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Research Article

Population structure and habitat preference of cave crickets (*Rhaphidophora* sp. (Orthoptera: Rhaphidophoridae)) in Sanghyang Kenit cave, Citatah karst area, West Java

Isma Dwi Kurniawan[1,2]*, Rahmat Taufiq Mustahiq Akbar[1], Risda Arba Ulfa[1], Mentari Kusuma Wardani[1], Birama Satria[1]

1) Department of Biology, Faculty of Science and Technology, UIN Sunan Gunung Djati Bandung, Jl. A.H. Nasution No. 105, Cibiru, Bandung, 40614

2) Indonesian Speleological Society, Ruko BSD Sektor IV Blok RD No.71, Lengkong Wetan, BSD City, 15322

* Corresponding author, email: ismadwikurniawan@uinsgd.ac.id

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ABSTRACT

Cave crickets are considered as a keystone species that can be used as a cave ecosystem bioindicator. Developing caves as tourism has considerable potential to disturb cave cricket populations. This study aimed to investigate cave cricket population structure and their habitat preference in Sanghyang Kenit cave one year after it developed into a show cave. Data were collected through standardized visual searching in three cave zones: entrance, twilight, and dark. Besides cave crickets, other macroarthropods discovered in each zone were also recorded. Abiotic parameters of habitat comprised air and soil temperatures, RH, soil moisture, soil pH, and light intensity were measured. Data were analyzed to show cave crickets abundance, density, sex ratio, and age structure. Statistical analysis comprising Kruskal Wallis, non-metric multidimensional scaling, and correlation tests were performed. The cave cricket population in Sanghyang Kenit belonged to a single species, *Rhaphidophora* sp. The population was around 78-108 individuals and distributed in all cave zones. The abundance and density in twilight and dark zones were significantly higher than in the entrance. The number of males outperformed females with a 2.16 ratio. Besides, the population was dominated by the sub-adult class. Environmental parameters of twilight and dark zones tended to be similar to one another compared to the entrance. Cave crickets preferred habitats with dark, humid, and acidic soil pH. *Heteropoda* sp. and *Catagaeus* sp. were considered potential predators. This study implies the importance of protecting cave crickets in Sanghyang Kenit.

INTRODUCTION

Caves represent several extreme environments that generate unique ecosystem characters. The typical cave environments include total darkness, high humidity, and a stable microclimate (Prous et al. 2015; Kurniawan & Rahmadi 2019). Besides, caves are well-known as one of the most challenging environments for organisms due to the absence of sunlight, which limits visual organs from working properly. The darkness also inhibits photosynthetic organisms, resulting in low food availability and/or variation (Ravn et al. 2020). Caves biodiversity is generally lower than surface ecosystems because those extreme conditions act as limiting factors for a diverse group of living creatures (Prakarsa et al. 2021). Caves only can be inhabited by adaptive taxa that can cope with such a harsh environment. Therefore, caves and their biodiversity are unique and extremely sensitive (Mammola 2019).

All inhabited cave animals can be referred to as cavernicoles. These animals are classified into three groups according to their degree of cave adaptations and cave usages as their habitat: troglophile, trogloxene (subtroglophile), and troglobite/troglobiont (Howarth & Moldovan 2018a). Troglophiles are permanent resident of cave habitats, which also can inhabit surface habitats. Trogloxenes are partial cave dwellers that must leave caves periodically for biological functions, such as feeding. Meanwhile, troglobites are obligate cave animals that only can live exclusively in the caves realm (Culver & Pipan 2009; Prakarsa et al. 2021).

One of the essential cave-dwelling animals is cave crickets. Taxonomically, they belong to order Orthoptera, suborder Ensifera, and family Rhaphidophoridae. This family consists of more than 550 described species distributed into 80 genera (Ingrisch & Rentz 2009). All the family members have a humpbacked morphological appearance, relatively larger body size than the common cricket (subfamily Gryllinae), and are wingless. Moreover, they also can be recognized from their long antennae and strong enlarged hind legs (Di Russo & Rampini 2017; Song et al. 2020). All rhaphidophorids are nocturnal (Allegrucci et al. 2010). They occur in various humid habitats such as under logs, rocks, damp humus, tree holes, and many species restricted to caves (Epps et al. 2014; Hu et al. 2014). The cave dwellers are called cave crickets or cave weta, while surface inhabitants are known as camel crickets or spider crickets. Cave crickets are categorized as troglophiles that can complete their whole life cycle in caves. However, they can also be classified as trogloxene since several species periodically leave caves at night, mainly for foraging (Deharveng & Bedos 2012; Chandoo et al. 2013).

The existence of cave crickets population is vital for the continuity of caves ecosystem because it provides food for many cavernicoles. In Indonesian caves, cave crickets are the main prey for many predatory species, including whip spiders (order Amblypygi), huntsman spiders (family Sparassidae), and centipedes (order Scutigeromorpha) (Kurniawan & Rahmadi 2019; Prakarsa et al. 2021). In temperate caves where bats' guano supply is limited, their droppings and carcasses are the primary food sources for other cave-dwellers. Besides, their eggs are also consumed by smaller-sized arthropod groups like carabid beetles (Lavoie et al. 2007; Culver & Pipan 2009). Thus, cave crickets are often considered as keystone species in many cave ecosystems (Yoder et al. 2010; Epps et al. 2014).

Caves ecosystem in Indonesia has been experiencing escalated threats due to overexploitation by humans. Besides the rising numbers of extractive industries such as limestone quarries (Mulyani 2011; Subekti 2016), the increase of human visits to caves, mainly for tourism purposes, is a significant challenge for caves ecosystem continuity (Kurniawan & Rahmadi 2019;

Kurniawan et al. 2020). Caves have exciting attributes, such as beautiful speleothems or cave ornaments and cultural, historical, and religious values, that can attract people. Thus, many caves are developed as show caves, i.e., natural caves opened to public as tourist attractions. Several previous studies revealed that intense human visits to caves could alter cave microclimate conditions, including increased air temperature and CO_2 concentration, and aerobiological content (Fernandez-Cortes et al. 2011; Pacheco et al. 2020). Those environmental changes can bring serious menace for cave-dwelling animals resulting in population decrease and biodiversity loss.

Nowadays, the cave tourism industry in Indonesia is on a positive trend because of the excellent response from the community. This trend leads the opening of many new show caves, including Sanghyang Kenit, a show cave situated in West Java Province. This cave has been operated as a tourist place since 2019 and is managed by the local community. According to the preliminary observation of this study, the cave was inhabited by cave crickets. This study aimed to investigate cave cricket population structure and habitat preference in Sanghyang Kenit. Investigation related to the cave cricket population is essential to provide a baseline condition of a keystone species that can be used to detect ecological changes caused by tourism activities.

MATERIALS AND METHODS

Study Site

This study was conducted in Sanghyang Kenit cave, located in the Citatah karst area. This cave is administratively situated in the Cipatat sub-district, Bandung Barat district, West Java province, at the geographical coordinate 6° 51’35” S 107°20’51” E (Figure 1). The cave entrance is moderate in size and located in the Citarum riverside. This cave has a horizontal passage approximately 400 m in length, divided into three zones: entrance, twilight, and dark. The cave passage is a part of the Citarum drainage basin which is naturally passed by a high level of water current. Still, the Saguling hydroelectric power plant decreases the water flow, making it possible for humans to visit the cave. Sanghyang Kenit has both terrestrial and aquatic types of habitats. The terrestrial habitat consists of rocks, pebbles, soils, and sand substrates. The cave ceiling was inhabited by insectivorous bat populations that generated guano piles on the cave floor.

Field Data Collection

Data collection was carried out through a visual searching method by hand collecting and direct counting (Wynne et al. 2019). All visible cave cricket individuals during cave explorations were captured directly by hand with the help of gloves, small hand nets, and tweezers. The collection was conducted during daylight (1.00-4.30 pm) with three repetitions for each cave zone starting from the entrance, twilight, and dark zones. The method was standardized by a similar duration of sampling efforts (30 minutes per zone)

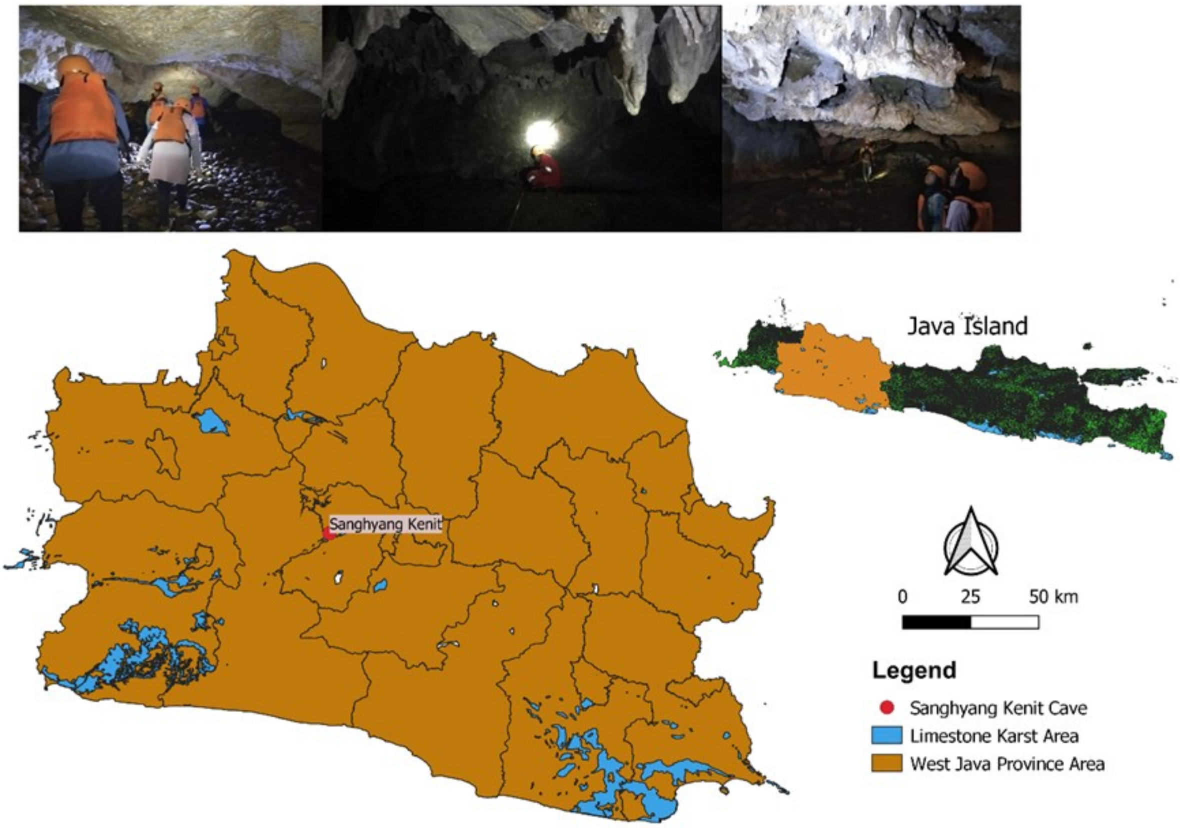

Figure 1. The location of Sanghyang Kenit cave and several images of its passage conditions.

and performed by three collectors, with good experience collecting cave-dwelling arthropods. Every collector was assigned to collect data in the different sampling areas, namely the right, left, and middle parts of the cave passage.

All collected cave crickets from each zone were placed in a container box to be counted for their number of individuals and categorized into sex and age class. The number of individuals was calculated by hand tally counter. Sex categorization (male/female) was distinguished based on the presence and absence of an ovipositor. At the same time, age structure was estimated based on three different body size categories (Carchini et al. 1994), namely small (< 3 cm), medium (3-5 cm), and large (> 5 cm). The classification of cave crickets based on their body size aimed to reveal the age proportion among juvenile (small), sub-adult (moderate), and adult (large) classes within the population. Cave crickets were released into their habitat immediately after the measurements were completed. Several individuals from each sex and body size category were carried off and preserved using 70% alcohol for morphological and morphometrical studies in the laboratory.

Along with the cave cricket collection, the richness and the number of individuals of the other cave-dwelling arthropods were also recorded. The data were used to detect potential predators and competitors of cave crickets. All collected arthropods were identified based on morphological characters up to the lowest possible taxon category. Besides, they were also classified into their role in the cave ecosystem.

Abiotic Parameters Measurement

Several associated abiotic parameters were measured during the study. Abiotic parameters were utilized to describe the habitat characteristic and its relation to cave cricket population. Soil and air temperatures, relative humidity (RH), soil moisture, light intensity, and soil pH were among the abiotic parameters that were assessed. Soil moisture and pH were measured using soil tester (Takemura DM-5), light intensity using light meter (Lutron LX-100), RH and air temperature using thermo-hygrometer (HTC-1), while soil temperature using soil thermometer (71200.080-vr). The measurements were conducted after the animal collection was completed. Each parameter was measured five times for each zone with three repetitions in the different sampling efforts. In addition, the total area of each zone was also estimated by measuring the length and width of the cave passage. The total area was used to calculate population density.

Data Analysis

The population structure was indicated by calculating the cave cricket abundance, density, sex ratio, and age structure. The formulas for each aspect are provided as follow:

Abundance:

$$N = \sum_{i=1}^{s} \mathrm{Ni}$$

where

N : abundance index

Ni : the number of individuals of targeted species,

Density:

$$Di = \frac{ni}{A}$$

where

Di : density of targeted species

ni : the number of individuals of targeted species

A : the total of the studied area (m^2)

Sex ratio:

$$X = \frac{J}{B}$$

where

X : sex ratio of targeted species

J : the number of male individuals

B : the number of female individuals

Meanwhile, the age structure analysis was carried out by comparing the relative abundance of each size category. The formula of relative abundance is as follow:

$$Relative\ Abundance\ (\%) = \frac{The\ number\ of\ Individual\ a\ size\ category}{Total\ Number\ of\ Individual\ all\ size\ category} x\ 100\%$$

Several statistical analyses were performed for different purposes. The Kruskal Wallis test was used to determine the abundance and density differences among cave zones. The test was processed using SPSS version 25. To highlight similarity and dissimilarity among cave zones according to their measured abiotic parameters and their relationship with cave cricket abundance, non-metric multidimensional scaling (NMDS) was performed. On the other hand, a correlation test was conducted to show the relatedness of cave cricket population with the other arthropod species discovered in the cave. NMDS and correlation tests were processed using R Studio under Vegan (function: metaMDS and combined with envfit) (Oksanen et al. 2020) and Corrplot packages (function: corrplot(cor) (Wei & Simko 2021), respectively. The results of the analyses were presented as table, plot, and graph to make better visualization and interpretation.

RESULTS AND DISCUSSION

Cave crickets occurring in Sanghyang Kenit consisted of only a single species. This species belonged to subfamily Rhaphidophorinae and genus *Rhaphidophora*. The typical characteristics of this subfamily include wingless, undeveloped sound organs, and membranous genitalia without complex structures. There are two genera from this subfamily that bear a great degree of similarity in Indonesia area: *Rhaphidophora* and *Stonycophora*. The Sanghyang Kenit population is classified into *Rhaphidophora* due to the absence of large copulatory processes on the male abdomen, which differs from *Stonycophora* (Di Russo & Rampini 2017). Moreover, *Stonycophora* was never reported inhabiting caves previously. Males can be easily distinguished from females by the absence of ovipositors (Figure 2b).

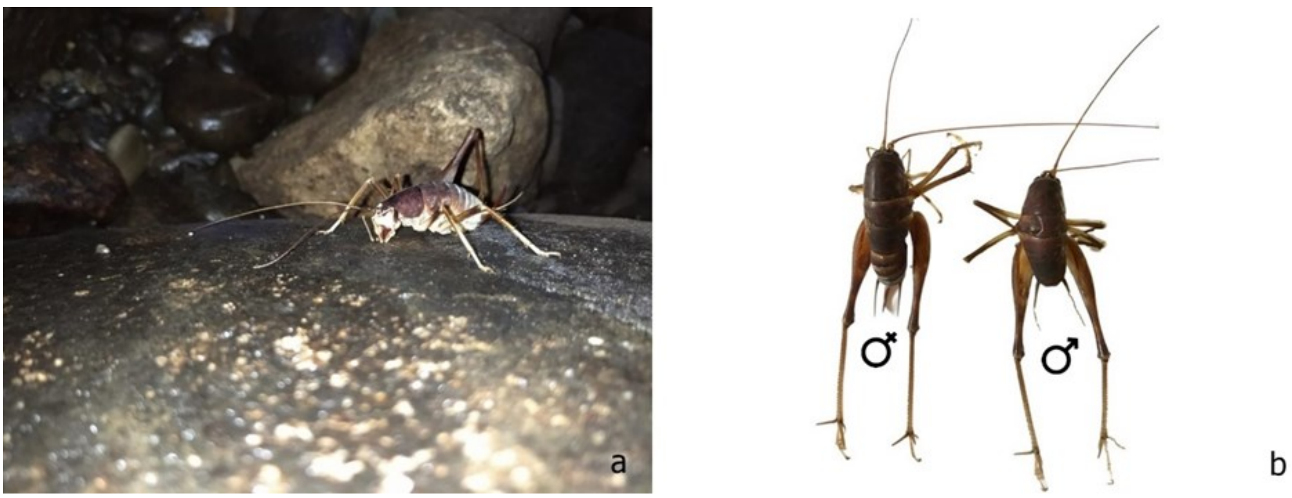

Figure 2. a) Sanghyang Kenit's cave crickets habitus, b). Comparison of female and male morphology.

There are two known genera of cave crickets living in Java: *Diestrammena* and *Rhaphidophora* (Rahmadi 2008). Up to recently, the distribution of these two genera is still unclear and seems to overlap. But many previous cave-dwelling arthropods studies had revealed that *Rhaphidophora* occurred in many karst area in Java including Tuban, Gunungsewu, Cilacap, Tasikmalaya, and Ciampea (Rahmadi 2002; Rahmadi & Suhardjono 2007; Prakarsa & Ahmadin 2017; Kurniawan et al. 2018a; Hasibuan & Lidiawati 2020; Hidayaturrohmah et al. 2021). Overall, at least 12 species belonging to genus *Rhaphidophora* have been described from Java, but only two species are reported to occupy cave realm. These species are *R. dammermani* and *R. dehaani* (Prakarsa et al. 2021). It is challenging to distinguish these two species based on morphological character because it needs specific taxonomical expertise. Moreover, the available references for these two species are limited. Thus, most previous studies only justified cave crickets until genera level and commonly used a uniform name, *Rhaphidophora* sp. Only a few studies had named cave crickets until species level, but, likely, the justifications were not made based on morphological characters but biogeographical evidence instead. Considering this approach, the species of Sanghyang Kenit's population can be suspected as *R. dammermani*. It is because the geographical location of the Citatah karst area is not far from Ciampea in Bogor, where the first specimens of this species were collected (Rahmadi 2011). A further sophisticated taxonomical study is needed to prove this hypothesis.

Abundance and Density

Cave crickets in Sanghyang Kenit were distributed in all cave zones. However, the number of individuals that occurred in each cave zone was highly different (Figure 3). The difference is confirmed by the result of Kruskal Wallis test, which shows a lower significant value than α ($\alpha < 0.05$). Most cave crickets were discovered in dark zone with 60-79 individuals, followed by twilight zone (16-26 individuals). The smallest abundance was in entrance zone, where only 2-4 individuals were recorded. Overall, around 78-109 individuals of cave crickets inhabited Sanghyang Kenit.

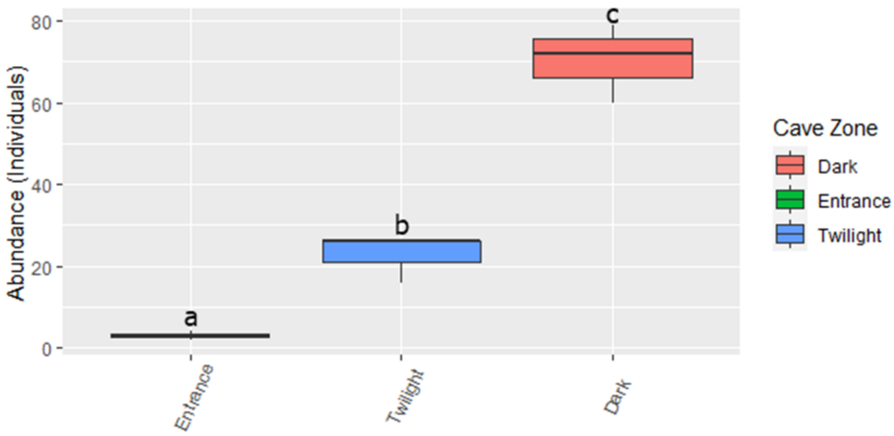

Figure 3. Comparison of cave cricket abundance across different cave zones. The different letter indicates different abundance among cave zones.

Even the cave has been operated as a tourist attraction, the population of cave crickets was still in great abundance. This abundance is relatively higher than previous cave cricket populations monitoring in the other show caves in Java. The study conducted by Kurniawan et al. (2017), performed by a similar sampling technique, demonstrated that cave cricket populations in the frequently visited show caves in the Gunungsewu karst area were only around 5-24 individuals. Furthermore, the study also revealed that wild caves were inhabited by more abundant cave crickets, with about 56-180 recorded individuals. As mentioned previously, Sanghyang Kenit is a new show cave where human visit is less intense. Minor disturbance allows the population to thrive prosperously.

In line with abundance, the cave cricket density among cave zones was also significantly different ($\alpha < 0.05$). However, the density in twilight and dark zones was relatively similar (Table 1). The entrance hosts the most significant area (3000 m^2), but the abundance of cave crickets in the zone was fewer. This result indicates that space is not the main factor deciding cave cricket distributions in caves. The difference in environmental parameters among cave zones is considered as the most important driving factor.

Table 1. The density of cave crickets across different cave zonation.

Cave Zone	Mean of Abundance (Individuals)	Zone Area (m^2)	Density (Ind/m^2)*
Entrance	3	3000	0.001a
Twilight	22.67	690	0.032b
Dark	70.33	1800	0.039b

*Kruskal Wallis test is significant at $\alpha = 0.05$. The different letter illustrates different density among cave zones.

Only few previous studies contained information regarding cave cricket density. Carchini et al. (1994) demonstrated that during three years of continuous monitoring of a cave cricket population (*Dolichopoda geniculata*), the density fluctuated but was always lower than one individual/m^2. However, the study was conducted in the temperate region, where caves condition is significantly different from the tropical region. Unfortunately, there is no published data about cave cricket density from Indonesian species for comparison.

The comparison of cave cricket density among cave zones (Table 1) shows that the value increases from the entrance to the dark zone. This result shows a similar pattern with the previous study conducted by Carchini et al. (1994), which revealed that density in the deeper area of a cave was essentially higher than near entrance area. However, the density between twilight and dark zones in this study was not statistically different. Most animals belonging to troglophiles are commonly abundant in twilight and dark zones due to preferable microclimate conditions suitable for this group (Howarth & Moldovan 2018b).

Sex Ratio

The result of the sex ratio analysis illustrates that males predominated in all cave zones. The sex ratio varied from 2.10 to 3.50. Overall, the number of males was twice higher than females (Table 2). Several previous studies had examined the sex ratio of different cave cricket species, and the results were highly varied. Lavoie et al. (2007) reported that a cave cricket species from the genus *Hadenoecus* had significantly more females than males, while Bernardini & Di Russo (2004) said a fair sex ratio (1:1) in the genus *Dolichopoda*. Up to the present, there is no specific information about the sex ratio of the genus *Rhaphidophora*.

Table 2. The sex ratio of cave cricket across different cave zonation.

Cave Zone	Mean of Abundance (Individuals)		Sex Ratio (Male/ Female)
	Male	Female	
Entrance	2.33	0.67	3.50
Twilight	15.67	7	2.23
Dark	47.67	22.67	2.10
Total	65.67	30.33	2.16

Most rhaphidophorids appear to have a polyandry mating system where females mate with more than one male (Fea & Holwell 2018). One essential benefit of this mating system is a sufficient sperm supply that improves fertilization probability (Slatyer et al. 2012). However, even though females can copulate with multiple males, rhaphidophorids and other ensiferans commonly have various mechanisms to control fertilization success more toward one male than other mates. There are compelling evidences of cryptic female choice mechanisms in which females manage fertilization in their favor. The mechanisms include manipulation of spermatophore attachment duration, sperm uptake regulation, re-copulation with the same male, modification in the rate of oviposition and/or the differential allocation of resources to eggs, and persistence during mating (Vahed 2015). Conversely, intraspecific competition among males to fight over females is evident within raphidophorids (Stritih & Čokl 2012). Sometimes, the agonistic behavior of males involves physical conflict (male-male combat). Thus, males have a particular structure on their hind legs used as armament. At the same time, it is also utilized to capture and grasp females during copulation (Conroy & Gray 2015).

Age Structure

The relative abundance (RA) comparison among size groups showed a homogenous pattern across cave zonation. The greatest RA came from the moderate class, followed by the large class, and the least was the small class (Figure 4). Thus, the accumulative RA from all zones also indicated a similar pattern. This result is in accordance with Lavoie et al. (2007), which reported the predominance of adult to juvenile. However, the comparison between sub-adult and adult was inconsistent with Carchini et al. (1994), that showed the domination of adult to sub-adult. In contrast, this study revealed the opposite result.

Carchini et al. (1991) revealed that age structure within cave crickets populations was diverse and highly dependent on the season and the natural condition of inhabited caves. According to the study, the population of cave crickets in artificial caves is extremely seasonal since food resources and climatic conditions mainly rely on surface environments. Nevertheless, in natural caves, where colonization is older and climatic condition less fluctuates, age structure tends to be more stable. However, further investigation and continuous monitoring, which cover both rainy and dry seasons, are needed to confirm whether the age structure of the Sanghyang Kenit's population is seasonal or year-round.

The domination of the sub-adult class is a good indicator for the sustainability of cave cricket population in Sanghyang Kenit. This domination indicates that the population is on a positive trend since many individuals are achieving sexual maturity. According to this, the reproduction rate probability is projected to increase, generating new individuals. As mentioned previously, cave crickets are a keystone species that provide food for a diverse group of cave-dwellers, both when they are in the form of eggs, nymphs, and adults (Culver & White 2012; Kurniawan & Rahmadi 2019). Therefore, the successful reproduction of cave crickets will guarantee their existence and the other species that rely on them (Benoit et al. 2004).

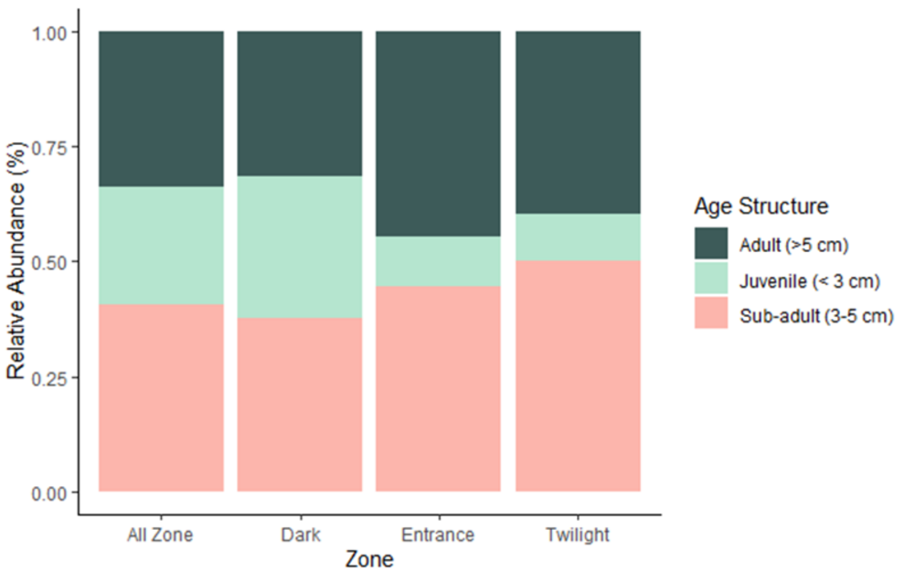

Figure 4. Comparison of relative abundance among size groups across cave zonation.

Habitat Preference based on Environmental Parameters

The results of abiotic environmental parameters measurement were varied across cave zonation. Nevertheless, twilight and dark zones embraced a remarkable similarity to one another than the entrance. This result is in line with previous studies that also indicated the same (Kurniawan et al. 2018b). NMDS output presented in Figure 5 illustrates that the similarity between those two zones occurred in almost all measured environmental parameters. In contrast, the entrance zone had a higher light intensity, air and soil temperatures, and soil pH, while relative humidity and soil moisture were significantly lower than in twilight and dark zones.

According to the cave cricket abundance and density that have been already discussed, it can be inferred that cave crickets in Sanghyang Kenit preferred twilight and dark zones as their habitat. Figure 5 also showed that abundance (blue arrow) steers from the area of twilight zone towards dark zone. This preference matched the environmental condition where both zones tended to be similar in most measured parameters. Hu et al. (2014) and Epps et al. (2014) mentioned that most cave crickets prefer dark and humid places since they are nocturnal animals. Low light intensity and high humidity were the characters of twilight and dark zones. In this regard, cave crickets were abundant in those two zones.

Cave crickets possess several morphological adaptations that support them to thrive in dark and humid environments. Even cave crickets have eyes, limited sunlight or total darkness in caves obstruct their visual organs from working properly. But, cave crickets have elongated appendages, particularly antennae, which they use as a sensory organ for orientation (Culver & Pipan 2009). In addition, they also have elongated legs that may be used for walking on irregular surfaces in the darkness (Lavoie et al. 2007). High humidity is stressful for most surface animals, but it brings crucial benefits to cave cricket's life. Compared to their surface relatives, the outer cuticle of cave crickets is significantly thinner, making them very sensitive to moisture loss caused by sunlight exposure, high temperature, and low humidity. Staying in humid caves prevents them from experiencing such dreadful evaporation (Lavoie et al. 2007; Howarth & Moldovan 2018a).

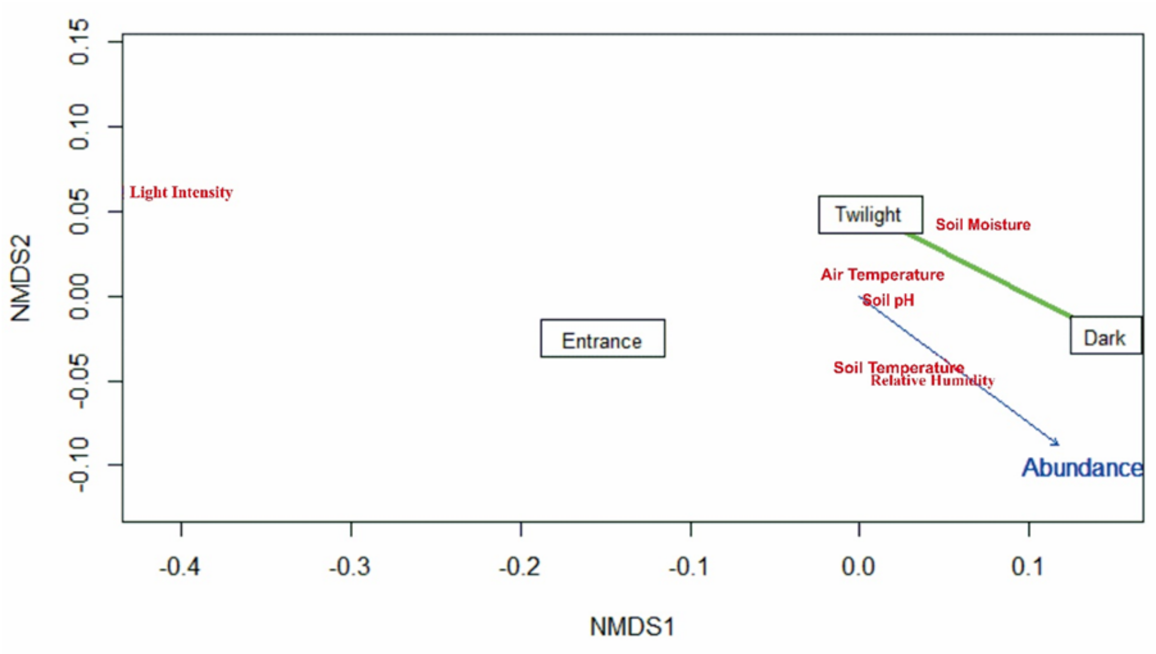

Figure 5. Relatedness among cave zones based on environmental parameters and its relation with cave cricket abundance.

Another essential factor promoting cave cricket preference over twilight and dark zones is food availability, particularly bats guano. This kind of organic matter is the most critical food source in tropical caves (Kovac 2018). A considerable proportion of cave-dwelling animals are guano-dependent, including cave crickets (Moulds 2004; Ferreira 2019). Bats population in Sanghyang Kenit was distributed from twilight to dark zones, which generated guano piles on the cave floor. Commensurate with cave crickets, bats prefer humid and dark places for their roosting sites (Furey & Racey 2016; Lizarro et al. 2020; Newman et al. 2021). The measurement of soil pH showed that twilight and dark zones have more acidic pH than the entrance. This is caused by guano deposits spread in those zones since guano has acidic pH (Mazebedi & Hesselberg 2020). Multiple studies have examined that guano was one of the main deciding factors for distribution, composition, and abundance of various cave-dwelling animals belonging to troglophiles and troglobiont (Tobin et al. 2013; Iskali & Zhang 2015). Therefore, conservation of cave crickets and other troglophiles in Sanghyang Kenit can be carried out by maintaining the bats population inside the cave.

Potential Predator and Competitor

Six other macroarthropods species were successfully recorded during the study. Those species are distributed into two classes (Arachnida and Insecta) and four orders (Aranea, Amblypygi, Blattodea, and Hymenoptera). These groups are well-known to have cavernicolous representatives (Romero 2009; Prakarsa et al. 2021). According to their roles in the ecosystem, most species are true predators, and only a single species acts as a detritivore. In addition, they occupied different cave zones. There were three species exclusively inhabiting entrance, two species in dark zone, and one species that occurred both in entrance and twilight zones (Table 3).

According to the correlation test result presented in correlogram (Figure 6), it can be seen that there are two species of macroarthropods having a strong positive correlation with cave cricket abundance, namely *Heteropoda* sp. and *Catagaeus* sp. This is indicated by the almost perfect circle form with dark blue in the correlogram between *Rhaphidophora* sp and the two mentioned species. This relation happened because *Heteropoda* sp. and *Catagaeus* sp. individuals were concentrated only in dark zone where cave crickets were abundant. Several studies have documented predatory activities of those

Table 3. The list of other macroarthropods in Sanghyang Kenit with their role and distribution within cave passage.

Class	Order	Morphospecies	Ecological Role	Distribution
Arachnida	Araneae	*Heteropoda* sp.	Predator	Dark
		Araneus sp.	Predator	Entrance
		Pholcus sp.	Predator	Entrance
	Amblypygi	*Catagaeus* sp.	Predator	Dark
Insecta	Blattodea	*Periplaneta americana*	Detritivore	Entrance, Twilight
	Hymenoptera	*Polistes* sp.	Predator	Entrance

two species to cave crickets in many Indonesian caves (Kurniawan & Rahmadi 2019; Prakarsa et al. 2021). Thus, the species were considered as potential predators for cave crickets.

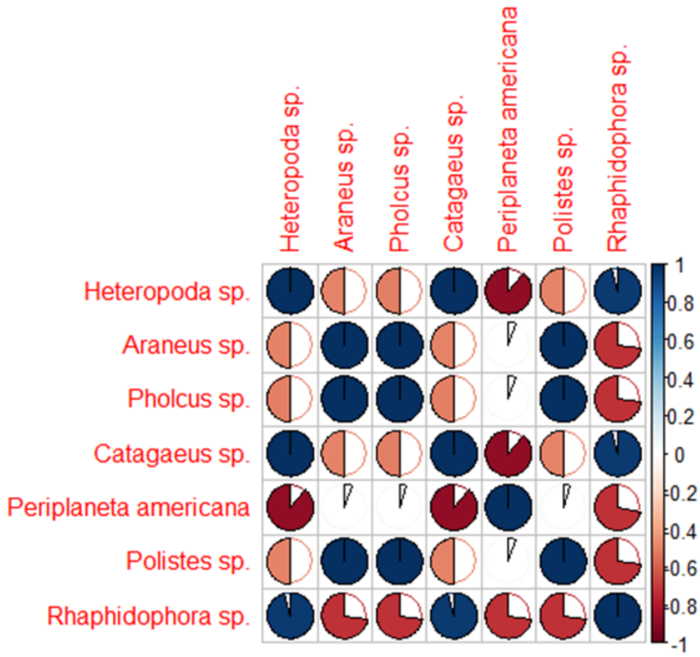

Figure 6. Correlation between cave crickets and the other recorded macroarthropods. A correlation of 1 (solid blue) indicates a perfect positive correlation, while -1 (solid red) depicts a perfect negative correlation.

The existence of predators indicates that cave crickets are an essential component of the cave's food web. Their population can influence the fate of upper trophic level species. In other words, disturbance of cave cricket population can indirectly affect those two predators' survival. This result implies an essential suggestion to the Sanghyang Kenit' show cave managers to ensure they manage the cave wisely. As previously discussed, intensely visited show caves appear to have a lower abundance of cave crickets than wild caves (Kurniawan et al. 2017). This strongly indicates that uncontrolled tourism activities can disturb cave crickets, resulting in population decline.

Among recorded arthropods, only one species can potentially be competitor for cave crickets, namely cockroaches (*Periplaneta americana*). This species was the only detritivore recorded during the sampling efforts. Like cave crickets, many cave-dwelling cockroaches are also guano consumers (Rahmadi & Suhardjono 2007; Ferreira 2019). They are common in a cave with rich guano deposits, and many are restricted to living in guano (guanobites) (Lucañas & Lit 2016). However, the competition likelihood for food between cave crickets and cockroaches in Sanghyang Kenit is considered low. According to their distribution within the cave, both species prefer different habitats. Cockroaches were abundant in entrance and twilight zones, while most cave crickets were concentrated in twilight and dark zones. There was a prospective competition in twilight zone where many individuals from both species gathered. But considering enough guano availability and their ability to leave the cave for foraging at night (since twilight zone is close to entrance), they are unlikely to compete for food in the cave. In this regard, they could coexist appropriately in the same area.

CONCLUSION

The cave cricket population that occurred in Sanghyang Kenit belongs to *Rhaphidophora* sp. This species was distributed in all cave zones with a total population of around 78-108 individuals. However, the abundance and density of cave crickets in twilight and dark zones were greater than entrance zone. Males predominated females with a sex ratio of 2.16. Moreover, the population was in a positive trend since the sub-adult class was dominating. Cave crickets preferred specific habitats with low light intensity, high humidity, and acidic pH. Two species of arthropods were considered potential predators, namely *Heteropoda* sp. and *Catagaeus* sp. This study implies the importance of protecting cave crickets in Sanghyang Kenit since the population is still growing and highly relies on the natural condition of the cave environment. Besides, they also play a vital role in the cave food web. Therefore, tourism activity in the cave should be managed wisely to prevent disturbances in the cave cricket population.

AUTHORS CONTRIBUTION

I.D.K designed the research framework, gathered references, analyzed data, and wrote the original manuscript, M.K.W and B.S collected and organized raw data, R.T.M.A and R.A.U revised and finalized the manuscript.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest in any part of this research.

REFERENCES

Allegrucci, G. et al., 2010. Cave crickets and cave weta (Orthoptera, Rhaphidophoridae) from the Southern End of the World: A molecular phylogeny test of biogeographical hypotheses. *Journal of Orthoptera Research*, 19(1), pp.121–130. doi: 10.1665/034.019.0118.

Benoit, J.B. et al., 2004. Mycoflora of a trogloxenic cave cricket, Hadenoecus cumberlandicus (Orthoptera: Rhaphidophoridae), from two small caves in Northeastern Kentucky. *Annals of the Entomological Society of America*, 97(5), pp.989–993. doi: 10.1603/0013-8746(2004)097[0989:MOATCC]2.0.CO;2.

Bernardini, C. & Di Russo, C., 2004. A general model for the life cycle of Dolichopoda cave crickets (Orthoptera: Rhaphidophoridae). *European Journal of Entomology*, 101(1), pp.69–73. doi: 10.14411/eje.2004.015.

Carchini, G., Russo, C.D. & Sbordoni, V., 1991. Contrasting age structures in cave cricket populations: patterns and significance. *Ecological Entomology*, 16, pp.305–314. doi: 10.1111/j.1365-2311.1991.tb00221.x.

Carchini, G., Rampini, M. & Sbordoni, V., 1994. Life cycle and population ecology of the cave cricket Dolichopoda geniculata (Costa) from Valmarino cave (Central Italy). *International Journal of Speleology*, 23(3/4), pp.203–218. doi: 10.5038/1827-806x.23.3.6.

Chandoo, M. et al., 2013. Frequency of missing legs in the cave cricket, Hadenoecus subterraneus. *Scientia Discipulorum*, 6, pp.56–61.

Conroy, L.P. & Gray, D.A., 2015. Male armaments and reproductive behavior in "Nutcracker" camel crickets (Rhaphidophoridae, Pristoceuthophilus). *Insects*, 6(1), pp.85–99. doi: 10.3390/insects6010085.

Culver, D.C. & Pipan, T., 2009. *The Biology of Caves and Other Subterranean Habitats*, New York: Oxford University Press.

Culver, D.C. & White, W.B., 2012. *Encyclopedia of Caves Second Edition* 2nd ed., USA: Elsevier Academic Press.

Deharveng, L. & Bedos, A., 2012. Diversity Patterns in The Tropics. In W. B. White & D. C. Culver, eds. *Encyclopedia of Caves*. China: Academic Press, pp. 238–250.

Epps, M.J. et al., 2014. Too big to be noticed: Cryptic invasion of Asian camel crickets in North American houses. *PeerJ*, 2014(1), pp.1–15. doi: 10.7717/peerj.523.

Fea, M. & Holwell, G., 2018. Combat in a cave-dwelling wētā (Orthoptera: Rhaphidophoridae) with exaggerated weaponry. *Animal Behaviour*, 138, pp.85–92. doi: 10.1016/j.anbehav.2018.02.009.

Fernandez-Cortes, A. et al., 2011. Detection of human-induced environmental disturbances in a show cave. *Environmental Science and Pollution Research*, 18(6), pp.1037–1045. doi: 10.1007/s11356-011-0513-5.

Ferreira, R.L., 2019. Guano communities. In W. B. White, D. C. Culver, & T. Pipan, eds. *Encyclopedia of Caves (Third Edition)*. Academic Press, pp. 474–484. doi: 10.1016/b978-0-12-814124-3.00057-1.

Furey, N.M. & Racey, P.A., 2016. Conservation Ecology of Cave Bats. In C. V. Christian & T. Kingston, eds. *Bats in the anthropocene: Conservation of bats in a changing world*. Switzerland: Springer, pp. 463–500. doi: 10.1007/978-3-319-25220-9.

Hasibuan, R.S. & Lidiawati, I., 2020. Potential Study of Sibiuk Cave as a directive for special interest tourism in Ciampea District , Bogor. , (2012), pp.623–635.

Hidayaturrohmah, N., Hernawati, D. & Chaidir, D.M., 2021. Keanekaragaman Arthropoda Berdasarkan 3 Zona Pencahayaan Di Gua Sarongge Tasikmalaya. *BIOTIK: Jurnal Ilmiah Biologi Teknologi dan Kependidikan*, 8(2), pp.245–258. doi: 10.22373/biotik.v8i2.7778.

Howarth, F.G. & Moldovan, O.T., 2018a. The Ecological Classification of Cave Animals and Their Adaptations. In Oana T. Moldovan, L. Kovac, & S. Halse, eds. *Caves Ecology*. Switzerland: Springer, pp. 41–67.

Howarth, F.G. & Moldovan, O.T., 2018b. Where Cave Animals Live. In Oana Teodora Moldovan, L. Kovac, & S. Halse, eds. *Caves Ecology*. Switzerland: Springer, pp. 23–37.

Hu, C., Yang, J. & Tu, W., 2014. Antennal epicuticular structure of camel crickets (Orthoptera: Rhaphidophoridae) for identifying the prey of Mustella sibrica Pallas. *Advances in Entomology*, 02(01), pp.1–7. doi: 10.4236/ae.2014.21001.

Ingrisch, S. & Rentz, D.C.F., 2009. Orthroptera. In V. H. Resh & R. T. Carde, eds. *Encyclopedia of Insect*. USA: Academic Press, pp. 732–743.

Iskali, G. & Zhang, Y., 2015. Guano subsidy and the invertebrate community in bracken cave: The world's largest colony of bats. *Journal of Cave and Karst Studies*, 77(1), pp.28–36. doi: 10.4311/2013LSC0128.

Kovac, L., 2018. Caves as Oligotrophic Ecosystem. In O. T. Moldovan, L. Kovac, & S. Halse, eds. *Caves Ecology*. Switzerland: Springer, pp. 297–307.

Kurniawan, I.D. et al., 2017. The Detection of Human Activities' Impact on Show Caves Environment in Pacitan, Indonesia. In S. Moore, Kevin; White, ed. *Proceedings of the 17th International Congress of Spelology*. Sydney, pp. 175–178.

Kurniawan, I.D. et al., 2018a. The difference on Arthropod communities ' structure within show caves and wild caves in Gunungsewu Karst area , Indonesia. *Ecology, Environment and Conservation*, 24(1), pp.72–81.

Kurniawan, I.D. et al., 2018b. Cave-dwelling Arthropod community of Semedi Show Cave in Gunungsewu Karst Area , Pacitan , East Java , Indonesia. *Biodiversitas*, 19(3), pp.857–866. doi: 10.13057/biodiv/d190314.

Kurniawan, I.D. & Rahmadi, C., 2019. *Ekologi Gua Wisata: Dampak Aktivitas Wisata terhadap Lingkungan dan Biota Gua serta Upaya Konservasinya*, Yogyakarta: Graha Ilmu.

Kurniawan, I.D. et al., 2020. Correspondence between bats population and terrestrial cave-dwelling arthropods community in Tasikmalaya karst area. *Communications in Mathematical Biology and Neuroscience*, 2020(59), pp.1–21. doi: https://doi.org/10.28919/cmbn/4830.

Lavoie, K.H., Helf, K.L. & Poulson, T.L., 2007. The biology and ecology of North American cave crickets. *Journal of Cave and Karst Studies*, 69(1), pp.114–134.

Lizarro, D. et al., 2020. Characterization of caves as bat roosts in the brazilian-paranense biogeographic region of bolivia. *Therya*, 11(3), pp.390–397. doi: 10.12933/therya-20-1008.

Lucañas, C.C. & Lit, I.L., 2016. Cockroaches (Insecta, Blattodea) from caves of Polillo Island (Philippines), with description of a new species. *Subterranean Biology*, 19(1), pp.51–64. doi: 10.3897/subtbiol.19.9804.

Mammola, S., 2019. Finding answers in the dark: caves as models in ecology fifty years after Poulson and White. *Ecography*, 42(July), pp.1331–1351. doi: 10.1111/ecog.03905.

Mazebedi, R. & Hesselberg, T., 2020. A preliminary survey of the abundance, diversity and distribution of terrestrial macroinvertebrates of Gcwihaba cave, northwest Botswana. *Subterranean Biology*, 35, pp.49–63. doi: 10.3897/subtbiol.35.51445.

Moulds, T., 2004. Review of Australian cave guano ecosystems with a checklist of guano invertebrates. *Proceedings of the Linnean Society of New South Wales*, 125(January), pp.1–42.

Mulyani, E., 2011. Produksi, Konsumsi Semen Dan Bahan Bakunyadi Indonesia Periode 1997 – 2009 Dan Prospeknya 2010 – 2015. *Jurnal Teknologi Mineral dan Batubara*, 7(2), pp.82–89.

Newman, B.A., Loeb, S.C. & Jachowski, D.S., 2021. Winter roosting ecology of tricolored bats (Perimyotis subflavus) in trees and bridges. *Journal of Mammalogy*, 102(5), pp.1331–1341. doi: 10.1093/jmammal/gyab080.

Oksanen, J. et al., 2020. Package 'vegan.' *Community Ecology Package*, pp.1–298. Available at: https://cran.r-project.org/web/packages/vegan/vegan.pdf [Accessed August 31, 2021].

Pacheco, G.S.M. et al., 2020. Tourism effects on the subterranean fauna in a Central American cave. *Insect Conservation and Diversity*, 2020 (September), pp.1–13. doi: 10.1111/icad.12451.

Prakarsa, T.B.P. & Ahmadin, K., 2017. Diversitas Arthropoda Gua di kawasan Karst Gunung Sewu, Studi gua-gua di Kabupaten Wonogiri. *BIOTROPIC The Journal of Tropical Biology*, 1(2), pp.31–36. doi: 10.29080/biotropic.2017.1.2.31-36.

Prakarsa, T.B.P., Kurniawan, I.D. & Putro, S.T.J., 2021. *Biospeleologi: Biodiversitas Gua, Potensi, dan Permasalahannya*, Yogyakarta: Bintang Pustaka Madani.

Prous, X., Ferreira, R.L. & Jacobi, C.M., 2015. The entrance as a complex ecotone in a Neotropical cave. *International Journal of Speleology*, 44(2), pp.177–189. doi: 10.5038/1827-806X.44.2.7.

Rahmadi, C., 2002. Keanekaragaman Arthropoda di Gua Ngerong, Tuban, Jawa Timur. *Zoo Indonesia*, 29, pp.19–27.

Rahmadi, C. & Suhardjono, Y.R., 2007. Arthropoda Gua di Nusakambangan Cilacap, Jawa Tengah. *Zoo Indonesia*, 16(1), pp.21–29.

Rahmadi, C., 2008. *Cave Fauna of Java*, Bogor. Available at: https://www.rufford.org/files/40.11.06 Detailed Final Report.pdf.

Rahmadi, C., 2011. Biospeleologi of java caves, Indonesia: a Review. In E. Haryono, T. N. Adjie, & Suratman, eds. *Asian Trans-Disciplinary Karst Conference 2011*. Yogyakarta, pp. 241–250.

Ravn, N.R., Michelsen, A. & Reboleira, A.S.P.S., 2020. Decomposition of Organic Matter in Caves. *Frontiers in Ecology and Evolution*, 8(October), pp.1–12. doi: 10.3389/fevo.2020.554651.

Romero, A., 2009. *Cave Biology Life in Darkness*, New York: Cambridge University Press.

Di Russo, C. & Rampini, M., 2017. A new species of the genus Rhaphidophora from Seram island (Moluccas, Indonesia) with notes on the geographic distribution of the subfamily Rhaphidophorinae (Orthoptera, Rhaphidphoridae) Claudio. *International Journal of Entomology Research*, 2(2), pp.55–58.

Slatyer, R.A. et al., 2012. Estimating genetic benefits of polyandry from experimental studies: A meta-analysis. *Biological Reviews*, 87(1), pp.1–33. doi: 10.1111/j.1469-185X.2011.00182.x.

Song, H. et al., 2020. Phylogenomic analysis sheds light on the evolutionary pathways towards acoustic communication in Orthoptera. *Nature Communications*, 11(1), pp.1–16. doi: 10.1038/s41467-020-18739-4.

Stritih, N. & Čokl, A., 2012. Mating Behaviour and Vibratory Signalling in Non-Hearing Cave Crickets Reflect Primitive Communication of Ensifera. *PLoS ONE*, 7(10), pp.1–10. doi: 10.1371/journal.pone.0047646.

Subekti, T., 2016. Konflik Samin vs PT. Semen Indonesia. *Jurnal Transformative*, 2(2), pp.189–202. Available at: https://transformative.ub.ac.id/index.php/jtr/article/view/136.

Tobin, B.W., Hutchins, B.T. & Schwartz, B.F., 2013. Spatial and temporal changes in invertebrate assemblage structure from the entrance to deep-cave zone of a temperate marble cave. *International Journal of Speleology*, 42(3), pp.203–214. doi: 10.5038/1827-806X.42.3.4.

Vahed, K., 2015. Cryptic Female Choice in Crickets and Relatives (Orthoptera: Ensifera). In A. V. Peretti & A. Ainseberg, eds. *Cryptic Female Choice in Arthropods*. Springer International Publishing, pp. 285–324. doi: 10.1007/978-3-319-17894-3_11.

Wei, T. & Simko, V., 2021. An Introduction to corrplot Package. *Package 'corrplot'*, pp.1–26. Available at: https://cran.r-project.org/web/packages/corrplot/corrplot.pdf [Accessed July 13, 2022].

Wynne, J.J. et al., 2019. Fifty years of cave arthropod sampling: Techniques and best practices. *International Journal of Speleology*, 48(1), pp.33–48. doi: 10.5038/1827-806X.48.1.2231.

Yoder, J.A. et al., 2010. The pheromone of the cave cricket, Hadenoecus cumberlandicus, causes cricket aggregation but does not attract the co-distributed predatory spider, Meta ovalis. *Journal of Insect Science*, 10(1), pp.1–10. doi: 10.1673/031.010.4701.