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The Impact of Lampenflora on Cave-dwelling Arthropods in Gunungsewu Karst, Java, Indonesia

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Abstract

The development of wild caves into show caves is required an installation of electric lights along the cave passages for illumination and decoration purposes for tourist attraction. The presence of artificial lights can stimulate the growth of photosynthetic organisms such as lampenflora and alter the typical cave ecosystem. The study was aimed to detect the effect of lampenflora on cave-dwelling arthropods community. Four caves were sampled during the study, 2 caves are show caves with the existence of lampenflora and 2 others are wild caves without lampenflora. Arthropods sampling were conducted by hand collecting, pitfall trap, bait trap and berlese extractor. Lampenflora comprises of algae (Phycophyta), moss (Bryophyta) and fern (Pteridophyta) grow mostly around white light lamps. Richness, diversity, and evenness indices of Arthropods are higher in caves with the existence of lampenflora compared to caves without lampeflora. This study clearly shows that the presence of lampenflora can increase Arthropods diversity and suppress dominancy of common Arthropods species in caves, also increasing the relative abundance of predators. This condition will shift the ecosystem equilibrium and lead to cave ecosystem destruction. The results of this study should be a scientific consideration for show cave development and management. Lampenfloras have to be removed from all caves and preventive efforts should be taken to minimize their growth.

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INTRODUCTION

Show caves recently become popular tourism object in Indonesia that can attract many tourists. Previously, tourism sector didn't consider caves as a valuable object. However, it changes and uses caves as one of the main iconic objects to promote their tourisms. For instance, promotion by Culture and Tourism Office of Yogyakarta Province that use show caves as their promotion headline. This phenomenon significantly increases show caves' popularity and contribute to the opening of many new show caves in many regions of Indonesia.

The opening of wild caves into show caves sometime requires installation of several kinds of infrastructures to ensure a safety and comfortability of cave visitors. It is also used to increase caves attractiveness (Cigna, 2011). Electric lights, concrete walkways, and blowers (big fans) are some infrastructures that can be found in show caves in Indonesia (Kurniawan *et al.,* 2017). Various colored electric lights are commonly installed in show caves by cave managers, it is not only for illumination but also decoration purposes so can be more interesting for visitors.

Cave has a typical environmental character, with darkness passages without natural light (Culver & White, 2012; Romero, 2009). The absence of natural light becomes a limiting factor for many species so only particular species that can deal with this extreme environment able to survive living in cave. The presence of artificial light in cave stimulates photosynthetic organisms called lampenflora to exist which they do not naturally occur because of the absence of sunlight (Cigna, 2011; Falasco *et al.,* 2014; Ivarsson *et al.,* 2013; Mulec & Kosi, 2009).

The presence of photosynthetic organisms in the dark zone of cave can leads speleothems deterioration and changes the typical cave ecosystem (Falasco *et al.,* 2014). Some previous studies indicated that lampenflora identified as one of the majors' threat to cave biodiversity and ecosystem. Lampenflora may presence a huge threat to cave-dwelling faunas because it is promoting the proliferation of external opportunistic species which may compete with them and shove them to extinction (Castello, 2014; Mulec & Kosi, 2009; Mulec *et al.,* 2008).

The arthropods are the most diverse and abundant group of faunas living in cave ecosystem, not only in the term of species richness but also in its roles in the ecosystem (Romero, 2009). This group is the dominant component in food webs of cave ecosystem so they play critical roles in the ecosystem balance maintenances (Romero, 2009; Suhardjono & Ubaidillah, 2012). The changes on arthropods community can be important indicators for cave ecosystem alteration. This study aims to detect the presence of lampenflora in show caves and to learn its impact to the structure of arthropods community. The results of this study are expected to be the basis and scientific considerations in the regulation and evaluation of show caves management in Indonesia.

METHODS

This study was conducted in Gunungsewu karst area, located in the southern of central of Java during December 2016-February 2017. There are 4 caves sampled during this study, comprising of 2 show caves (Gong and Tabuhan caves) located in Pacitan regency and 2 wild caves (Paesan and Kalisat) located in Gunungkidul and Wonogiri regencies. All caves are almost similar in term of features with fosile passages and the lenght of passages are no longer than 200 meter.

Arthropods were sampled by hand collecting, pitfall traps, baited pitfall traps, and berlese extractor. The hand collecting was conducted using gloves, brushes, and tweezers for 90 minutes (30 minutes x 3 observers). Pitfall traps were made by vial bottles (5 cm in diameter) and filled with 96% alcohol and glycerin (9:1 in ratio), while the bait traps based on Hunt & Millar (2001) designed with cheese bait. Pitfall traps were installed 5 pieces each, while the bait traps are 2 pieces and left for 48 hours. The modified berlese extractor used 15W bulb lamps and placed 20 cm above the samples. Samples of soil were taken as much as 2 liters and extracted for 4-6 days.

All collected arthropods are identified based on morphological characters to the lowest possible taxon-level. All samplings were conducted only in the dark zone of each cave. The data were analyzed by calculating richness (Margalef), diversity (Shannon-Wienner), and evenness indices. The results were visualized in tables and graphics.

RESULTS AND DISCUSSIONS

The Presence of Lampenflora in Show Caves

Gong and Tabuhan are famous show caves, managed by the local government. Both caves are part of iconic tourism sector in Pacitan regency, East Java. These show caves already had massive infrastructure installations, such as concrete walkways, electric lights, and blowers with room perfume (only in Gong cave). Electric lights that are installed in the Gong cave have various colors, while in Tabuhan only white and yellow. Those lights are switched on every day from 07.00 am to 04.00 pm but it is likely be longer when many visitors are still presence, particularly in holidays (Kurniawan *et al.,* 2017) .

The presence of lighting system and long duration of lighting in the dark zone of Gong and Tabuhan show caves leads to the growth of lampenfloras (Figure1). There are 3 groups of photosynthetic organisms which construct the lampenfloras community, they are algae colonies (Phycophyta), Mosses (Bryophyta) and Ferns (Pteridophyta). These groups of photosynthetic organisms are known to be the main components of lampenflora and the former groups in the ecological succession patterns (Mulec & Kosi, 2009). Lampenflora which is living in Gong and Tabuhan caves is attached on the surface of speleothems. It is located near the places where the electric lights are installed.

Lampenfloras in Gong and Tabuhan prefer to be occured around white light color than others, it is because lampenfloras in both caves are mostly found near white color of electric lights. The optimum light for photosynthesis reaction is on the red and blue wavelengths (Borowski *et al.,* 2015; Haryadi *et al.,* 2017). While in Gong and Tabuhan, less lampenfloras were found near these two colors of electric lights. This assumes that the temperatures among electric lights were different. High temperature of electric light is inappropriate for lampenflora growth (Falasco *et al.,* 2014)subterranean ecosystems are generally extremely oligotrophic habitats, receiving poor supplies of degradable organic matter from the surface. Human direct impacts on cave ecosystems mainly derive from intensive tourism and recreational caving, causing important alterations to the whole subterranean environment. In particular, artificial lighting systems in show caves support the growth of autotrophic organisms (the so-called lampenflora. The red and blue electric lights used in Gong and Tabuhan are alleged to produce higher temperatures, leading to unsuitable condition for almost lampenflora to be occured. But, further study must be taken to prove this hypothesis.

White light color is a polychromatic light that actually comprises many colors with diference wavelenghts, included red and blue (Angelsky *et al.,* 2008). This means that white color of electric light also contains optimum wavelength for photosynthesis reaction. Appropriate temperature condition and availability of light with optimum wavelengths for photosynthesis are indicated to be the reasons why lampenflora in Gong and Tabuhan prefer to life near white color of electric light. Besides, the distance between light installations and substrate is also influential. The lamp, which is installed far from the ground or cave`s ornament, is likely to generate lower quantity lampenflora.

Arthropods Taxa in All Caves

Six classes, 18 orders, and 59 morphospecies of arthropods were collected in four studied caves. The list of morphospecies its roles in cave ecosystem and their category of cave adaptation can be seen in Table 1.

Based on their role in cave ecosystem, arthropods in the study compose of two groups decomposer and predator. The composition of decomposer and predators are showed in Figure2.1, where the decomposer is 54% from all species recorded and predators is 46%. Decomposer faunas are commonly dominating cave ecosystem. The ability to consume the wide range of organic materials (opportunistic forager) such as guano, carrion, and other transferred organic materials from outside if presence is the main reason why decomposers species are more dominance in caves (Culver & Pipan, 2009). According to Table 1, it can be seen that Collembola and *Acari* are the main groups contributing many species, and members of these groups are mostly acting as decomposers in cave.

Based on morphological features, only one species, Oniscidae (Isopoda) from Tabuhan cave depicts the high degree adaptation in cave with reduced eyes and white in color and its considered as troglobite (obligate cave species). Most of the species of arthropods that were found in this study belong to troglophile with 58 species (Figure2.2). The presence of troglobitic fauna in a show cave should be get more attentions because cave fauna that is classified as troglobite is known to have a small population size and vulnerable to extinction (Culver & Pipan, 2009; Culver & White, 2012; Romero, 2009). Environmental changes caused by human activities and unsympathetic management of show cave can be a serious threat for troglobitic species (Kurniawan *et al.,* 2018; Macud & Nuñeza, 2014).

Richness, Diversity and Evenness Indices Calculation of Lampenflora

The results of richness, diversity and evenness calculation show a similar pattern in all caves, which all indices value are higher in the show caves with lampenflora inside than others

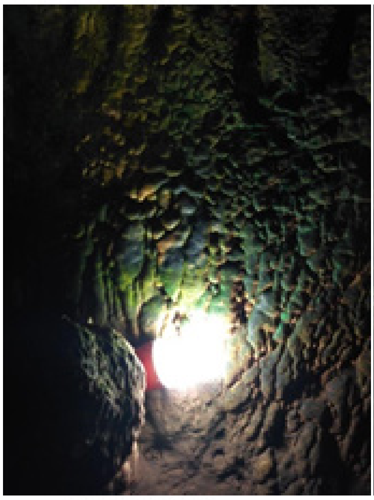
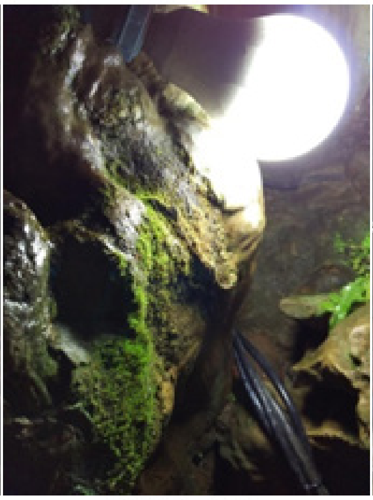


Figure 1.1



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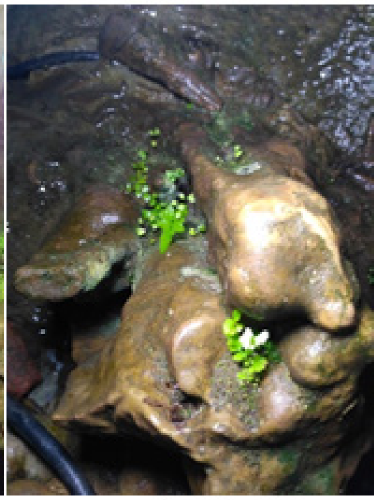

Figure 1.3

Figure 1.4

Figure 1. The presence of lampenflora. 1.1-1.3 lampenfloras in Gong (1.1 Phycophyta, 1.2 Bryophyta, 1.3 Pteridophyta) 1.4 lampenflora in Tabuhan

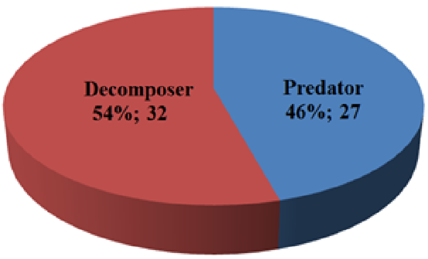

Figure 2.1

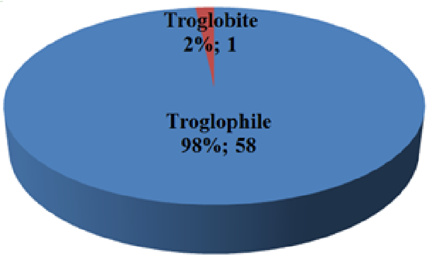

Figure 2.2

Figure 2. The composition of arthropods species based on role in ecosystem (Figure2.1) and cave adaptation categories (Figure2.2)

Tabel 1. List of arthropods found in all caves

Class	Order	Morphospecies	Cave Adaptation	Role
Collembola	Entomobryomorpha	*Ascocyrtus* sp.1	Troglophile	Decomposer
		Ascocyrtus sp.2	Troglophile	Decomposer
		Cyphoderidae sp.1	Troglophile	Decomposer
		Cyphoderidae sp.2	Troglophile	Decomposer
		Cyphoderidae sp.3	Troglophile	Decomposer
		Entomobrya sp.	Troglophile	Decomposer
		Entomobryidae sp.	Troglophile	Decomposer
		Folsomides sp.1	Troglophile	Decomposer
		Folsomides sp.2	Troglophile	Decomposer
		Paronellidae sp.	Troglophile	Decomposer
		Siera sp.	Troglophile	Decomposer
	Poduromorpha	*Hypogastruridae* sp.	Troglophile	Decomposer
Crustacea	Isopoda	Oniscidae	Troglobite	Decomposer
Diplopoda	Spirostreptida	*Trachyjulus tjampeanus*	Troglophile	Decomposer
Chilopoda	Geophilomorpha	*Mecistocephalidae* sp.	Troglophile	Predator
	Scolopendromorpha	*Otostigmus spinosus*	Troglophile	Predator
Arachnida	Amblypygi	*Charon* sp.	Troglophile	Predator
		Sarax javensis	Troglophile	Predator
	Opiliones (Laniatores)	Epedanidae	Troglophile	Predator
	Aranea	*Aranea* sp.1	Troglophile	Predator
		Aranea sp.2	Troglophile	Predator
		Aranea sp.3	Troglophile	Predator
		Ctenidae	Troglophile	Predator
		Oonopidae	Troglophile	Predator
		Pholcidae sp.1	Troglophile	Predator
		Pholcidae sp.2	Troglophile	Predator
		Salticidae sp.	Troglophile	Predator
		Theridiidae sp.	Troglophile	Predator
	Acari	*Acari* sp.1 (Mesostigmata)	Troglophile	Decomposer
		Acari sp.2 (Oribatida)	Troglophile	Predator
		Acari sp.3 (Mesostigmata)	Troglophile	Decomposer
		Acari sp.4 (Gamasida: Uropodidae)	Troglophile	Decomposer
		Acari sp.5 (Oribatida)	Troglophile	Predator
		Acari sp.6	Troglophile	Decomposer
		Acari sp.7 (Oribatida)	Troglophile	Predator
		Acari sp.8 (Oribatida)	Troglophile	Predator
		Acari sp.9 (Prostigmata)	Troglophile	Decomposer
	Scutigeromorpha	*Scutigera* sp.	Troglophile	Predator
Insekta	Coleoptera	*Ambrosiodmus obliques*	Troglophile	Decomposer
		Anthicidae	Troglophile	Predator
		Unidentified	Troglophile	Predator
		Cucujidae sp.1	Troglophile	Decomposer
		Cucujidae sp.2	Troglophile	Decomposer

	Dyctinidae	Troglophile	Predator
	Eucnemidae	Troglophile	Decomposer
	Staphylinidae (Aleocharinae)	Troglophile	Predator
	Staphylinidae (Paederinae sp.)	Troglophile	Predator
Diptera	*Megaselia* sp.	Troglophile	Decomposer
	Muscidae	Troglophile	Decomposer
Isoptera	Termitidae	Troglophile	Decomposer
Orthoptera	*Rhaphidophora* sp.	Troglophile	Decomposer
Lepidoptera	*Tinea* sp.	Troglophile	Decomposer
Psocoptera	*Psocoptera* sp.	Troglophile	Decomposer
Hymenoptera	*Formicidae* sp.1 (Dolichoderinae)	Troglophile	Predator
	Formicidae sp.2 (Myrmicinae)	Troglophile	Predator
	Formicidae sp.3 (Formicinae)	Troglophile	Predator
Immature Insecta	*Larvae* sp.1 (Coleoptera)	Troglophile	Decomposer
	Larvae sp.2 (Diptera)	Troglophile	Decomposer
	Larvae sp.3	Troglophile	Decomposer

wild caves without lampenflora. The differences value of all indices among caves can be seen on the Figure 3 present below.

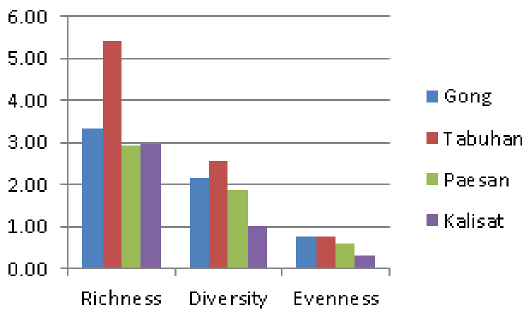

Figure 3. Differences on richness, diversity, and evenness among caves

The higher value of richness and diversity indices in Gong and Tabuhan that posses lampenflora indicate that these two caves relatively have more species diversity than Paesan and Kalisat that don't posses lampenflora. Higher evenness value also indicates that community of arthropods in these two show caves are less dominated by single or more species. The population size of each species found in these show caves tends to relatively equal to one another. On the other hands, lower values of indices in wild caves indicate that caves without lampenflora are relatively having less species diversity and the community are dominated by some particular species.

The high biodiversity and low level of dominancy are generally used as an indicator for stable and healthy ecosystems (Rahmasari *et al.,* 2015; Rosada *et al.,* 2017; Yadav & Mishra, 2013). But this condition cannot be applied for cave ecosystem. Cave has unique environmental characters that support difference ecosystem condition. This environment is characterized by the permanently absence of light, high air humidity, stable temperature, high CO_2 and often limited food resources (Bento *et al.,* 2016; Palacios-Vargas *et al.,* 2011; Simões *et al.,* 2015)

In the term of biodiversity and dominancy, undisturbed cave ecosystem has an opposite conditions with the general ecosystem condition that mentioned before. Cave ecosystem relatively possesses less species diversity and generally dominated by particular species that have evolved to adapt in these extreme condition (Culver & Pipan, 2009). Some species that belong to troglophile sometimes will have bulk of populations, otherwise some species belong to troglobite will only have small population sizes (Suhardjono & Ubaidillah, 2012). This study proves that the presence of lampeflora can alter the typical cave ecosystem by raising the species diversity and suppressing species dominancy.

Difference on Mophospecies Compositions and Relative Abundaces of Arthropods among Caves

All caves have relatively similar dominan Arthropods taxa in the term of species richness. *Acari*, Entomobryomorpha, *Aranea*, Coleoptera, Hymenoptera, Amblypygi, Orthoptera, Diptera and insect *larvae* are the dominant orders in all caves (Figure 4.). Those groups of Arthropods are commonly found in cave environments and contribute to bulk of species in cave ecosystem.

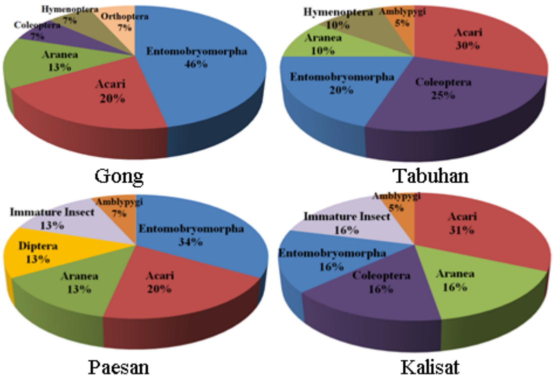

Figure 4. Difference on morphospecies compositions

Assessment of biota communities condition cannot be seen partially only from the diversity of taxa, but also must consider the abundance of each taxa. Figure 5 presents the data about the differences on relative abundances of the 6 dominant orders in each cave.

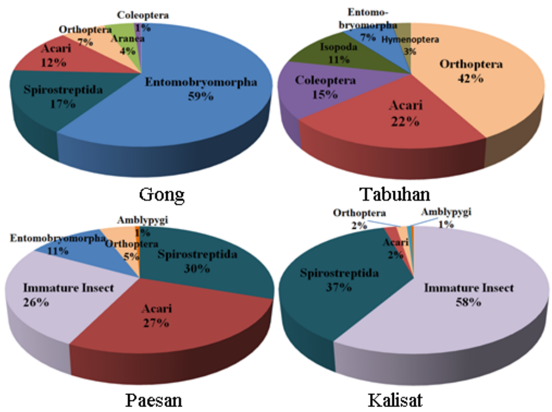

Figure 5. Difference on relative abundaces

According to Figure 5, it can be seen that there is a clear difference of arthropods community between caves without lampenflora and caves with lampenflora, by focussing on the relative abundance of dominant taxa. Wild caves without lampenflora are mostly dominated by some orders which have members that act as decomposers. They are Spirostreptida, *Acari*, Entomobryomorpha, insects *larvae* groups and Orthoptera. The different conditions occurred in show caves that possess lampenflora where there are 3 orders that predominantly act as predators are on the list of dominant taxa. They are Hymenoptera, Coleoptera (Family: *Staphylinidae*) and *Aranea*. This result means that show caves with lampenflora are more likely to increase the relative abundance of predators. This condition will shift the ecosystem equilibrium and lead to ecosystem destruction.

Another important finding of this study shows that the relative abundance of Amblypygi (*Charon* sp. and *Sarax javensis*) in the show caves with lampenflora declines significantly. Moreover, in the dark zone of Gong cave, even a single individual of Amblypygi is unlikely to be found. However, there are at least 3 individuals of Amblypygi occurred in etrance zone. The Amblypygi in Gong cave seems to change their habitat preference from dark zone to entrance zone. *Charon* sp. and *Sarax javensis* are common Arthropods found in dark zone of cave in Gunungsewu karst area (Rahmadi, 2008). The declining population and changing habitat preference of both species are the important indicators for cave ecosystem alteration.

In addition, millipede *Trachyjulus tjampeanus* (Spirostreptida: Cambalopsidae) is also a common species found in cave, particularly in the Gunungsewu karst area. The population of this species in the show caves with lampenflora is lower than in the caves without lampenflora. This millipede population in Gong is 15 individuals and Tabuhan is only an individual, whereas in Paesan and Kalisat population of this species are much more abundant with 1042 and 879 individuals. This result proves that the presence of lampenflora and tourism activities in the dark zone of caves are able to attract invasive species to exist and directly or indirectly disrupt the cave ecosystem continuity by declining populations of common cave-dwelling Arthropods.

Up to now, the presence of lampenfloras in Gong and Tabuhan show caves still gets little attention. The removals of lampenflora in both caves were almost never conducted. Moreover, the cave managers seemed to allow the lampenflora to exist because some visitors thought that lampenflora bears aesthetics value. The results of this study is expected to be a scientific consideration for show cave development and management policy. Both show cave managers and visitors should conceive lampenflora as harmful to cave ecosystem sustainability. In order to conserve cave ecosystem, lampenfloras have to be removed from all show caves and preventive efforts should be taken to minimize their growth.

CONCLUSIONS

Lampenflora found in Gong and Tabuhan show caves comprises algae colonies (Phycophyta), mosses (Bryophyta) and ferns (Pteridophyta). The use of white color of electric light and the proximity of lamps to the substrate have a tendency to generate more lampenfloras. The presence of lampenfloras can alter the structure of cave fauna community by increasing species diversity and suppressing the dominance of common cave-dwelling fauna species, also increasing the relative abundance of predators. In order to conserve caves ecosystem, lampenfloras have to be removed from all caves and preventive efforts should be taken to minimize their growth.

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