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CORRESPONDENCE BETWEEN BATS POPULATION AND TERRESTRIAL CAVE-DWELLING ARTHROPODS COMMUNITY IN TASIKMALAYA KARST AREA

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Abstract: Troglonemes particularly bats play an important role in subterranean habitat. They provide organic material and induce cave microclimate that influence cave-dwelling biota, including arthropods. This study aimed to learn how bats population influences cave-dwelling arthropods community. Data collections were performed in three caves which had different bats species in Tasikmalaya karst area namely Liang Boeh, Liang Seungit and Sarongge. We recorded bats population, guano production, physicochemical condition of caves passage, and arthropods community in each cave. All samplings were only conducted in the specific sites of the dark zone where bat populations were aggregated. Data indicated that Liang Boeh was inhibited by *Hipposideros* sp (± 472 individuals),

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Liang Seungit by Pteripodidae and *Miniopterus* sp. (± 188 individuals), and Sarongge by *Rhinolophus* sp. (± 1194 individuals). Guano production was positively correlated with bats population. Chemical compositions of soil were varying among bats species. Bats population strongly induced caves physicochemical condition. A total 15986 individuals of cave-dwelling arthropods belonging to 5 Classes and 18 Orders were recorded. Our result revealed that bats population determined arthropods community. Caves with greater bats population size and dominated by insectivorous species would potentially have greater diversity and abundance of cave-dwelling arthropods.

Keywords: cave; arthropods; bats; guano; climatic; edaphic

2010 AMS Subject Classification: 62P10.

1. INTRODUCTION

Tropical caves are one of important habitats for numerous bats species. They provide favorable climatic condition for roosting sites. For instance, humid, cool, dark, stable microclimate and safe from predators. In contrast with temperate zone where bats generally use caves as a shelter during hibernation, bats in tropical zone use caves as their diurnal roosts for resting over daylight, mating, caring their offspring, and taking social interaction [1], [2]. As a nocturnal fauna, cave-dependent bats will leave caves during night for foraging, and return to the caves at the dawn. This periodical behavior indicates them as troglloxenes, the part-time cave residents[3], [4].

Troglloxenes particularly bats play important roles in maintaining ecosystem sustainability both inside and outside cave habitats. Frugivorous bat (Megachiroptera) is a substantial agent of pollination and seed dispersal for hundreds of flowering plants. Meanwhile, insectivorous species (Microchiroptera) acts as population control of nocturnal insects and other arthropods [4]–[9]. Their role is even more critical in caves realm. They produce guano which is one of the main sources of energy for cave-dwelling organisms [10]. In the absent of photoautotrophs, bats guano exhibits the base of food web which determines cave ecosystem [3], [8], [11].

Frugivorous and insectivorous bats can be easily found in tropical caves. Meanwhile,

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cave-dwelling bats in karstic caves are commonly predominated by insectivorous species. The suggested reason why karstic caves can attract insectivorous bats is because of their abundance of calcium content. Insectivorous bat diets, insects and other arthropods, are poor source of calcium. Beside of providing favorable condition for roosting, karstic caves also provide calcium for bats [1].

Arthropods are the most dominant fauna in caves, both in the term of diversity and abundance. They are the main component of cave's food web so their presence is critical in maintaining ecosystem equilibrium [10]. A numerous species of arthropods decomposer is a guano-dependent. They life by consuming bats guano and or microorganisms that life in guano substrate. In other hands, the predatory groups only can occur if decomposer groups are present [4], [12]. Hence, the existence of bats in caves is unquestionably substantial for arthropods community.

Tasikmalaya karst area is one of karst areas in Indonesia which is still poorly studied. This karst area is situated in West Java province of Indonesia. The recent data shows that Tasikmalaya karst area has more than 500 registered caves. The subterranean biology of this karst area was still received little attention. In addition, the existence of cave ecosystem in this karst area has serious threats. For instance, phosphate mining for fertilizer and bats hunting for food and medicine. Besides, cave tourism and extractive industry particularly limestone quarrying were also found in this karst area.

Similar to many other karstic caves in tropical zone, caves in Tasikmalaya are also inhabited by bats and arthropods. Up to recently, how bats population influence cave-dwelling arthropods diversity and abundance in Tasikmalaya karst area was still little discussed. Therefore, our study tried to reveal the relationship between bats population and cave-dwelling arthropods community in several caves situated in Tasikmalaya karst area. The main objectives of this study were to determine how different species and population size of bats induce physicochemical conditions of caves passage and its relation to arthropods diversity and abundance. The result of this study could widely contribute to conservation effort of caves ecosystem in Tasikmalaya karts area and other karstic caves particularly in tropical zone.

2. MATERIAL AND METHODS

A. Study Sites

The study was conducted in Tasikmalaya karst area which is situated in West Java Province of Indonesia. This karst area covers approximately 158.301 ha with more than 500 karstic caves. Data collection was performed in three caves namely Liang Boeh (S 7°32'20,1" E 108°10'56,2"), Liang Seungit (S 7°32'23,6" E 108°10'54"), and Sarongge (S 7°34'37,6" E 108°12'10"). The caves were selected purposively based on their similar characters. All study caves are dry caves with length of passage less than 100 m and inhabited by different species of bats.

B. Arthropods Collection

Bats were trapped through a mist-net which was situated at the cave entrance during dawn periods when bats population left the caves for foraging. Bats population size was estimated through direct counting with help of a hand counter for an hour at the roosting sites during daylight where bats population aggregated. Fresh guano produced per night was collected by expanding a wide size of plastic sheet below the roosting site. Arthropods were collected through hand collecting, pitfall traps, and Berlese extractors. Hand collecting was performed by 3 collectors for 30 minutes for each cave. Pitfall traps were made by vial bottles (5 cm in diameter) filled by 70% alcohol and glycerin with 9:1 in ratio and established 5 pieces in each cave for 2 days. One-liter soil samples were taken from each cave and extracted for 5 days through Berlese extractor tunnels. All collected arthropods were identified based on morphological characters up to the lowest possible taxon level.

C. Measurements of Physicochemical Parameters

Physicochemical conditions of sampling sites were measured to know how bats population induce caves environment. Several physical parameters including air temperature, air humidity, soil temperature, and soil moisture were recorded directly in the field during the sampling periods. Meanwhile, chemical contents of soil located below the roosting sites including C-organic, N-total, C/N, P₂O₅, K₂O HCL, and pH were tested in the laboratory.

D. Statistical Analysis through GLLVM Ordination

GLLVM is an extended of GLM which has latent variables. The concept of GLLVM analysis is the same as principle component analysis, which is create the multivariate ordinations. More specifically GLLVM can be seen in [13]–[15]. Distributions that can be used follow the type of data. Optimizations that can be used between laplace approximation [16] and variational approximation [17], [18] by evaluating accuracy using AIC, AICc, and BIC [19]. A GLLVM relapse the mean abundance μ_{ij} against the environmental variables and vector of $d \ll m$ latent variables, $\mathbf{u}_i = (u_{i1}, \dots, u_{id})^T$:

$$g(\mu_{ij}) = \eta_{ij} + \alpha_i + \beta_{0j} + \mathbf{x}_i^T \boldsymbol{\beta}_j + \mathbf{u}_i^T \boldsymbol{\beta}_{0j} + \boldsymbol{\gamma}_j$$

Where $\boldsymbol{\beta}_j$ and $\boldsymbol{\gamma}_j$ are vectors of species explicit coefficients identify with the covariates and dormant factors. The stretch out of this can be reached in [13].

$$BIC = -2l + p \log(n)$$

A good model will have a large log likelihood value, so the value of $-2l$ will be small. A good model also does not contain many parameters[20]. So that a small BIC value indicates that the model is the best [21].

3. MAIN RESULTS

A. Bats Population and Guano Production

Four species of bats from different suborders were found in the study caves. Three species belonged to Microchiroptera (insectivorous), while another one species was Megachiroptera (Frugivorous). All insectivorous bats were successfully identified until genera, namely *Hipposideros* sp., *Miniopterus* sp., and *Rhinolophus* sp. represents in Figure 1a,b,c, respectively, while one species of frugivorous was only identified up to family due to no individual of this species was trapped through mist-net for further identification. Meanwhile, we could easily identify it as Pteripodidae in Figure 1d from their typical face appearance and their fresh guano that contained seeds [22], [23]. All these recorded taxa were common in Indonesia [24]–[26].

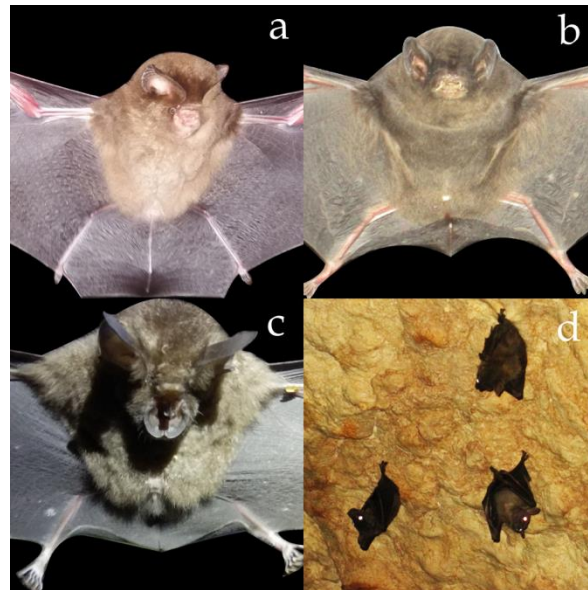


Figure 1. Bats species in each cave. a. *Hipposideros* sp., b. *Miniopterus* sp., c. *Rhinolophus* sp., and d. Pteripodidae

The recorded bats species were distributed in different caves. *Hipposideros* sp. was only found in Liang Boeh, *Rhinolophus* sp. in Sarongge, while Pteripodidae and *Miniopterus* sp. were only recorded in Liang Seungit. In addition, their populations in each cave were also certainly different. The greatest bats abundance was recorded in Sarongge with approximately 1194 bat individuals, followed by Liang Boeh 472 individuals, and Liang Seungit 188 individuals respectively. Bats abundance was associated with the production of fresh guano in each cave. These two parameters are positively correlated one another. As seen in Table 1, cave with greater bats abundance tends to produce greater fresh guano.

Table 1. Mean of bats population and guano production

Caves	Bats Species	Bats Population (Individual)	Guano Production/Night (Gram)
Liang Boeh	<i>Hipposideros</i> sp.	472±235	148±18
Liang Seungit	Pteripodidae <i>Miniopterus</i> sp.	188±6	10±1
Sarongge	<i>Rhinolophus</i> sp.	1194±121	222±29

The difference of bats species inhabiting the study caves are probably caused by multiple factors. One of the important factors is a roost-site preference by bats. Each bat species has specific roost requirements [27], [28]. The difference on cave structural characters including wide, height, entrance size and ornament complexity are presumed to be the main reason of this different roosting site selections [1], [2].

At the same time, each cave also showed substantial difference on bats abundance. Beside of natural condition, human-induced disturbances occurred in the study caves might be one of important factors that responsible for the difference[29]–[32]. The study caves were experiencing distinctive forms and degrees of human disturbance. For instance, phosphate mining occurred in Liang Boeh, meditation and tourism in Liang Seungit and bats hunting in Sarongge. Meanwhile, only disturbance in Liang Seungit that still occur up to recently. Beside of noise, light, and microclimate alteration caused by human visits, volatile substance used in meditation such as incense might also disturb cave biota, including bats. According to local residents, bats population in Liang Seungit was immense beforehand and dominated by insectivorous species (local resident in Java can differ insectivorous to frugivorous bats from their body size). The population then declined after exposed by human and currently dominated by frugivorous species.

B. Cave Physical Condition Induced by Bats Population

Bats population can influence microclimate condition in caves. Biological activity of bats in caves produces entropy which accumulates as heat. Previous studies had noted that large bats population contribute to higher temperature of caves passage [33], [34]. Caves with large bats population also relatively possessed a higher relative humidity [35]. Bats produce plentiful water via excretion (i.e. water vapor and urine) which then contribute to higher relative humidity of caves passage. The impact of bats population on soil physical condition was also substantial. In dry caves, guano produced by bats becomes important sources of water [36]. Soil moisture in the location of guano piles was relatively higher than soil without guano. On the other hand, the

presence of guano also determines soil temperatures. Fresh guano or newly produced guano releases temperature to their surroundings. The process of guano decomposition (fermentation) by microbes also produces heat that is released to environment. These mechanisms generate higher temperature condition in soil with guano piles. Besides, we performed GLLVM with negative binomial with log-likelihood: -228.8329, Degrees of freedom: 23 and Bayesian information criterion (BIC): 508.2019. Moreover, we used poisson and reached the log-likelihood: -226.6886, Degrees of freedom: 17 and Bayesian information criterion (BIC): 490.73. From this simulation we created the ordination by GLLVM poisson.

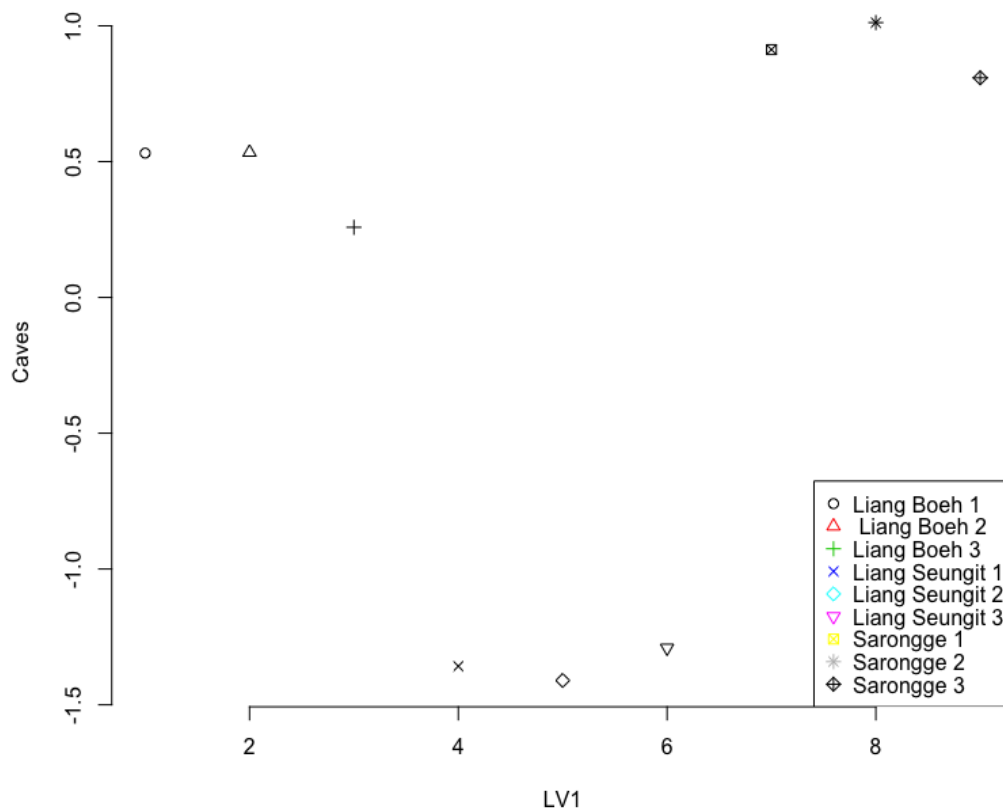


Figure 2. Ordination of bats population and physical parameters

Figure 2 illustrates the physical parameter differences among the study caves. Liang Boeh and Sarongge tend to have similar physical conditions one another, while Liang Boeh has slightly difference condition of physical parameter comparing to them. Based on this result, bats

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population size can be summarized as one of the main causes of physical parameter differences. Liang Boeh and Sarongge with large bats population have different physical parameters with Liang Seungit which possesses fewer bats population. This finding proves that bats population is highly influence caves physical condition. According to average measurement of physical parameters in each cave (Table 2), it can be seen that caves with larger bats population have relatively higher values of air temperature, soil temperature, relative humidity and soil moisture compared to caves with less bat population.

Table 2. Temperature and humidity condition of study cave

Caves	Air Temp. (°C)	Soil Temp. (°C)	Relative Humidity (%)	Soil Moisture (%)
Liang Boeh	24.90±0.17	24.00±0.00	93.00±4.00	98.33±0.58
Liang Seungit	25.17±0.06	23.00±0.00	92.33±2.52	80.67±1.15
Sarongge	27.10±0.96	26.00±0.00	93.00±2.65	100.00±0.00

C. Soil Chemical Composition

Bats guano is the main source of nutrient in a majority of karstic caves. They provide essential organic material which can support various living things [10]. Chemical content of bats guano varies with the dietary strategy of the bat. Every bat species produces guano with different degree of chemical contents. It is caused by specific diet preferences by bat species. Previous studies noticed that guano of insectivorous bats has relatively higher chemical content compared to frugivorous species [37], [38]. Figure 3 illustrates the differences on soil chemical composition in the study caves elaborated from selected parameters including C-organic, N, C/N, P, K, and pH. It can be seen clearly that the difference on bats species and population size generate soil chemical composition disparity within the study caves.

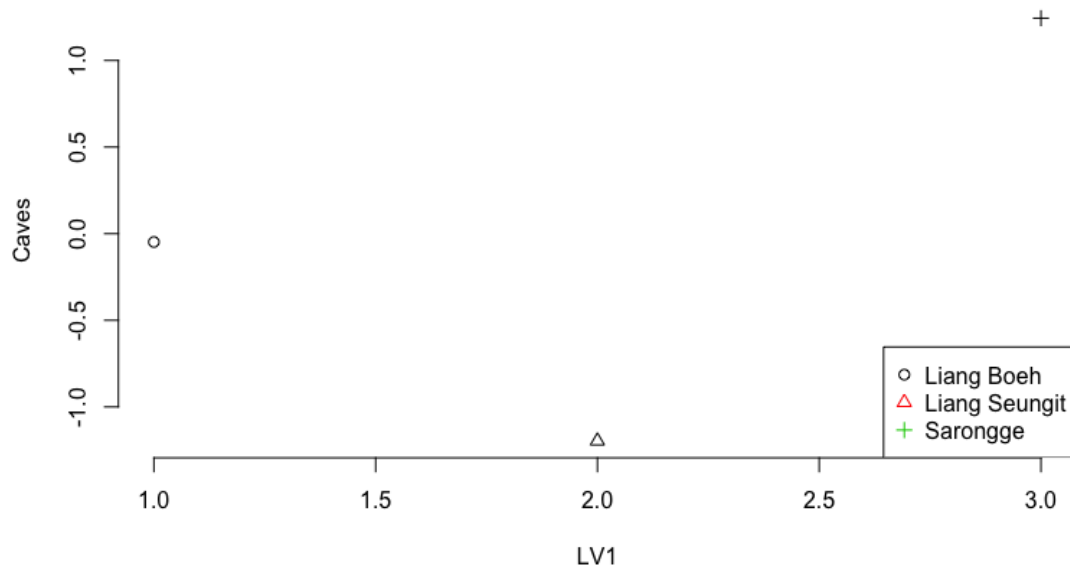


Figure 3. Ordination of bats population and soil chemical composition

According to the chemical composition measurement in Table 3, Liang Seungit had relatively higher values in almost all chemical content except for K. As mentioned previously, this cave was occupied by both insectivorous and frugivorous bats species. The combination of insectivorous and frugivorous guanos is presumed to generate variation in soil chemical contents and produce higher chemical composition as the result. The slightly lower chemical composition of C, N, C/N, and P in Sarongge compared to Liang Boeh and Liang Seungit might be due to different age of guano. The cave floor of Sarongge was covered by fresh guano. Therefore, soil sample collected from this cave was dominated by fresh guano. The value of soil pH supports this assumption since Sarongge had a higher soil pH compared to the other caves. Several studies noticed that fresh guano is generally more alkali and becomes more acidic when older [10], [39]. Newly produced guano has lower chemical composition because the process of fermentation that may adulterate chemical composition does not occur yet. The process of decomposition involves microorganisms that can improve nutrient composition of substrate under different condition [40].

Table 3. Chemical composition of soil in study caves

Caves	C-organic	N-total	C/N	P ₂ O ₅	K ₂ O HCl 25%	pH
Liang Boeh	25.03	4.18	5.98	7712.07	337.26	5.50
Liang Seungit	42.80	6.06	7.06	8899.38	265.83	5.50
Sarongge	7.28	2.08	3.50	709.13	222.38	5.96

D. Arthropods Community

The study caves were inhabited by various of arthropod groups. In total, 15986 individuals of arthropods belonging to 5 Classes and 18 Orders were sampled during the study. All Orders recorded in this study are common to be found in caves habitat [41]–[44]. The majority of morphospecies were similar to taxa noticed by several previous studies on terrestrial cave-dwelling arthropods in Java [35], [45], [46]. According to their class, Insecta was a dominant group with the greatest species richness (16 morphospecies), followed by Arachnida (7 species), Collembola (6 species), Diplopoda (2 species) and Crustacea (1 species) respectively.

Table 4. Arthropods richness and abundance in each cave

Taxa	Liang Boeh		Liang Seungit		Sarongge	
	Richness	Abundance	Richness	Abundance	Richness	Abundance
Arachnida						
Amblypygi	1	9	1	5	1	7
Aranea	2	2	-	-	3	86
Acari	1	10	1	7	1	16
Uropygi	1	4	1	1	1	5
Collembola						
Entomobryomorpha	-	-	2	55	3	55
Poduromorpha	2	67	-	-	2	76
Crustacea						
Isopoda	-	-	-	-	1	47
Diplopoda						
Helminthomorpha	-	-	-	-	1	2
Spirostreptida	1	11063	1	13	1	4088
Insecta						
Blattodea	-	-	2	55	1	125
Coleoptera	4	7	-	-	1	3
Diptera	-	-	-	-	2	26
Hemiptera	-	-	1	1	-	-
Hymenoptera	-	-	-	-	1	11
Lepidoptera	-	-	1	2	1	4
Orthoptera	1	15	1	17	1	95
Psocoptera	-	-	1	1	-	-
Unidentified	-	-	-	-	1	6

Arthropods taxa were distributed differently in the study caves (Table 4). Several morphospecies could be found in all caves. For instance, *Stygophrynus* sp. (Amblypygi: Charontidae), *Thelyphonus* sp. (Uropygi: Thelyphonidae), *Trachyjullus tjampeanus* (Spirostreptida: Cambalopsidae) and *Rhaphidophora* sp. (Orthoptera: Rhaphidophoridae) in Figure 4. These morphospecies are well-known to life in the subterranean habitat and common in Javan caves [12]. At the same time, the rest of morphospecies were only found in a single or restricted cave.

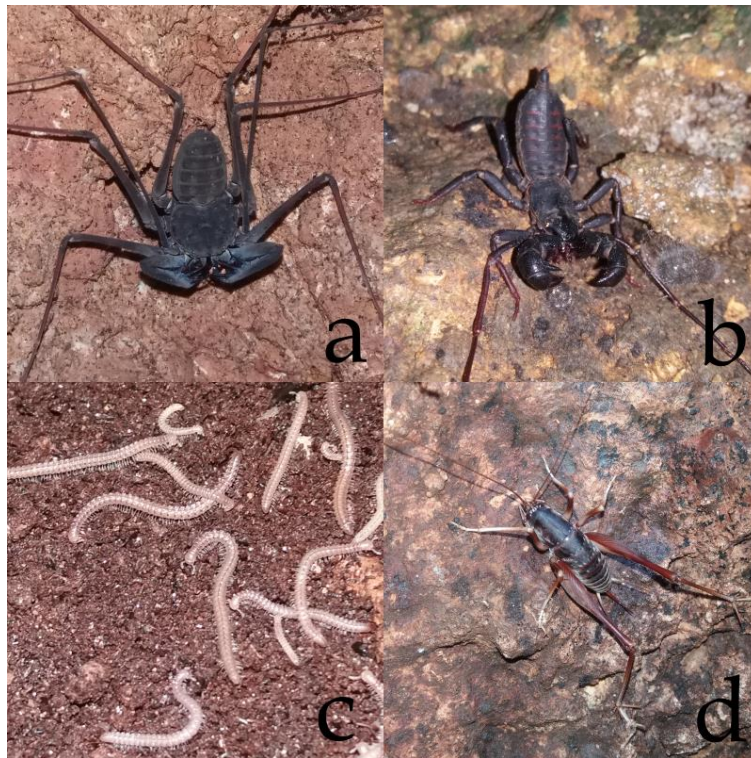


Figure 4. Several morphospecies distributed in all study caves. a. *Stygophrynus* sp., b. *Thelyphonus* sp., c. *Trachyjullus tjampeanus*, and d. *Rhaphidophora* sp.

The variation on the taxa distribution in the study caves generates different species richness and abundance. In the term of species richness, Sarongge was the greatest with 22 morphospecies followed by Liang Boeh (13 morphospecies) and Liang Seungit (12 morphospecies) respectively. On the other hand, the greatest arthropods abundance was found in Liang Boeh with 11177 individuals followed by Sarongge 4652 individuals, and the least Liang Seungit with only 157 individuals.

E. Correlation between Bats Population and Arthropods Community

The difference on arthropods community structure in the study caves might be caused by different physical and chemical conditions induced by bats population that have been previously discussed. Figure 5 shows the correlation among arthropod's richness and abundance in the study caves. In general, arthropod communities of Sarongge and Liang Boeh were more similar one another than Liang Seungit. It is indicated by the positive values of correlation of arthropod's richness and abundance between Sarongge and Liang Boeh. Furthermore, the correlation value of arthropod's abundance between Sarongge and Liang Boeh was certainly immense. These correlation patterns indicate that bats population and guano production generate similar impact on the species richness and abundance of arthropods in both caves.

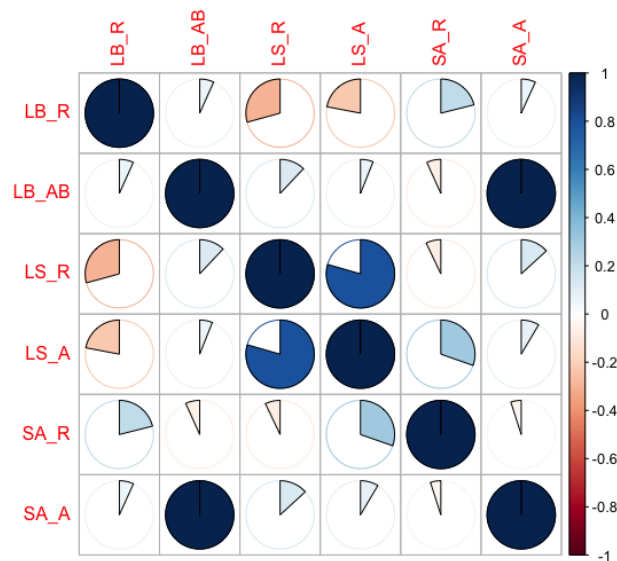


Figure 5. Correlation of arthropod's richness and abundance in the study cave

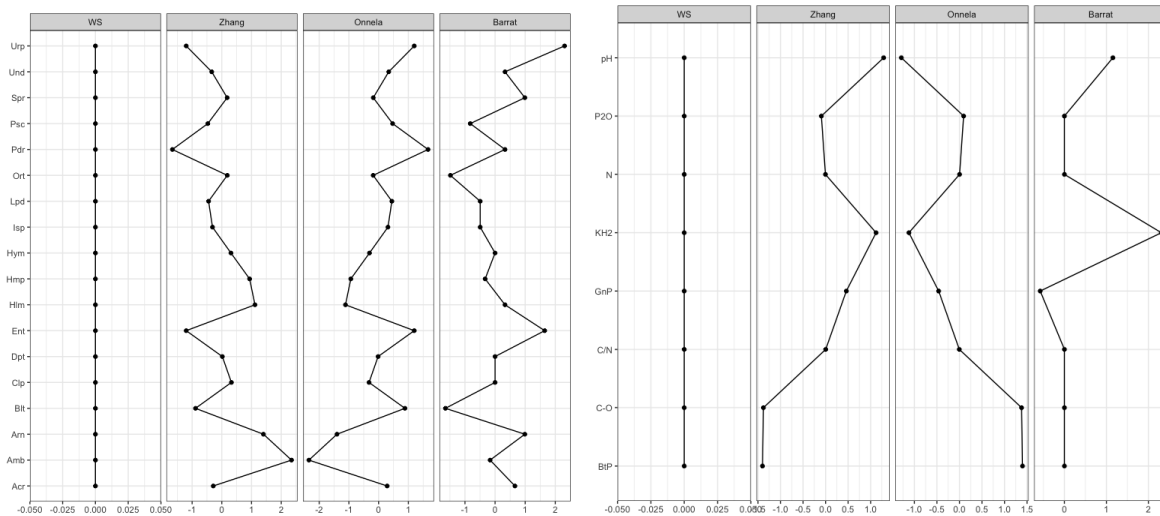


Figure 6. Strength of Bats Population (left) and Strength of Environmental Variables (right)

Figure 6 above is the proximity information between arthropods group. According to the criteria of Zhang, Onnela, and Barrat, Amblypygi has more information that can explain the effect of bat population on guano production with richness and abundance. On another hand, both the Zhang criteria and Onnela show that the relationship between the bats population in each cave is different. As mentioned previously, Sarongge and Liang Boeh were inhabited by insectivorous bats. Both caves had great bat populations which produced plentiful guano. At the same time, these caves were also inhabited by arthropods with greater richness and abundance compared to Liang Seungit. According to the composition of arthropods community (Table 4), it can be seen that there were high species domination by several morphospecies in Sarongge and Liang Boeh. The morphospecies which dominate these caves are well-known to life in guano pile of insectivorous bats. For instance, millipede (*Trachyjullus tjampeanus*), Cockroach (Blattidae), and woodlice (Isopoda) in Figure 7 [47]. Based on this fact, it can be proposed that the type of insectivorous bats and larger bats population which produce plentiful guano may support greater arthropods diversity and abundance to occur in a cave.

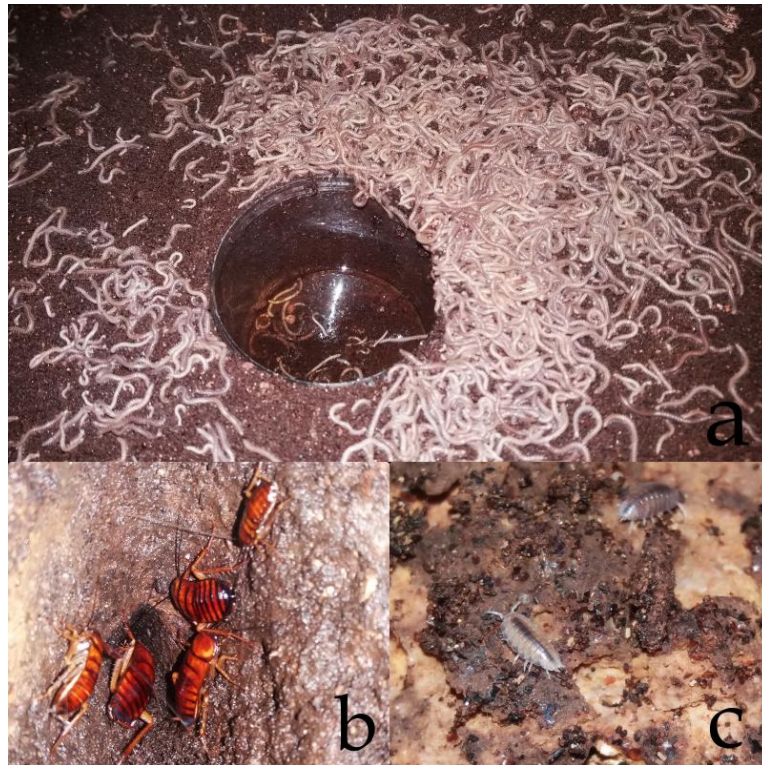


Figure 7. Morphospecies dominating the study caves. a. Bulk of *Trachyjullus tjampeanus* individuals in Liang Boeh, b. Cockroach (Blattidae) population in Sarongge, and c. Woodlice (Isopoda) in Sarongge.

In contrast with Sarongge and Liang Boeh, Liang Seungit was inhabited by less species richness and abundance of cave-dwelling arthropods. Smaller bats population produced less guano. Fewer guano was unable to support many arthropods both in terms of diversity and abundance. At the same time, the majority of guano in this cave was frugivorous type which is not favorable for several dominant arthropods in caves. For instance, *Trachyjullus tjampeanus* which contributes to bulk of arthropods abundance in Sarongge and Liang Boeh was significantly lower in Liang Seungit. Furthermore, this species was never be found aggregated on the fresh guano of frugivorous bats. Even chemical composition of soil in this cave was better than the two other caves, it was likely that cave arthropods prefer guano quantity rather than quality.

Our results bring important concern on the conservation of cave ecosystem in tropical region. Bat is a keystone species in the dry cave's ecosystem [48]. Cave-dwelling arthropods community

is highly depended on bats population. The presence of bats population in caves induces physical and chemical conditions which then determine arthropods community in the caves. Based on this result, it is an obligation to protect bats population in order to conserve the whole of caves ecosystem. Unfortunately, threats for bats population in Tasikmalaya are currently even more intense. Human activities including limestone quarrying, guano harvesting, bats hunting for bushmeat or medicine, and cave tourism industries which severely threaten cave-dwelling bats worldwide [1], [29], [32], [49], [50], also occur in Tasikmalaya karst area. As mentioned previously, the biology of caves in this karst areas were still poorly understood. This biodiversity would be potentially displaced before studied due to bats population disturbances. Therefore, conservation effort to save bats population should be taken by all stakeholders. Information about the importance roles of bats as ecosystem services provider should be spread properly to local residents in order to make them understand about the consequences of losing bats for their life.

4. CONCLUSION

The study caves were inhabited by different bats species and population size which contribute to different guano availability. Guano production was higher in caves with greater bats population. Physicochemical parameters of the caves were strongly correlated with bats population. Caves with larger bats population had higher temperature and humidity. Combination between frugivorous and insectivorous bats guano in caves would potentially generate richer soil chemical composition. A total 15986 individuals of cave-dwelling arthropods belonging to 5 Classes and 18 Orders were recorded in this study. Our data confirm that the difference on bats population generated different arthropods community. Bats determined cave-dwelling arthropods community by two schemes, their types of species whether frugivorous or insectivorous and their population sizes. The type of insectivorous bats and greater bats population size supported greater arthropods diversity and abundance.

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AUTHORS' CONTRIBUTIONS

Isma Dwi Kurniawan, implements the system and does species identification, writes the paper, and acts as corresponding author. Cahyo Rahmadi, does the supervision, species identification, project administration, and funding acquisition. Rezzy Eko Caraka proofs and validates the instrument, proposes the methods, writes and revises the manuscript. Iman Aulia Rahman does the data curation. Ida Kinasih does the data curation and species identification. Toni Toharudin does the supervision, Rung Ching Chen does the supervision, Youngjo Lee, does the supervision. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

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