest preference of bat species at bat-dwelling caves in Gombong Karst, Central Java, Indonesia Biodiversitas 18: 864-874.* A study on the diversity of bat species, their community structure and pattern of roosting preference, has been conducted in twelve caves in Gombong Karst, Central Java. Bats were caught at the roosting place during the day. Length, width, and height of cave passage were measured, as well as a number of entrances and cave’s ventilation were also calculated. In addition, microclimate parameters were measured under the bat roosts. Data were analyzed by ANOVA, Redundancy analysis (RDA) and canonical correspondence analysis (CCA). Fifteen species (eleven species of insectivorous bats and four species of fruit bats) were recorded. The result also shows that the length, height, and width of the cave passage influenced the community structure of bats. While the other physical factors, i.e. sound intensity, distance from the cave entrance, temperature, humidity, and light intensity influence the bat nesting preference. Furthermore, there were five groups of bats which have a specific pattern of roosting preference.

Keywords: Bat, cave, Gombong karst, roosting preference

INTRODUCTION

Indonesia is one of a country rich in biodiversity. One of them is the karst ecosystem. Karst ecosystem is a community of living creatures with various environmental factors located in the certain area contained bedrock in term of limestone or chalk. The specific characteristics of karst region are sinkholes gaps (water nests), underground rivers and caves (Gutiérrez et al. 2014).

Gombong Karst region is one of large karst region in Indonesia specifically located in the southern part of Central Java, at a latitude of 7 ° 27'-7 ° 50 ' and 109 ° 22' - 109 ° 50 'E (Disparhub Kebumen 2004). This region is part of the Sunda shelf. According to Whitten et al. (1996), Sunda shelf was originally a shallow tropical sea with a lot of precipitated calcium carbonate in the basis produced by limestone skeleton of animals and foraminifera. The seafloor was pushed up by tectonic style which consequently formed rows of karst hills. This is reinforced by the CGS-GAI (2006), which stated that the surface layers of Gombong Karst contained limestone formed from many fossils of marine life such *as Radiolaria, Hedbergella, Ratalipora* and *Bolivisoides* cf. *exculpta*. Furthermore, the process of abrasion caused the dissolved process of limestone continuously resulting in the formation of branching cave, with the dark and damp conditions, a stable temperature, and a limited air circulation. According to Duran and Centano (2002), the walls and the roof in each cave formed different physical characteristics and microclimates. Those differences caused each cave possessed a unique microclimate inhabited by a specific type of fauna and diverse species. According to Altringham (1996) and Zahn and Hager (2005), several species of bats preferred to form a nest in those caves as pleasant habitat presented by cave conditions which mostly in damp conditions, stable temperature, and tranquil condition. However, each species of bats apparently choose nest in the appropriate caves based on the need of their body condition (Nam 2009). In the area of Gombong karst, there are about 112 karst caves in which of more than 60 caves were bat inhabitation (Disparhub Kebumen 2004). It is predicted that in each cave of Gombong karst region possessed a diverse species of bats.

Based on several results of the study, it is highly evidenced that each species of bats apparently choose nest in the certain cave based on the need of their body conditions. Zahn and Hager (2005) reported that *Myotis daubentonii* males, for example, occupy the cooler site of the cave in Central Europe compared to that of *M. daubentonii* females. Duran and Centano (2002) also proved that *Pteronotus quadridens* nested in the cave with the range temperature from 28^{o}C to 35 °C, but *Erophylla sezekorni* formed a nest in the cave at a temperature between 25°C and 28° C. According to Wiantoro (2012) who researched the caves in Buni Ayu, Sukabumi, West Java proved that the physical form and the temperature of caves were important factors to determine the perch of diverse bat species. In that research, the average air temperature of caves ranged between 26.67 and 28.46 ^{o}C, while the air humidity ranged from 81.5 to 84.48%. In addition, many studies reported that another factor such as the physical and microclimate condition of caves had effects on the nest selection of bat in caves of Gombong karst region.

The objectives of this study were to assess the diversity of cave-dwelling bats in Gombong Karst region in Kebumen, Central Java, and to assess the effect of physical condition of caves to the community structure of bats, as well as to identify physical factors and the microclimate of the cave influenced on the pattern of bat nest selection in caves. It was hypothesized that the diversity, abundance, and evenness of bat species in caves was significantly influenced by the physical form of caves such as the length of the hallway, the height of hall, the number of doors, and the amount of cave's ventilation. In addition, it was predicted that the pattern of bat nest selection was influenced by the distance of the cave entrance, the roof height, the temperature and humidity, the wind speed, the light and sound intensity, levels of oxygen and ammonia levels around the nest.

MATERIALS AND METHODS

The research location

The location of this study was in Gombong Karst region, Kebumen, Central Java located at latitude of 7°36 '- 7°48' and 109°24'-109°28' W. Observations were carried out in 12 caves located in the Gombong karst region including the Macan cave (07°39.745 S, 109°26.163 E); Celeng cave (07°42.38 S, 109°23.624 E); Dempo cave (07°40.195 S, 109°25.632 BT), Jatijajar cave ((07°39.994 S, 109°25.262 E), Kampil cave (07°42.389 S, 109°23.836 E); Kemit cave (07°42.247 S, 109°23.638 E); Liyah cave (07°42.392 S, 109°23.838 E); Petruk cave (07°42.315 S, 109°24.130 E); Sigong cave (07°42.487 S, 109°23.389 E); Tiktikan cave (07°40.166LS, 109°25.595 E); Tratag cave (07°42.267 S, 109°23.66 E) (Figure 1). Identification of samples was then conducted in the Laboratory of mammals at Research Center for Biology, Indonesian Institut of Sciences (LIPI) in Cibinong, Bogor, West Java, Indonesia.

Research methods

Based on the preliminary survey, it was known that there were 112 caves in Gombong karst region which were then selected about 10% of a total number of caves or around 12 caves as an object of the research. Those 12 caves were then divided into four groups based on the length of the hall of the cave, i.e short hall cave which less than 100 m (Tiktikan cave, Tratag cave and Sigong cave); medium hall cave with the range from 100 m to 200 m (Macan cave, Dempo cave, and Kampil cave), the long hall cave with the range of 200 m to 350 m (Inten cave, Kemit cave, Jatijajar cave), and the long hall cave with the range of more than 350 m (Petruk cave, Celeng cave and Liyah cave). The coordinates of each cave were determined using GPS. Observation of nesting bats done by searching all hall of cave started from the entrance to the duck of the cave.

The physical parameters of the cave were measured including the length, the width and the height of the hallway cave, the number of entrance and ventilation of the cave. The length of cave hallway was measured from the entrance to the duck of cave using tape meter. The method used in this study was forward method (HIKESPI 2004) which conducted as follows: the first person stand to the first point of the cave and the second one at the second point in the turn way of the hallway cave until the measurement was done; the same procedure was continued to the next point of the hallway cave until the last point in the duck of cave. The width of the hallway cave was measured as follows: the five location in the hallway was determined randomly which were then measured their width (perpendicular from one wall to the other wall of the opposite cave) using a laser distance meter, and then calculated the average. The height of hallway cave was also measured at five locations which were randomly selected and then calculated the average (HIKESPI 2004).

Physical parameters of nest microclimate were measured during the light day under bat nest location by selecting the closest distance from the nest site which could be easily reached. These measurements were repeated until three times in different days. Equipment used in this study such as air temperature for measuring relative humidity, weather meter for measuring wind speed, the measurement of light intensity using a lux meter, and sound intensity using a sound level meter. In this study, the wind speed was measured using anemometer and the percentages of oxygen levels using oxygen meters. The measurement of air ammonia content was done as follows: the air under bat nest was inspired using a piped vacuum which was then flowed into Pingel already containing NH_3 as an absorbent for 120 minutes. The absorbent solution that has been mixed with NH_3 from the air was transferred into a sealed tube. NH_3 concentration readings were performed in the laboratory using a spectrophotometer.

Before catching a bat samples, the estimation of the number of bat species living in each nest was done by observation using infra-red binoculars binocular. If there were more than one bat species in a nest, it must be ensured that both types of species were caught. Sampling was carried out at each bat nest. The sampling method was done by considering the condition of the cave including cave formations, stalactites position and the height of cave roof height. The sampling method was done as follows: 1) using sessile net (hand net), if the formation of cave was simple and could be easily reached using hand net; 2) Using a mist net which was installed in the hall of the cave, when the nest location was in high position, and the hall way of the cave was too wide. Mist net was installed at the closest distance from the nest (<5 meters) for a moment while waiting and observing the bat targets were finally trapped. In this method, it must be ascertained that the captured bats came from the observed nests (not from other nests) because during the sampling, commonly, bats will fly sporadically as an effect of the arrival interruption from the observer. At that time, the mist net mounted on bamboo was immediately spread so that it was highly hoped that the captured bats were from the observed nests. Samples of captured bats were then incorporated into calico bags, which were then measured their morphometry using the mammal identification book by Corbet and Hill (1992).

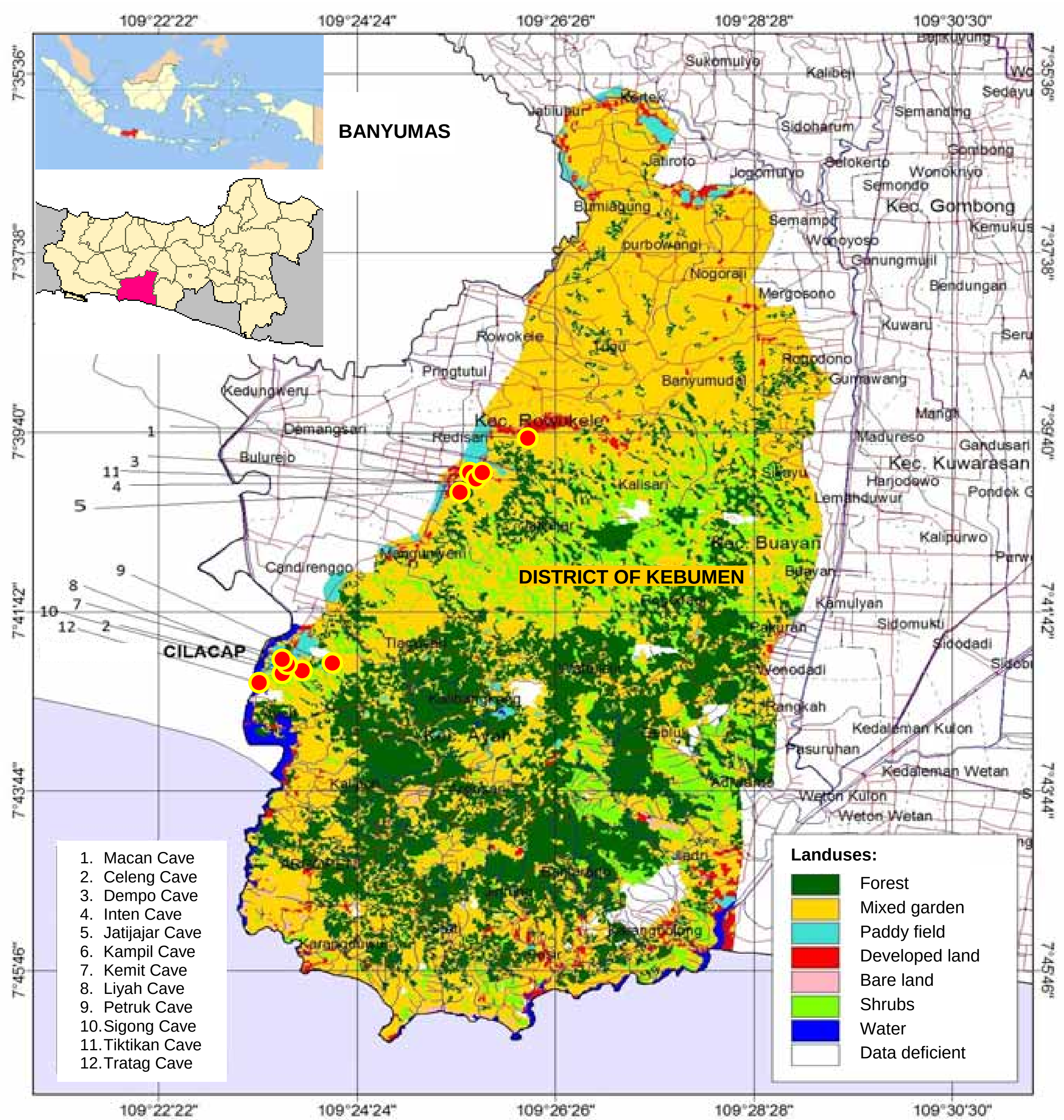


Figure 1. The LANDSAT satellite images of Gombong karst in Kebumen, Central Java, Indonesia (Modification of Wijayanti et al. 2012)

Data analysis

The abundance of bat population in each nest was calculated by estimating the vast nest using the formula as follows: P = D x L. Where P = abundance of bat populations (individuals); D = density (individuals / meter^2); and L = area of occupancy (meter^2) (Saroni 2006). The index of bat species diversity in each cave was determined using formula of diversity index (H ') by Shannon and Wiener as follows: H' = - Σ (ni / N) ln (ni / N); Where H '= index of diversity; ni = number of an individual species i; N = the total number of individuals (Magurran 2004). Evenness index was analyzed using Simpson evenness index (E), with the following formula E = H '/ ln S; Where, E = equity index, H '= index of diversity; S = the number of species (Magurran 2004).

The tendency of the relationship between the physical parameters of the caves and the structure of bat community were analyzed by multivariate analysis RDA (redundancy analysis). RDA is a model translation of linear regression with variables X and Y. The physical parameters were analyzed including long hallway of the cage, the height of hallways, the wide of hallway cave, the amount of ventilation, and the number of the cave entrance. RDA was then calculated using Canoco software for Windows 4.5 (Koneri 2007). The correlation value of physical factors caves with the structure of bat community was determine using Spearman correlation test with a level of confidence at 95% using SPSS software 15 version.

The effect of cave microclimates toward the bat nest selection was analyzed by multivariate analysis CCA (canonical correspondence analysis) using Conoco software for Windows 4.5. The use of CCA method aimed to determine the relationship of the data matrix and the environmental factors as well as reveal the maximum information of both parameters simultaneously in the graphic forms. The data matrix consisting of bat species and environmental factors in terms of different nine parameters including the entrance distance, the nest height, temperature, humidity, light intensity, sound intensity, wind speed, air oxygen percentage, and air ammonia levels. The highest effect of the microclimates on the selection of bat nest was sorted out using RDA (redundancy analysis) with forwarding selection method which was then tested using a Monte Carlo permutation with a number of 199 random permutations (Koneri 2007).

RESULTS AND DISCUSSION

The biodiversity and the pattern of bat nest distribution

From the total of 12 observed cave, 10 of them has been inhabited by bats, and two other were uninhabited. Type of bats living in caves consisted of four species of fruit bats such as *Cynopterus horsfieldii, Cynopterus brachyotis, Rouseattus amplexicaudatus, Eonycteris spelaea* (Figure 2), and eleven species of bats eating insects including *Chaerophon plicatus*, *Hipposideros ater, Hipposideros* cf. *ater, Hipposideros* sp.*, Hipposideros bicolor; Hipposideros sorenseni, Hipposideros diadema, Rhinolophus borneensis, Rhinolophus affinis, Miniopterus australis,* and *Miniopterus schreibersii* (Figure 3).

Petruk cave became the most inhabited cave of bat species with around nine types of bats living on it, followed by a Celeng cave (4 bat types), Dempo cave, Liyah cave, Inten cave, Kemit cave, Jatijajar cave which consisted of 3 type of bats, Macan cave (2 types), Sigong caves and Tratag cave (1 species). However, Tiktikan cave and Kampil cave apparently were not populated. The physical condition of the cave and community structure of bats found in Gombong Karst caves was presented in Table 1. There were indications that some species of bats only occupied one nest in a cave. Interestingly, in the Jatijajar cave, two nests of bat species, *H. sorenseni*, were found in one cave which the location of those nest was far apart from each other. Meanwhile, in other caves, the species of bats only occupy one nest in a cave.

In this study, Fruit bats that mostly found in the nest were species of *E. spelaea* (5 nests), followed by *C. brachyotis* (4 nests), *R. amplexicaudatus* (3 nests); and *C. horsfieldii* (1 nest). Insectivorous bats were *H. sorenseni* (6 nest), followed by *Hipposideros* sp. and *C. plicatus* with 2 nests while another species such as *H. diadema, M. australis, M. schreibersii, R. affinis* and *R. borneensis* with only one nest. The distribution of species and abundance of bats found in each cave was presented in Table 2.

The number of bat species found in Kars Gombong caves reached 15 species or at least 10% of a total 230 found species in Indonesia reported by Suyanto et al. (2001). The number of found species in this study could be categorized in high number compared to other researchers, which has been conducted either in different regions in Indonesia and another country. For example, research conducted by Pujirianti (2006) found 13 species of bats in karst region of Alas Purwo, Apriandi et al. (2008) found 10 species of bats in caves of Gudawang, Bogor, West Java; and Wiantoro (2012) found 5 species of bats in the cave of Buni Ayu, Sukabumi, West Java. However, the number of species found in this study was less than those obtained by Suyanto and Struebig (2007) which found 36 species of bats in the karst area of East Kalimantan Sangkulirang. Outside Indonesia, eight type of bats was found in Karst Istanbul Turkey (Furman and Ozgul 2002), 11 species of bats in Britain Britain (Parsons et al.,2002) and 14 species of bats in Wind Cave Nature Reserve in Sarawak Malaysia (Rahman et al. 2011). The results of this study indicated that diversity of bat species in Gombong Karst was high. This might happen due to the different size of caves and geomorphology of caves in Gombong Karst regions leading to the varied formation of the physical environment. Each different condition of caves produced a unique micro-habitats which potentially inhabited by different species of bats. Besides, the food availability of feed and water sources in Gombong Karst region also supported many species of bats to live and survive. The caves used as a location in this study was located entirely in karst forest surrounded by farmland. According to Riswan et al. (2006), the vegetation of karst forest in Gombong Karst region consisted of 187 plant species included 125 genera and 60 plant tribes. Based on the observation of the research location, most farmland in Kars Gombong planted by rice crops and other plantation crops including maize, cassava, rambutan, durian, banana, and vegetables. The agricultural and forest vegetation provided food for all season especially for insectivorous bats and fruit bats. Research conducted by Arrizabalaga et al. (2015) in Karrantza Valley, northern Iberian Peninsula, proved that each type of insectivorous bats required most of all specific phase of insects as the main food for bats in line with the growth stage of the bat. Therefore, the existence of insectivorous bats in a habitat not only depended on the availability of different types of insects as a food source but also the availability of insects with different phases of development throughout the season. The diversity of plant species of forest and farmland around Kars Gombong could provide the insects with different phases throughout the season. This was also reinforced by Threlfall et al. (2012) in Sydney, Australia who reported that most of the bat activity showed a significant different in varied types of habitats. The most preferred region of bat activity was dense vegetation followed by riparian (vegetation around the river), shrubs, sandy soil and the lowest settlement.

Figure 2. The species of fruit bats were found in the 10 of observed caves of Gombong Karst, Central Java, Indonesia: A. *C. horsfieldii*; B. *C. brachyotis*; C. *E. spelaea*; D. *R. amplexicaudatus*

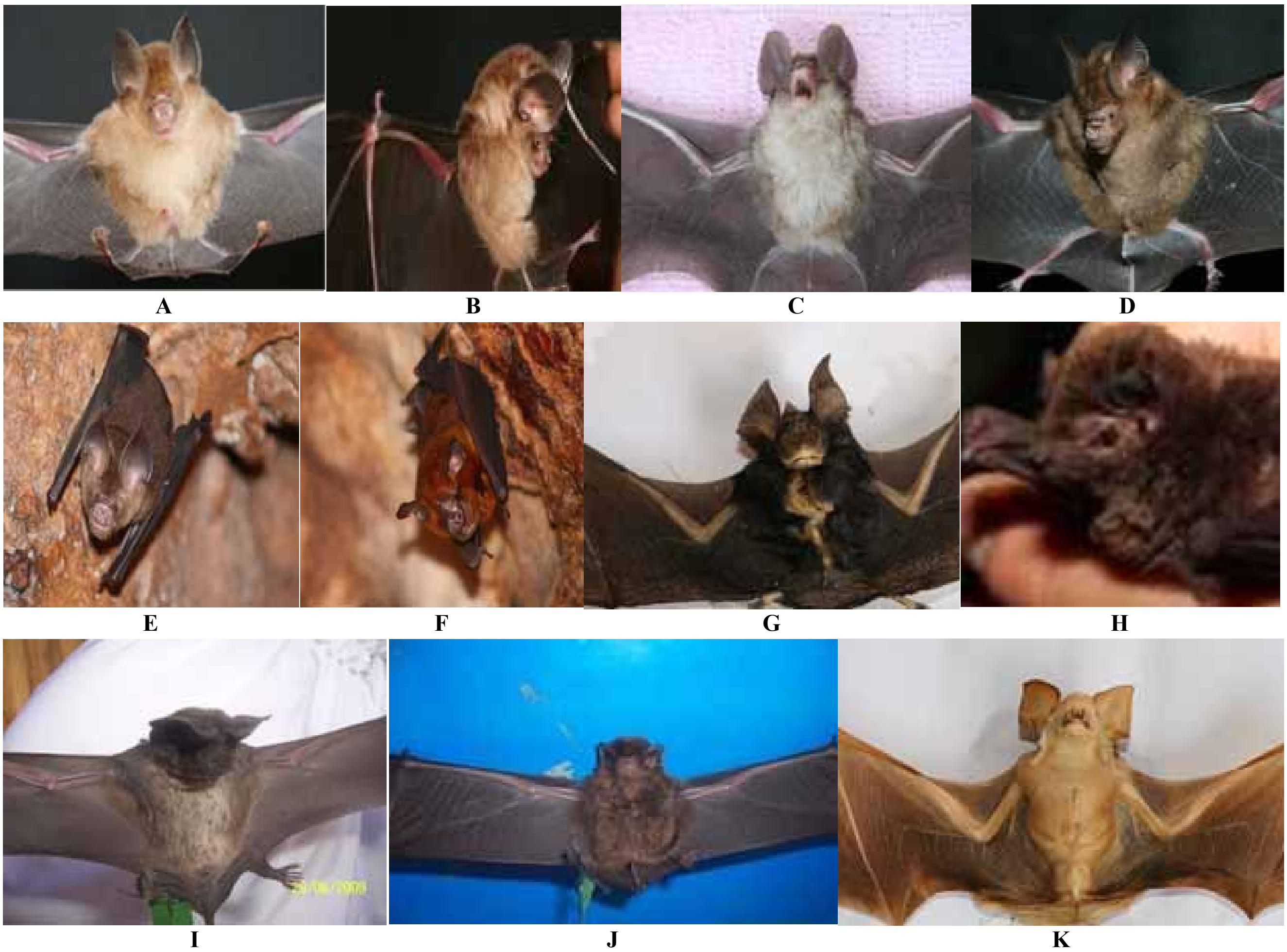


Figure 3. The species of insectivorous bats were found in the 10 of observed caves of Gombong Karst, Central Java, Indonesia. A. *H. ater*; B. *H.* cf. *ater*; C. *H. bicolor*; D. *H. sorenseni*; E. *Hipposideros* sp.; F. *R. affinis*; G. *R. borneensis*; H. *M. schreibersii*; I. *C. plicatus*; J. *M. australis*; K. *H. diadema*

The number of bat species was mostly found in Petruk cave. This might happen due to the environmental variation formed in Petruk cave. This was in accordance with Castillo et al. (2009) who reported that the environmental conditions inside the cave were different can differ in each different zones leading to the separation of microclimates in a cave space. Those microclimate separations could trigger the organism diversity. In Deal karst, *E. spelaea* was a type of fruit bats that commonly found. According to Acharya et al. (2015). *E. spelaea* was fruit bats whose mostly formed a nest in caves. These fruit bats have developed the echolocation ability to adapt in a dark cave. Furthermore, these species could hunt to the far area up to 8 km from their nest in the cave located in Southern Thailand (Acharya et al. 2015). In Indonesia, *E. spelaea* has been found nesting in the karst cave (Maryanto and

Table 1. The physical condition of caves and the community structure of bats in Gombong Karst, Central Java, Indonesia

Cave name	The cave physical condition					The structure of bat community			
	PL (m)	LL (m)	TL (m)	P	V	N (individual)	S	H'	E
Sigong	40	4.8	1.8	1	0	3.7±1.15	1	0	-
Tiktikan	58	8.2	3.1	1	0	0	0	0	-
Tratag	68	8.4	2.6	2	4	2.0±1.20	1	0	-
Dempo	104	18	8.9	3	4	82.5±14.80	3	0.47±0.07	0.39±0.03
Kampil	104	4.4	3.1	1	0	0	0	0	-
Macan	185	10.4	4.2	2	1	98.3±11.59	2	0.16±0.09	0.53±0.02
Inten	208	18	14.2	1	2	1008.3±7.10	3	1.02±0.01	0.67±0.01
Kemit	210	10.2	6.8	1	0	1266.6±44.00	3	0.85±0.16	0.55±0.08
Jatijajar	310	12.8	12.6	3	3	802.0±52.40	3	0.93±0.10	0.58±0.07
Liyah	380	22	8.4	2	2	715.0±125.60	3	1.03±0.01	0.65±0.01
Celeng	410	26	6.2	1	0	876.0±26.00	4	0.91±0.08	0.05±0.13
Petruk	420	32	14.2	2	3	4540.6±45.00	9	1.49±0.09	0.21±0.01

Note: PL = The length of cave hallway; P = the number of the cave entrance; S = the number of species; LL = the width of cave passage; V = ventilation cave; H '= index of biodiversity; TL = the height of cave passage; N = abundance; E = index of evenness

Table 2. The distribution and abundance of bat species in each observed caves in Gombong Karst, Central Java, Indonesia

Cave name	Bat species	The abundance of species (individual)
Barat	*C. brachyotis*	2.91
	H. sorenseni	96
Celeng	*R. amplexicaudatus*	5.33
	E. spelaea	5.33
	C. plicatus	606.6
	H. sorenseni	263.3
Dempok	*R. amplexicaudatus*	4.5
	E. spelaea	2
Inten	*E. spelaea*	3.25
	M. australis	488.75
	R. affinis	550
Jatijajar	*C. horsfieldii*	5.3
	H. sorenseni	313.2
	Hipposideros sp.	261.3
Kemit	*E. spelaea*	4
	H. sorenseni	458
	Hipposideros sp.	205.3
Liyah	*C. brachyotis*	4.25
	M. schreibersii	388
	H. sorenseni	365
Petruk	*C. brachyotis*	2.5
	R. amplexicaudatus	3.25
	H. sorenseni	115
	C. plicatus	3137.5
	H. bicolor	467
	H. diadema	18.5
	H cf. *ater*	577
	H. ater	135.5
	R. borneensis	50
Sigong	*E. spelaea*	3.6
Tratag	*C. brachyotis*	6

Maharadatunkamsi 1991; Suyanto 2001; Pujirianti 2006). Interestingly, two types of fruit bats found in this study, *C. horsfieldii* and *C. brachyotis*, were found nesting in karst cave. These findings were in contrast to previous research conducted either in Indonesia or other countries which mentioned that those species could not be found nesting in karst caves. Both species of bats were often found nesting in the trees (Ruczynski et al. 2007; Soegiharto and Kartono 2009). In this study, those species were found in the mouth of the cave. This might happen due to the mouth/door of observed caves mostly occupied by wide tree canopy, which it was predicted as a favored habitat for those species. Both types of bats periodically migrated from the tree canopy around one cave entrance to other cave entrance. In addition, the mouth of the cave where bats were discovered had a big size of cave entrance causing the light of the sun could intensely enter the cave. Therefore, C. *horsfieldii* and *C. brachyotis* allowed to use their sight brightly inside the cave as well as seeing outside the cave. Based on the results, five clans of insectivorous bats were successfully obtained in this study. These results apparently in line with previous researchers who reported that those clan mostly formed a nest in karst caves located in both Indonesia and other countries (Zahn and Hager 2005; Saroni 2006; Pujirianti 2006; Apriandi et al. 2008; Rahman et al. 2011). This indicated that these clans were cave dwellers whose already well-adapted to the environmental conditions of the cave. According to Zahn and Hager (2005), these several types of bats selected the cave as their habitat due to the suitable condition of the cave for living purposes such as damp conditions, stable temperature, and less noise. Under these conditions, bats could minimize water shortage for reducing evaporation, could choose the right temperature for the body, and could avoid the noisy causing the bat death. The dark conditions inside caves become unnecessary problem for insectivorous bats because they had echolocation system which could detect objects around them using the reflected wave (echo/ echo) with ultrasonic frequency. This echolocation enabled bat to determine the space orientation in the dark caves (Ulrich et al. 2003; Rahman et al. 2011).

The structure of bat community

The community structure in this study was in term of bat presence in the certain space in caves by identifying and analyzing the abundance, species diversity index and evenness index. Results showed that the abundance and diversity index of bat species was highest in Petruk cave, while the highest evenness index was obtained in Inten cave. The average and standard deviation of the community structure of bat cave were presented in Table 1. The result from RDA analysis showed that there was a correlation between the structure of bat community and the physical characteristics of the cave. To be specific, the physical cave parameters including long cave passage (PG), the wide hallways of cave (LG) and the high cave passage (TG) was significantly correlated (P <0.05) with abundance (N), an index of biodiversity (H ') and evenness index of bat (E). However, the number of doors (P) and the number of cave ventilation (V) was not significantly correlated (P> 0.05) with an abundance (N), species diversity index (H ') and evenness index bat (E) (Figure 5). The highest correlation of all cave parameters was achieved from the length of cave passage (RS = 0827; P <0.05). The positive correlation was achieved from the property type (S) relative to cave dimension including the height, width and length of cave hallways with the highest correlation was achieved from the length of cave hallways (RS=0.884; P< 0.05). While species diversity index (H') positively correlated with the cave dimension (length, width, height) with the highest correlation was obtained from the width of cave hallway (RS=0.898; P < 0.05). Another positive correlation was also achieved from the evenness index (E) relative to the dimension of the cave with the highest correlation was obtained from the width of cave hallway (RS = 0.757; P <0.05). It means that the more size value of cave dimension (length, width, and height), the structure of bat community including the number of bat population, the species diversity and the proportion of bat nest distribution would be greater and higher. However, the number of ventilation and the amount of the cave entrance had no significant correlation (P> 0.05) with the structure of bat community. It means that the structure of bat community in terms of abundance, species diversity index and evenness index of bats in Gombong Karst caves did not influence by the number of doors and the number of cave ventilation.

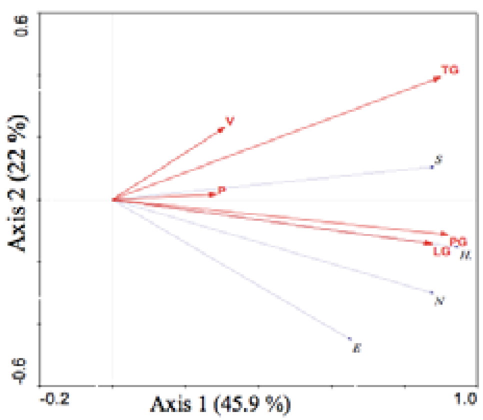


Figure 5. Redundancy analysis (RDA) for relationships between the structure of bat community and physical cave parameters. Abundance (N), property type (S), diversity (H'), and evenness (E) with a long bat cave passage (PG), wide hallways cave (LG), a high cave passage (TG), the amount of the cave door (P), and a number of caves ventilation (V).

Results from RDA analysis in this study was in line with Maguran (2004) who reported that the wider habitat in a certain region would lead to the increasing number of organism population whose living in that region. The long cave hallway could cause the separation of microclimates in the cave space. The more microclimates were formed, it will cause many bat species nesting in these cave room. These findings were in accordance with Sevcik (2003) who reported that the diversity index of bat species especially *Plecotus auritus* and *P. austriacus* was higher in line with the wider size of cave hallways. Furthermore, *P. auritus* had a more free maneuver than *P. austriacus* causing this species had the more ability to exploit the habitat further (Sevcik 2003). Therefore, the narrow cave hallways would likely be inhabited by a certain type of bat whose had a specific ability in doing maneuver in the cave. While in the wider cave hallways, most types of bats had a diverse ability to maneuver in the cave. These also supported by Wiantoro (2012) who found that the physical characters of cave passage in Buni Ayu, Sukabumi cave determined the diverse type of bats nesting inside cave, although the physical performances of the cave were done by descriptive analysis without further detail measurements analysis. Wiantoro (2012) also stated that *R. affinis* nesting in the cave hallways with many ornamental characters had a good maneuver, while *Miniopterus magnater* roosting in the cave without ornamental characters had a less maneuver performance. In this study, most physical characters of cave hallway in the Gombong karst were observed although there was no standard method for measuring the physical characters of cave hallway with full of stalactite and stalagmite so that the effect of the physical characters of cave hallway to the bat diversity in the cave was not observed further. Interestingly, findings in this study were in line with Wiantoro (2012) that *R. affinis* mostly formed a nest in the narrow cave. This also supported by Phelps et al. (2016) who stated that the formation of cave hallways positively correlated with the diversity of bat species.

Caves with a short corridor (<100 m) can be inhabited by fruit bats while caves with a long hallway (> 100m) was a favored habitat for insectivorous bats. The short cave corridor had microclimate with hot, light, dry and noisy conditions which become unpleasant conditions for insectivorous bats for survival life. Interestingly, in Kampil cave with the cave hallway more than 100 m in long, the length of 4.2 m and height of 3.1 m was inhabited by bats. It was predicted that another physical factors and microclimate of the cave as limiting factors to bat for nesting in the cave. Another factor such as human interference had the influence to the bat nest. In this study, it was found that there was an excavation activity by illegal miners along the hallway of Kampil cave which disturbed bats to nest in the cave. The same case was found in Tiktikan cave with the short corridor around 58 m which had no bat inhabitation due to the limestone mining activities in the cave. This mining activity is continuously running which cause an annoying sound for bats. This was supported by Bungkley et al. (2015) who successfully proved that anthropogenic activities inside cave could reduce the activity of bats by disturbing the reception of echolocated signal of bats.

In this study, the number of the cave entrance and the amount of cave ventilation did not influence the structure of bat community including the abundance, the diversity index, and evenness index. This might happen due to most type of bats commonly use one-way cave entrance or the same ventilation to exit and enter the cave. This was in line with Schnitzler et al. (2006) who proved that flight route of bats for foraging and nesting purposes apparently use the same route. Interestingly, this information was transferred from parents to a child by the following behavior.

The pattern of bat nest selection

Based on the RDA analysis using forward selection showed that five physical parameters of microclimates including the distance from the cave entrance, the temperature, humidity, light intensity, and the sound intensity had influenced the selection of bat roost. Of all the five parameters, the sound intensity was a dominant parameter which influences the bat nest selection. This happens due to the highest eigenvalue was achieved in the sound intensity followed by the distance of cave entrance, the temperature, humidity and light intensity (Table 3). These results were in accordance with Schnitzler et al. (2006) who proved that the echolocation signal of certain bat species such as *Nyctalus noctula* and *Rhinolophus ferrumequinum* in the close habitat was longer than in open habitat. This happens because in the close room the echo production was complex which causes the difficulty for bats to analyze the echolocation wave. Therefore, in the closed room such as inside cave, the little disturbance will cause bats failed to analyze the reflected wave. Of those reasons, some type of bats possessing a low frequency of echolocation (having a sensitive hearing) will choose to nest in the place with the sound intensity close to zero, while another bat species having less sensitive hearing will mnest to the location with the high sound intensity. This result was also reinforced by Threlfall et al. (2012) who conducted research in Sydney, Australia that *Tadarida brasiliensis* had 40% lower activity level in the noisy location triggered by compressor machine rather than in the quiet location. While other bat species including *Myotis californicus, M. cillolabrum, M. lucifugus,* and *Parastrellus hesperus* were not affected by noise. The echolocation of bat species emitting a low frequency (35 kHz <<) responded to noise by decreasing the activity up to 70% in a noisy location than in a quiet location. While bats using the high frequency of echolocation (>> 35 kHz) had no indication on the changes of activity levels. Furthermore, echolocation represented a great diversity in terms of duration and amplitude, which had a correlation with bat environmental habitat (Teeling 2009).

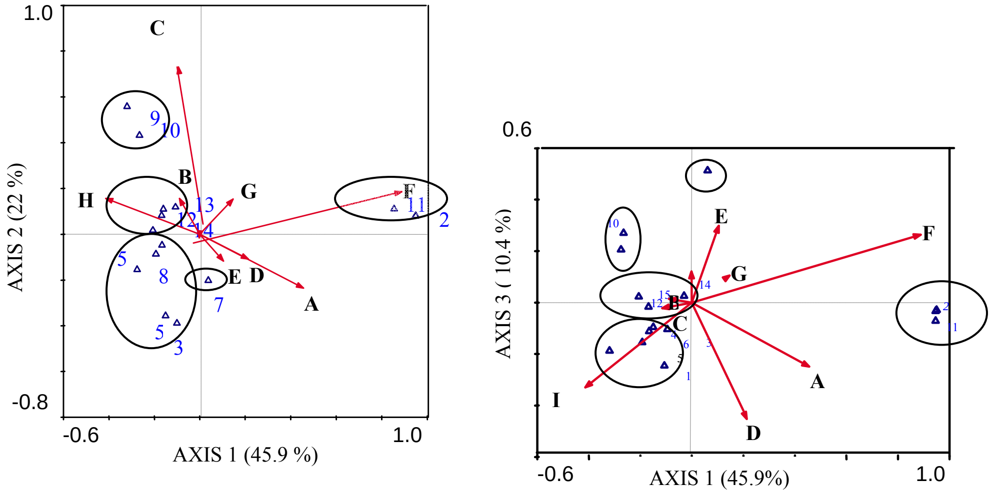
The distance of cave entrance was the second parameter after the sound intensity having an effect on the bat roost selection. This was because flying in a cave passage with long and narrow physical characters, bats need to take a good maneuver. As a result, in selecting a nest site, bats with a good maneuver ability tended to choose nest sites in the far distances from the hallway cave because it was the safer place from human interference. Instead, bats with the inability to pass through a long cave passage selecting a nest in a location close to the entrance cave for easy maneuvers. According to Bar et al. (2015), the flying maneuver of bats in the dark room had a correlation with sensory control. Bats should improve sound sensor by integrating sensory information for flight guidance. Of the reason, it is predicted that bats nesting in the far distance from cave entrance was bats with a good sensoric control ability toward the sound.

Other physical parameters including temperature, humidity, and the light intensity were also critical factors for bat nest selection. In this study, the temperature was ranked number 3 of all physical parameters of microclimates relative to bat nest selection. This was in accordance to Zukal et al. (2005) who reported that *Myotis myotis* and *Rhinolophus hipposideros* preferred to nest in the warm site with the temperature from 20^{o}C to 26^{o}C for hibernation in the cool season. This was because this type of bats was grouped as homoiotherm animal (having a constant body temperature) which had a narrow tolerant capacity on the ambient temperature. This tolerant limits might vary in each type of bat species so that different bat species might choose different nesting privilege. The humidity was also the fourth physical factors which influence the bat nest selection. According to Baudinete et al. (2000), the petagium membrane (wing) of the bat is composed of a thin skin layer which is very sensitive to drought. This caused bats with a thin patagium membrane likely nesting in the damp sites while bats with a thick patagium membrane preferred to choose in the dry cave. Another physical parameters, the light intensity was the fifth physical factors which influence the bat nest selection. In this study, fruit bats mostly formed a nest in the high light intensity while insectivorous bats tended to choose in the low light intensity. This was in line with Rahman et al. (2011) who reported that fruit bats tended to use their sight to determine room orientation. While insectivorous bats tended to use their echolocation ability to determine room orientation so that they did not require the light and preferred to choose a nest in the low light intensity.

Table 3. The physical parameter of microclimates influence the bat nest selection

The physical parameters	The rank of influential factors	F	λ	P value
Sound intensity	1	10.21	0.09	0.0050*
Entrance distance	2	5.69	0.05	0.0050*
Temperature	3	4.89	0.04	0.0050*
Humidity	4	1.98	0.02	0.0200*
Light intensity	5	1.84	0.01	0.0100*
Ammonia	6	1.53	0.01	0.1100
Height of cave	7	1.41	0.01	0.1600
Wind speed	8	1.31	0.01	0.2200
Oxygen levels	9	0.96	0.00	0.2300

Note: F = F ratio; λ = eigenvalue; * = Significantly different (P <0.05). Data obtained from the analysis of the RDA with forwarding selection method and tested by using Monte Carlo Permutation with 199 random permutations.



A **B**

Figure 6. Analysis Canonical Correspondence Analysis (CCA) types of bats based on the physical condition of the microclimates nest. A. Between axis 1 and axis 2, B. Axis 1 and axis 3. 1 = *C. plicatus*; 2 = *H. ater*; 3 = *H.* cf. *ater*; 4 = *H. bicolor*; 5 = *H. diadema*; 6 = *Hipposideros* sp. 7 = *H. sorenseni*; 8 = *M. australis*; 9 = *M. schreibersii*; 10 = *R. affinis*; 11 = *R. borneensis*; 12 = *C. brachyotis*; 13 = *C. horsfieldii*; 14 = *E. spelaea*; 15 = *R. amplexicaudatus*; A = The distance from the mouth of the cave; B = Height from the floor of the cave; C = Temperature D = humidity; E = intensity of light; F = intensity of the sound; G = H = Oxygen wind speed; I = Ammonia.

In order to determine the relationship between the physical factors of microclimates and the preference of nesting selection in each bat species, CCA (Canonical correspondence analysis) was conducted to know the grouping tendency of bat species relative to the pattern of bat nest selection. The result from CCA trends showed that five groups of bat species could be formed based on their nesting preference after they were compared to the physical parameters of microclimates (Table 4). Group 1 was mostly fruit bat members, including *C. brachyotis, C. horsfieldii, E. spelaea* and *R. amplexicaudatus* Group 1 was classified based on the physical parameters such as the sound intensity> 20 db, close to the cave entrance (<50m), hot (temperature> 28.5^{o}C), dry (humidity <65%), and light (intense light> 50 lux). This group apparently had the same preferences on nest selection due to the same characters of anatomy and physiology. This was consistent to Nam (2009) who reported that each type of bats needs the specific cave environment in accordance with the body's metabolism. Furthermore, most Megachiroptera members or fruit bats commonly nest on the tree rather than in the cave (Ruczynski 2007). This happened because Megachiroptera still depending on the sight than the echolocation ability so that they need a light to determine the environmental orientation. The pattern of bat nest selection in this group causes they can inhabit in the short hallway of the cave which less than 100 m such as in Sigong cave and Tratag cave. This was because inside these caves mostly had a space with hot, light, dry and noisy conditions.

Group II consisted of *H. sorenseni*. Based on the nested mapping, this group was mostly found in Gombong Karst cave around eight nests. This showed that the preference habitats of this group were cool, damp, dark and quiet conditions as presented in Gombong Karst cave. This finding was a novel results obtained in this study because there were no researches who reported the same findings, yet. Group III comprised of *M schreibersii* dan *R. affinis*. This finding was supported by Apriandi et al. (2008) who reported that *R. affinis* in some caves in Karst Gudawang Bogor were located in the site with average 180 m from the cave entrance, with a temperature of 27.5^{o}C and humidity 96%. Group IV consisted of *C plicata, H. cf. ater, Hipposideros sp,* dan *H. bicolor*. This research was in line with Twente (2004) who found *C plicata* in thousand numbers in a dome cave in Istambul, Turkey at a distance of 200 m from the cave entrance, with the temperature of 27.5^{o}C. Group V consisted of *H. ater* and *R. borneensis* which was found at a distance of more than 250 m from the cave entrance. This was a slightly different from research conducted by Saroni (2006) who found that these species was found at a distance of 152 m from the cave entrance, with a temperature of 25^{o}C and humidity 85%.

Table 4. Bats grouping based on the nest selection patterns

Bat group	Type of bats	Sound intensity (db)	Distance from cave entrance (m)	Temperature (°C)	Humidity (%)	Light intensity (lux)
I	*C. brachyotis* *C. horsfieldii* *E. spelaea* *R. amplexicaudatus*	≥ 20 (noisy)	≤ 50 (close)	≥28.5 (hot)	≤65 (dry)	≥ 50 (light)
II	*H. sorenseni*	0.5 to 20 (quiet)	50 to 150 (medium)	≤28.5 (cool)	65 to 75 (damp)	5 to 50 (dark)
III	*M schreibersii* *R. affinis*	≤0.5 (very quiet)	150 to 250 (far)	≥28.5 (hot)	65 to 75 (damp)	5 to 50 (dark)
IV	*C. plicatus* *H.*cf.*ater* *Hipposideros* sp. *H. bicolor*	0.5 to 20 (quiet)	150 to 250 (far)	≤28.5 (cool)	≥75 (very damp)	≤5 (very dark)
V	*H. ater* *R. borneensis*	≤0.5 (very quiet)	≥250 (too far)	≤28.5 (cool)	≥75 (very damp)	≤5 (very dark)

In conclusion, from these results, we can conclude that the types of bats nesting in Gombong Karst caves comprised a total of 15 bat species in which four types of them were fruit bats and 11 species were insectivorous bats. The abundance, diversity index of species and evenness of bats in Gombong Karst caves significantly correlated with the length of the hallway cave, cave wide, and high cave passage. The more dimension size of hallway cave including the length, width, and the height, it resulted in the higher level of abundance, diversity, and evenness of bat species. While the number of the entrance to the cave and the amount of cave ventilation did not significantly correlate with the structure of bat community. Physical parameters and microclimates of caves including sound intensity, distance from the mouth of the cave, temperature, humidity, and light intensity had significant effects on the selection of bat nest. Based on that parameter, there was 5 group of bat that selected the nesting site with a specific pattern. Based on this research, Gombong Karst is of importance to be proposed as a conserved region due to its high diversity of bat species. In addition, it is a crucial need for mapping the potential use of caves based on the pattern of bat nest selection in accordance with the scientific information and results obtained from this study.

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