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Macroinvertebrates diversity in Dat's and Asbang fak sol caves in the municipality of Matanao, Davao Del Sur

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Abstract

This research assessed the macroinvertebrate diversity found in Dat's and Asbang Fak Sol Caves in Matanao, Davao del Sur, and providing baseline data critical for cave conservation efforts. It utilized a quantitative descriptive research design in terms of describing the characteristics of macroinvertebrate communities found in these caves. This design included collecting, systematically, information on species diversity, abundance, and physicochemical conditions of cave sediments without interfering with any variables in as much detail about the current state of the ecosystems. Subsidiary zones then came into place within each cave, which include the entrance, twilight, transition, and deep zones. Physicochemical conditions in cave sediments were also assessed. A total of 250 individuals representing 36 genera of macroinvertebrates was accounted for. The richness of macroinvertebrates in Dat's Cave was greater than those accounted for at Asbang Fak Sol Cave based on Shannon, Simpson, and Margalef indices. Effective species diversity of both caves was equivalent. *Pheidole* sp. dominated Dat's Cave, while *Myrmicaria* sp. dominated Asbang Fak Sol Cave. Soil analysis showed slightly alkaline condition as well as sandy loam texture for both caves, while Asbang Fak Sol Cave held fewer organic materials. The results therefore unveil that macroinvertebrate communities are an important component of an intact cave ecosystem. The study therefore warrants targeted conservation practices aimed at protecting the peculiar diversity of macroinvertebrates in Dat's and Asbang Fak Sol Caves. This study sets a valuable baseline in eventual ecological studies and conservation planning for those and similar cave systems.

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Introduction

Macroinvertebrates are significant cave biodiversity, though their ecological importance is less considered in global conservation efforts. These include insects, crustaceans, mollusks, arachnids, and annelids, which are vital components of the food chains of freshwater ecosystems and are found in various running water habitats (Superada and Tampus, 2015). In reality, nothing is well known about the ecology of cave-dwelling macroinvertebrates, who are often excluded from conservation plans and the management of protected areas (Sugai *et al.*, 2015; Medellin *et al.*, 2017).

The troglomorphic or cave-adapted invertebrate species characteristically have a limited geographic range and are constantly threatened with extinction because of human activity.

These species can be highly valuable as bio-indicators for the assessment of health in biogeographic region, habitat, and protected area. They are also crucial to species that need protection (Galindo-Perez *et al.*, 2017). Yet, even in areas where the biodiversity that subsists underground is well known, the faunas of caves-whether consisting of macroinvertebrates or any other group-still are by and large undescribed, and relatively big gaps in our knowledge of these ecosystems persist. For example, in North America, despite monitoring programs, many species that live in caves remain undescribed; it is estimated to find more than 20 new troglomorphic species each year (Wynne, 2018).

New Mindanao discoveries of special fauna include blind fish by Larson and Husana (2018), crabs by Husana *et al.*, 2015 from Negros, and cockroaches from the Polillo Islands by Lucañas and Lit, 2016 reveal huge potential but as yet largely undiscovered biodiversity in caves of this region. The growing threats from human activities point to the need for detailed biological inventories to form a basis for evidence-based plans aimed at protecting and conserving these fragile ecosystems (Wynne *et al.*, 2018). To this end, the present study inventoried the macroinvertebrates of Dat's and Asbang Fak Sol Caves in the Municipality of Matanao, Davao del Sur. More particularly, this study enumerated the macroinvertebrate species present, discuss and determine relative abundance, population diversity, and population density, and interpret the physicochemical conditions of sediments in these caves.

Research questions

1. What were the macroinvertebrate species present in Dat's and Asbang Fak Sol Matanao Caves?
2. What were the relative abundance, population diversity, and density of these macroinvertebrates?
3. What were the physicochemical conditions of the sediments in these caves?

Materials and methods

Research design

This study applied a quantitative descriptive research design to systematically gather and analyze data regarding the macroinvertebrate communities of Dat's and Asbang Fak Sol Caves within the Municipality of Matanao, Davao del Sur. According to Creswell (2014), such a design is essentially focused on describing the nature of any population or phenomenon without altering any variables. This approach was ideal for the study since it was aimed at giving an in-depth account of the present state of the macroinvertebrates inhabiting these caves.

This was the design applied in the study to establish the specific macroinvertebrate species that existed at a given relative abundance, diversity of populations, and density. The physicochemical conditions of the sediments were further assessed. The data collection processes took the form of observations and records of the existing conditions within the caves, without which the natural environment is not disturbed. This method allows the researcher to capture biodiversity and ecological dynamics of populations precisely with macroinvertebrates, yielding important insights into the current status of such ecosystems without introducing external variables that could alter the results.

Research respondents

The population under this study were the macroinvertebrates in Dat's and Asbang Fak Sol caves, which are in Matanao, Davao del Sur. The sample was these macroinvertebrates from four zones for each cave: entrance zone, twilight zone, transition zone, and deep zone.

Several methods were involved during the sampling technique in general and overall analysis. The first sampling method was handpicking coupled with direct counting aided by bright light with a flashlight or headlamp (Macud and Nuñeza, 2014). Besides handpicking, core sampling was employed. The sampling of ground areas with extensive cavages on the floors was done using an 8-cm wide, 15-cm long soil corer. This soil corer was sieved to isolate the macroinvertebrates (Iskali and Zhang, 2015). Large twigs, branches, and pieces of wood were taken as sample to capture more diverse invertebrates range. Specimens collected were preserved in 70% ethanol for later identification. Systematic allocation was divided into four zones: entrance zone, twilight zone, transition zone, and deep zone, and each one of them corresponds to the light conditions and environments of caves (Enriquez and Macud, 2014). The researcher obtained permission from the local authorities, for example, the mayor of the municipality and the barangay captain and was accompanied by trained personnel from the DENR throughout the study (Vaughan, 2012).

Research instrument

Two caves were characterised systematically and sampled for this study, namely Dat's Cave and Asbang Fak Sol Cave in Matanao, Davao del Sur, Philippines. The instrument used in the differentiation of each zone in every cave was the digital lux meter that would measure the light intensity and therefore distinguish the entrance from the transition and deep zones.

Length, width, and height of the zone as well as the floor area are measured with a digital laser meter. The measurement was performed during daylight hours, from 8 AM to 3 PM, based on procedure followed by Plenzler (2012).

Specifically, the methods implemented closely approximate those used by Macud and Nuñeza in previous studies (2014). Flaglets were placed at either end of each zone to make it easier to see where one begins and ends. Other data collected include drip rates of water as well as air and water temperatures using digital thermometers and hygrometers.

Macroinvertebrate samples were collected through handpicking, direct counting, and core sampling. For the core sampling method, three core samples were taken from each subsite using a 15cm long and 8-cm wide soil corer. In the laboratory, samples were processed wherein macroinvertebrates were separated using a 1 mm sieve and preserved in 70% ethanol. Identification was performed with the help of a compound microscope, AmScope, MU900 camera. Specimens were photographed with a Xiaomi Redmi Note 10 Pro, which provided good-quality images for making species identification easier.

Specimens were identified using observation and identification of morphological features. The specimens were then confirmed by taxonomic experts via e-mail, which gave them proper classification. Good data collection and processing of samples will ensure that the reliability and validity in the outcome of the study is very high.

Three soil samples were taken one meter apart each for every subsite. It obtained sediment at 0-15 cm depth using a soil auger. It placed in labelled plastic bags and it came to air-dried for 72 hours at room temperature. Samples of the dried soil were packed in a re-sealable plastic container and submitted to the Department of Agriculture Regional Soils Laboratory, Region XI, Davao City for physicochemical analysis. Textural classification of the soil was accomplished through mechanical analysis that is highly dependent on the size and type of solid particles that compose the soil. Additionally, the properties involved in this study include the soil pH value and organic matter found in the soils through the Walkley Black method. Organic matter present in the soils can be a source of food to the detritivores and may enhance growth and microbial activity within the cave (Silva *et al.*, 2011; Marques *et al.*, 2016).

Data analysis

Data were analyzed for ecology using several quantitative measurements. The Shannon diversity index (H) was made use of to get apportionment or diversity of a community ∑i=1S -pi ln pi. H is the Shannon diversity index while Pi=fraction of entire population comprising species i; S= number of species found. Evenness or Pielou index (J) is the Shannon diversity divided by the logarithm of a number of taxa J=H/(ln S). Richness was measured using Margalef diversity index d=(S-1)/(ln N). The effective number of species was also computed to determine the true diversity of the community.

To calculate the relative abundance, in percent, of macroinvertebrates, the following formula was employed:

RA={(Number of individuals in each cave zone)/(Number of individuals in all cave zones)}×100

Population density (PD) is the number of organisms that occur in an area, whereas population size is the quantity of organisms. A formula below was applied to obtain the population density of macroinvertebrates within each cave (Kurniawan *et al.*, 2022).

PD=(Number of individuals)/(Area of the cave)

Results and discussion

Identification, relative abundance, population density, and diversity of macroinvertebrates

There were 105 individuals recorded in Dat's cave belonging to three phyla: Annelida, Arthropoda, and Mollusca. A huge percentage of the macroinvertebrates in Dat's cave (Fig. 1) was from phylum Arthropoda (85%) followed by phylum Mollusca (13%) and lastly, phylum Annelida (2%). The data can be attributed to the fact that arthropods were the most common cavernicolous fauna, and they play an important role in cave ecosystems. They are ensuring the long-term viability of food webs as well as the equilibrium of the cave environment (Kurniawan *et al.*, 2018).

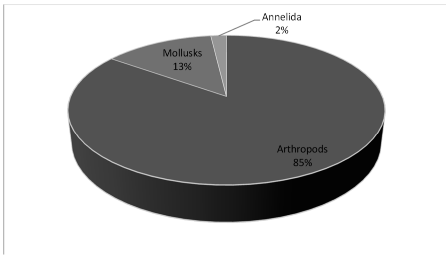

Fig. 1. Major taxonomic groups in Dat's cave

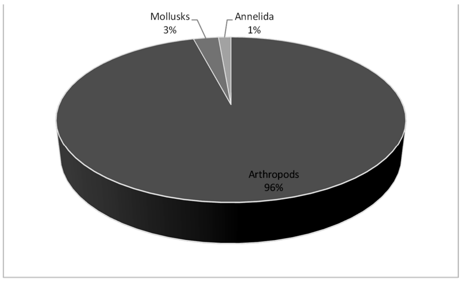

Fig. 2. Major taxonomic groups in Asbang Fak Sol cave

Similarly, there were 145 individuals recorded in the Asbang Fak Sol cave belonging to three phyla: Annelida, Arthropoda, and Mollusca. A considerable percentage of the macroinvertebrates in Dat's cave (Fig. 2) was from phylum Arthropoda (96%), followed by phylum Mollusca (3%) and phylum Annelida (1%). In actuality, the Asbang Fak Sol cave has a huge roosting site of bats compared to Dat's cave, having almost no presence of guano deposits. In line with this, the data revealed may be caused by caves permanently occupied by huge colonies of bats that frequently result in forming a niche arthropod community that exploits the bats' resources. The bats provide a continual allochthonous energy intake into the cave by feasting on fruit, insects, or other nutrients on the outside and returning to supply food in the form of blood, feces, and other waste products, or carrion on the inside. Predators and parasites on other arthropods may be introduced as the food web develops. The arthropod population may become very numerous in individuals due to the bats' high energy input, but the number of species is usually limited due to the limited range of resources available (Braack, 1989).

Table 1. Macroinvertebrates in different zones of Dat's cave

Phylum	Family	Genus	Common names	E	T	TR	D	*
								89
Arthropoda	Araneidae	*Nephila* sp.	Golden Orbweaver Spider	1				1
	Carabidae	*Mastax philippina*	Bombardier beetle	1				1
		Notagonum sp.	Ground beetle	1				1
	Charonidae	*Charon* sp.	Whip spider		2	5	5	12
	Coccinellidae	*Sticholotis* sp.	Ladybird beetle	1				1
	Coreidae	*Hygia* sp.	Leaf-footed bug	1				1
	Cryptodesmidae	*Ophrydesmus* sp.	Millipede	1				1
	Ctenidae	*Ctenus* sp.	Wandering spider	2				2
	Formicidae	*Pheidole* sp.	Big-headed ant	40				40
		Strumigenys sp.	Snappy, Detritus Ant	5				5
	Philosciidae	*Burmoniscus* sp.	Isopod	2			1	3
	Pholcidae	*Crossopriza* sp.	Tailed cellar spiders	2				2
		Uthina sp.	Cellar spider	4				4
	Potamidae	*Isolapotamon* sp.	Freshwater Crab	1			3	4
	Rhaphidophoridae	*Diestrammena* sp.	Cave cricket	3	1		1	5
	Sparassidae	*Heteropoda* sp.	Huntsman spider	3		1	1	5
	Theridiidae	*Episinus* sp.	Comb-footed spider			1		1
								14
Mollusca	Achatinidae	*Achatina fulica*	Giant African land snail	3	3	2	5	13
		Paropeas achatinaceum	Air-breathing land snail			1		1
Annelida	Megascolecidae	*Pheretima* sp.	Earthworm	2				2
		Total		73	6	10	16	105

E1: Entrance zone; T: Twilight zone; TR: Transition zone; D: Deep zone;*: Total number of individuals

Table 1 shows the average number of macroinvertebrates in each zone of Dat's cave. Macroinvertebrates were abundant in the entrance zone with 73 recorded individuals, followed by the deep zone (16), transition zone (10), and twilight zone (6), respectively.

The entrance zone of the cave contained three phyla: Annelida, Arthropoda, and Mollusca. The most abundant phylum is the Arthropoda that consists of 12 families with 15 genera. The most significant average number was recorded by *Pheidole* sp. with 40 individuals, followed by *Strumigenys* sp. (5), *Uthina* sp. (4), the *Heteropoda* sp. and *Diestrammena* sp. with three recorded individuals, and the *Ctenus* sp., *Burmoniscus* sp., *Crossopriza* sp. with two registered individuals. In addition, one representative was also observed near the following macroinvertebrates: *Nephila* sp., *Mastax philippina*, *Notagonum* sp., *Sticholotis* sp., *Hygia* sp., *Ophrydesmus* sp., and *Isolapotamon* species. Three of *Pheretima* sp. in the Phylum Megascolecidae were also observed in the entrance zone and two observations of *Achatina fulica* from phylum Mollusca.

The twilight zone comprised the Phyla Arthropoda and Mollusca. The arthropod species were present as two genera from two different families with two recorded observations of *Charon* sp. and one *Diestrammena* species. *Achatina fulica* belonging to phylum Mollusca was also encountered with three counts.

The cave also has the transition zone that accommodates two phyla: Arthropoda and Mollusca. The arthropods present there contain three genera belong to various families. Such included *Charon* sp. (5), *Heteropoda* sp. (1), and one *Episinus* species. Last is the *Achatina fulica* (2) and *Paropeas achatinaceum* (1).

The last deep zone was home to the presence of two phyla: Arthropoda and Mollusca. The arthropods were represented by five genera under different lineages of families. There were *Charon* sp. with five recorded observations, *Crossopriza* sp., *Isolapotamon* sp. with three recorded sightings, and a single individual of *Burmoniscus* sp., *Diestrammenas* sp., and *Heteropoda* sp. *Achatina fulica* of phylum Mollusca was also recorded with five counts.

Table 2. Macroinvertebrates in different zones of Asbang Fak Sol cave

Phylum	Family	Genus	Common names	E	T	TR	D	*
								139
Arthropoda	Ballophilidae	*Ballophilus* sp.	Centipede				1	1
	Charonidae	*Charon* sp.	Whip spider	2	4	2	11	19
	Chlorocyphidae	*Rhinocypha colorata*	Jewel damselfly		1			1
	Coenagrionidae	*Pseudagrion pilidorsum*	Narrow-winged damselfly	1				1
	Ctenidae	*Ctenus* sp.	Wandering spider	1			1	2
	Formicidae	*Myrmicaria sp.*	African ant	50				50
	Limoniidae	*Hexatoma perennis*	Crane fly	1				1
	Philosciidae	*Burmoniscus* sp.	Isopod				2	2
	Pholcidae	*Uthina* sp.	Cellar spider	38		1		39
	Potamidae	*Isolapotamon* sp.	Freshwater Crab	1	2		7	10
	Ptilodactylidae	*Ptilodactyla* sp.	Toe-winged beetle				1	1
	Rhaphidophoridae	*Diestrammena* sp.	Cave cricket		2	1	7	10
	Tetragnathidae	*Opadometa fastigata*	Pear-shaped leucauge	2				2
								4
Mollusca	Achatinidae	*Achatina fulica*	Giant African land snail	1		1	1	3
	Achatinidae	*Paropeas achatinaceum*	Air-breathing land snail	1				1
Annelida	Megascolecidae	*Pheretima* sp.	Earthworm	2				2
		Total		100	9	5	31	145

E1: Entrance zone; T: Twilight zone; TR: Transition zone; D: Deep zone;*: Total number of individuals.

As noted, *Achatina fulica* was the only macroinvertebrate noticed in the three zones of the cave. The study is somewhat similar to Faulkner and company (2019) in the Kuumbi Cave, Zanzibar, as this species is believed to be part of the natural ecosystem of this cave and its surroundings. They are seen in all the areas of the cave. Moreover, from the macroinvertebrates in the cave, *Pheidole* sp. This species also recorded the highest sightings. Another study of Batucan and Nuñeza (2013) revealed the same species in the entrance zones of caverns in Siargao Island Protected Landscape and Seascape, Philippines. As was expected, most of the found ants foraged on leaf litter and crawled under the small plants growing in the entry zone, which was the generally more favorable condition outside the cave in comparison to the deep zone.

Table 2 shows the average number of macroinvertebrates in Asbang Fak Sol cave zone. Macroinvertebrates were abundant in the entrance zone with 100 recorded individuals, followed by the deep zone (31), twilight zone (9), and transition zone (5), respectively.

The entrance zone of the cave included three phyla: Annelida, Arthropoda, and Mollusca. The most abundant phylum is the Arthropoda that was composed of eight families with eight genera. The *Myrmicaria* sp had the largest average number with 50 recorded individuals, followed by *Uthina* sp. (38), the *Opadometa fastigata,* and *Charon* sp. with two recorded individuals *Pseudagrion pilidorsum*, *Ctenus* sp., *Hexatoma perennis,* and *Isolapotamon* sp. with the one registered individual. There were two *Pheretima* sp. from the Phylum Megascolecidae observed in the entrance zone along with two genera of mollusks, *Achatina fulica* and *Paropeas achatinaceum*, with one observation.

The twilight zone was dominated by the Phylum Arthropoda with only four families and four genera. The most abundant arthropod recorded was *Charon* sp., which occurred four times, followed by the *Isolapotamon* sp. and *Diestrammena* sp. with two specimens, and a single count for *Rhinocypha colorata.*

This phylum was represented by the two main ones, which were Arthropoda and Mollusca, in the cave transition zone. These arthropods comprised three genera from a different family. Among these were Charon sp. (2), *Uthina* sp. (1), and finally, *Diestrammena* sp. The mollusks were represented only by one *Achatina fulica*.

Table 3. Relative abundance (%) of macroinvertebrates in Dat's Cave

Macroinvertebrates	EZ	T	TR	D	Total
Pheretima sp.	1.905	-	-	-	1.905
Nephila sp.	0.952	-	-	-	0.952
Mastax philippina	0.952	-	-	-	0.952
Notagonum sp.	0.952	-	-	-	0.952
Charon sp.	-	1.90	4.762	4.762	11.429
Sticholotis sp.	0.952	-	-	-	0.952
Hygia sp.	0.952	-	-	-	0.952
Ophrydesmus sp.	0.952	-	-	-	0.952
Ctenus sp.	1.905	-	-	-	1.905
Pheidole sp.	38.095	-	-	-	38.095
Strumigenys sp.	4.762	-	-	-	4.762
Burmoniscus sp.	1.905	-	-	0.952	2.857
Crossopriza sp.	1.905	-	-	-	1.905
Uthina sp.	3.810	-	-	-	3.810
Isolapotamon sp.	0.952	-	-	2.857	3.810
Diestrammena sp.	2.857	0.95	0.000	0.952	4.762
Heteropoda sp.	2.857	-	0.952	0.952	4.762
Episinus sp.	-	-	0.952	-	0.952
Achatina fulica	2.857	2.86	1.905	4.762	12.381
Paropeas achatinaceum	-	-	0.952	-	0.952

E: Entrance zone 1; T: Twilight zone; TR: Transition zone; D: Deep zone

Two phylum comprised the deep zone of the cave, which were Arthropoda and Mollusca. The arthropods present had seven genera belonging to various families, including *Charon* sp. with 11 recorded observations, *Isolapotamon* sp. and *Diestrammena* sp. (7), *Burmoniscus* sp. (2), and a single record of *Ballophilus* sp., *Ctenus* sp., and *Ptilodactyla* species. The *Achatina fulica* from phylum Mollusca was recorded with one count.

In all zones of this cave, Charon sp. can be found. In Kasilak cave at San Isidro, Davao del Norte, Salaga (2020) conducted a study and discovered the same species of whip spider were also abundant and wide to the zones. Perhaps one reason why whip spiders are abundant in all caves is the availability of prey. Horvath and others have also indicated that availability of prey affects density and diversity of spider assemblage.

Furthermore, the *Myrmicaria* sp. had the highest number in the cave, similar to Batucan and Nuñeza (2013) study in caves of Siargao Island Protected Landscape and Seascape, Philippines. Tinaut and Lopez (2001), many data originate from samples taken at locations that are not entirely cavernicolous, such as partially lighted zones and cave entrances, or areas outside the caves. In addition, Pape (2016) reported that caves had been found to include more than half (56%) of ant subfamilies and nearly a quarter (24.4%) of currently legitimate genera. This widespread distribution across the family suggests that these animals have a long history of living in caves. It also alludes to the ant's global presence, where they opportunistically occupy the most available habitats. Cave openings allow animals to enter and exit caves, providing a source of nutrients for caves. Species richness and animal abundance are often higher at cave-surface interactions than in cave interiors. Ant colonies that use cave route networks can concentrate their activity near-surface connections, where resources are abundant.

The macroinvertebrates in Dat's cave were not distributed in all of the cave zones because there were organisms that were found in only one zone, and there was only one macroinvertebrate found to be present in all of the zones that is the mollusk, *Achatina fulica*. *Achatina fulica* was most abundant in the deep zone with 4.762%, twilight zone with 2.86%, and entrance zone with 2.857%, and least abundant in the transition zone with 1.905%. The relative abundance of the macroinvertebrates in each zone is found in Table 3. Macroinvertebrate genera with all individuals observed once in a specific zone had a relative abundance of 0.95%, such as *Nephila* sp., *Mastax philippina*, *Notagonum* sp., *Sticholotis* sp., *Hygia* sp., and *Ophrydesmus* sp. that were only found in the entrance zone. Moreover, *Episinus* sp. and *Paropeas achatinaceum* were found only in the transition zone with a relative abundance of 0.95%. *Pheidole* sp. is relatively abundant with 38.09%, followed by *Strumigenys* sp. (4.76%) and *Uthina* sp. (3.81%) in the entrance zone only.

Charon sp. was also observed in all the cave zones except in the entrance zone. It was highly abundant in the transition and deep zones with 4.76%, and the least abundant in the twilight zone with 1.90%. *Diestrammena* sp. was seen in three cave zones, the most abundant in the entrance zone with 2.86%, and equal in the twilight and deep zones with 0.952%, respectively. Moreover, the *Heteropoda* sp. was also observed in three cave zones, the most abundant in the entrance zone with 2.86% and equally abundant in the transition and deep zones with 0.952%.

The *Sticholotis* sp. and *Nephila* sp. were cited in both entrance and deep zones once with 0.952%. Similarly, the *Burmoniscus* sp. was found in the same zone and more abundant in the entrance zone (1.91%) than the deep zone (0.95%). Comparatively, *Isolapotamon* sp. was more abundant in the deep zone (2.857%) than in the entrance zone (0.95%).

Table 4. Relative abundance (%) of macroinvertebrates in Asbang Fak Sol Cave

Macroinvertebrates	EZ	T	TR	D	Total
Pheretima sp.	1.379	-	-	-	1.379
Ballophilus sp.	-	-	-	0.690	0.690
Charon sp.	1.379	2.759	1.379	7.586	13.103
Rhinocypha colorata	-	0.690	-	-	0.690
Pseudagrion pilidorsum	0.690	-	-	-	0.690
Ctenus sp.	0.690	-		0.690	1.379
Myrmicaria sp.	34.483	-	-	-	34.483
Hexatoma perennis	0.690	-	-	-	0.690
Burmoniscus sp.	-	-	-	1.379	1.379
Uthina sp.	26.207	-	0.690		26.897
Isolapotamon sp.	0.690	1.379	-	4.828	6.897
Ptilodactyla sp.	-	-	-	0.690	0.690
Diestrammena sp.	-	1.379	0.690	4.828	6.897
Opadometa fastigata	1.379	0.000	-	-	1.379
Achatina fulica	0.690	-	0.690	0.690	2.069
Paropeas achatinaceum	0.690	-	-	-	0.690

E: Entrance zone 1; T: Twilight zone; TR: Transition zone; D: Deep zone

The data revealed that most of the macroinvertebrates recorded belong to order Araneae. This is congruent to Enriquez and Nuñeza (2014) study, where they found that three biological zones of the cave in Mindanao include parameters such as temperature, relative humidity, and cave surface. These affect the distribution and abundance of spider species. The presence of guano could have a role in the increased quantity of spiders in caves (Cabili and Nuñeza, 2014). Furthermore, Samu and colleagues (1999) discovered that the distribution of spider species is strongly linked to the cave's structural surface; thus, the relationship between spiders and habitat was considered, especially that outside the cave, it is not very forested.

On the second cave, the macroinvertebrates in the Asbang Fak Sol cave were also not distributed in all of the cave zones because there were organisms that were found in only one zone, and there was only one macroinvertebrate found to be present in all of the zones that is the *Charon* sp. It was most abundant in the deep zone with 7.568%, followed by the twilight zone 2.759%, and equally least abundant in both entrance and transition zones with 1.379%. The relative abundance of the macroinvertebrates in each site is found in Table 4.

Some macroinvertebrates were found in a single zone of the cave, such as *Myrmicaria* sp. that was most abundant with a relative abundance of

34.483%, *Pheretima* sp. with 1.379%, *Pseudagrion pilidorsum,* with 0.690%, *Hexatoma perennis* with 0.69%, *Paropeas achatinaceum* with 0.69% and *Opadometa fastigata* with 1.379% in the entrance zone; *Rhinocypha colorata* with 0.69% in the twilight zone; and *Ballophilus* sp. with 0.69%, *Ptylodactyla* sp. with 0.69% and *Burmoniscus* sp. with 1.379% in the deep zone.

The *Uthina* sp. was recorded in the two zones of the cave. It was highly abundant in the entrance zone with 26.207%, and in the transition zone with 0.69%. Similarly, the *Achatina fulica* was also seen in the entrance, transition, and deep zones in which they were equally abundant with 0.69%. The *Isolapotamon* sp. was also recorded in the cave in which it was highly remarkable in the deep zone with 4.828%, followed by the twilight zone with 1.379%, and least abundant in the entrance zone with 0.69%. Lastly, the *Ctenus* sp. was also equally large in entrance and deep zones, with 0.69%.

Data showed that most of the species of macroinvertebrates could be found in the deep zone. According to Barr and Holsinger (1985), turbellarians, gastropods, millipedes, spiders, pseudoscorpions, opilionids, isopods, amphipods, decapods, collembolans, diplurans, beetles (Carabidae, Leiodidae, Pselaphidae), fishes, and salamanders are among the major taxonomic groupings of animals having numerous troglobitic species. Many authors have stressed the preadaptation of troglobites' progenitors to microhabitats such as chilly, moist forest floor humus, gloomy swamps, or spring mouths.

Moreover, few macroinvertebrates were unusually sighted in the cave zones, such as *Rhinocypha colorata*, *Pseudagrion pilidorsum*, *Hygia* sp., and *Hexatoma perennis*. This is consistent with Mazebedi and Hesselberg's (2020) findings that surface-dwelling macroinvertebrates are more likely to enter the cave by accident while crawling near the cave entrance. Some of the less common species discovered near the cave's entry in this study may have entered the cave by accident or sought temporary shelter.

Table 5. The population density in the different caves

Caves	No. of organisms	Area (m^2)	Population density
Dat's Cave	105	468.608	0.224
Asbang Fak Sol Cave	145	1087.799	0.133

Table 5 shows the population density of the two caves. Comparatively, the density of Dat's cave was 0.224 with an area of 468.608 m^2 containing an average number of 105 recorded individuals of macroinvertebrates; thus, it was higher than the Asbang Fak Sol cave with a density of 0.133 in an area of 1087.799 m^2 with 145 organisms.

The results revealed can be attributed to the conclusion stated by Barr (1967) that the size of a cave trechine's geographic range is determined not just by the continuous extent of the karst region in which it lives but also by the species' mobility and activity. Finally, competition between species with similar ecological niches will likely put additional constraints on range expansion. High dispersal potential arising from vast areas of thick, geologically undisturbed, extremely caverniferous limestones may explain the high occurrence of sympatry in the Mississippian plateaus. According to the predation hypothesis of Paine (1966), a higher proportion of predators in more diversified populations prevents overcrowding and monopolies of a few prey species.

In cave research conducted by Jourdan and company (2014), they concluded that different factors impacting population dynamics could explain variation in population density; for example, environmental heterogeneity may contribute to population disparities. Photophobic behavior has been hypothesized as a feature that promotes the colonization of permanently dark tunnels and the selection of microhabitat.

In addition, high dispersion potential results in a wide range of species and frequent sympatry. The modal size of troglobites can be increased in complex cave systems, resulting in higher population density and stability (Barr, 1967).

Table 6. Biodiversity indices, richness, and evenness in Dat's Cave

Specification	E	T	TR	D	Total
Species	17	3	5	6	31
Individuals	73	6	10	16	105
Shannon	1.872	1.011	1.359	1.561	1.451
Richness	3.729	1.116	1.737	1.803	2.097
Evenness	0.661	0.921	0.845	0.871	0.824
Effective number of species	6.498	2.749	3.893	4.762	4.476

E: Entrance zone 1; T: Twilight zone; TR: Transition zone; D: Deep zone

The biodiversity indices, richness, and evenness of Dat's cave are shown in Table 6. The highest diversity index was recorded in the entrance zone with 1.872 that had an equivalent diversity as a community with six equally-common species, followed by a deep zone with 1.561 (5 equally-common species), transition zone with 1.359 (4 equally-common species), and the least was the twilight zone with 1.011 (3 equally-common species).

In terms of the richness, the entrance zone had the most number of different species with 3.729, followed by the deep zone with 1.803, the transition zone with 1.737, and the least is the twilight zone with 1.116. Relatively, the evenness of the species was found to be high in the twilight zone with 0.921, followed by the deep zone with 0.871, transition zone with 0.845, and the least even was the entrance zone with 0.661.

The light zone contributes the most species richness to the cave arthropods, as the species found in these zones are predominantly species present in the outside cave environment. Arthropods dwelling in these zones are expected to be less affected by changes in environmental conditions than those living in the dark zone. The arthropods that live in these zones are more adaptable to changes in the environment (Kurniawan *et al.*, 2018).

Furthermore, the evenness in the deep zone of the cave can be caused by an environmental factor. The presence or lack of light is the most influential ecological factor on the ground and wall fauna. Furthermore, when one moved closer to the inner sections, the temperature dropped and stabilized, affecting the ground fauna, while relative humidity dropped, affecting the parietal fauna. The temperature and relative humidity in the cave's interior was more consistent than outside, and the inner sample locations likewise had fewer trophic resources (Ballestra *et al.*, 2021).

Table 7. Biodiversity indices, richness, and evenness in Asbang Fak Sol Cave

Specification	E	T	TR	D	Total
Species	11	4	4	8	27
Individuals	100	9	5	31	145
Shannon	1.225	1.273	1.332	1.660	1.373
Richness	2.172	1.365	1.864	2.038	1.860
Evenness	0.511	0.918	0.961	0.798	0.797
Effective number of species	3.405	3.572	3.789	5.257	4.006

E: Entrance zone 1; T: Twilight zone; TR: Transition zone; D: Deep zone

On the second cave, the Asbang Fak Sol cave, the biodiversity indices, richness, and evenness are shown in Table 7. The highest diversity index was recorded in the deep zone with 1.66, followed by the transition zone with 1.332, the twilight zone with 1.273, and the least was the entrance zone with 1.225. In terms of the effective number of species, the deep zone consistently had the highest index of 5.257, followed by the transition zone with 3.789, the twilight zone with 3.572, and the least was the entrance zone with 3.405.

In line with the diversity indices, the richness among the cave's four zones also varies. The entrance zone had the most number of different species with 2.172, followed by the deep zone with 2.038, the transition zone with 1.864, and the least was the twilight zone with 1.365. The distribution of the macroinvertebrates of each zone was moderately uneven; thus, the zone with the highest evenness value was the transition zone with 0.961, followed by the twilight zone with 0.918, the deep zone with 0.798 the least was the entrance zone with 0.511.

According to Delsinne and company (2010), various variables in arid environments decrease richness by reducing available resources. The presence of bats for roosting is influenced by cave temperature variations, which in turn affects the availability of more ants since bat droppings are potential food sources, including other invertebrates that may be present. Because it acts as a conduit for air to enter and circulate inside the caves, the primary access or entrance size is crucial. A larger entrance allows more air to permeate the cave's deeper levels, regulating temperature and humidity and allowing the presence of ants and other species in caves.

Moreover, we can also observe that the deep zone has more species than the entrance zone. This shows that species found in the deep zone are cave-adapted creatures, as they are prevalent in the deep zone where natural light is scarce. According to Hadley and colleagues (1981), most deep cave zones are characterized by everlasting darkness, steady temperatures, and continual high humidity. Species limited to these zones (troglobites) are thought to have physiological responses that mimic the physical environment. Likewise, detritus banks in river bottoms are home to a variety of benthic invertebrates (Allan, 1996). Sinking streams, which wash logs, twigs, leaves, bacteria, and epigean animals (including zooplankton) into caves, and trogloxenes, which deposit their eggs and feces in caves and often die there and contribute their bodies to the ecosystem, are the two primary sources of food input into cave ecosystems. Plant fragments are deposited along the banks of subterranean waterways, where bacteria and fungi slowly degrade them. Decomposers provide food for detritusfeeding animals (millipedes, collembolans, and dipterans), which predators consume (e.g., pseudoscorpions, opilionids, spiders, carabid beetles). Cave community diversity appears to be dependent on the degree to which the geology of the cave area facilitates cave colonization by species that are ancestral to troglobites, as well as the ability for multiple invasions of cave systems via dispersal along subterranean routes, rather than the factors usually cited to explain greater diversity in the tropics (Barr, 1967).

Table 8. pH, organic matter, and texture of the Cave soil in Dat's Cave

Zones	pH	Organic matter		Soil texture
		% OM	% OC	
Entrance	7.595 Slightly alkaline	7.06 Medium	4.1 Medium	Sandy loam
Twilight	7.375 Slightly alkaline	4.94 Low	2.87 Low	Sandy loam
Transition	7.295 Slightly alkaline	3.85 Low	2.24 Low	Sandy loam
Deep	7.635 Slightly alkaline	5.02 Low	2.92 Low	Sandy loam
Average	7.475	5.218	3.033	

Physicochemical properties of sediments

Table 8 shows the pH values, organic matter, and texture of the cave soil in Dat's cave. The data revealed that all cave zones were slightly alkaline, with the deep zone having the highest pH value of 7.635, followed by the entrance zone (7.595), twilight zone (7.375), and transition zone (7.295). The results can be associated with the increased number of different species in Dat's cave with 17 arthropods, such as *Nephila* sp., *Mastax philippina*, *Notagonum* sp., *Charon* sp., *Sticholotis* sp., *Hygia* sp., *Ophrydesmus* sp., *Ctenus* sp., *Pheidole* sp., *Strumigenys* sp., *Burmoniscus* sp., *Crossopriza* sp., *Uthina* sp., I*solapotamon* sp., *Diestrammena* sp., *Heteropoda* sp., and *Episinus* species.

A similar pH result was also reported by Van Straalen and Verhoef (1997), where a considerable interspecies heterogeneity in arthropod pH preferences was one of the most intriguing findings in this study. Despite several species having a wide range of preferences, the median pH ranged from 2.9 to 7.6. The pH of the soil varies a lot from place to place (Bringmark, 1989). The pH gradients are connected with ions whose concentration in the soil solution is pH-dependent, such as calcium, aluminum, iron, and various phosphate species. Soil pH directly impacts soil invertebrate communities, which is a key structuring component (Van Straalen and Verhoef, 1997).

The carbon content of soil organic matter is measured as total organic carbon. Organic matter and total organic carbon are two terms that are frequently and wrongly used to denote the same soil fraction. Organic matter differs from total organic carbon in that it often includes all elements that are components of organic compounds, not only carbon, such as hydrogen, oxygen, and nitrogen. Because organic matter is difficult to quantify directly in laboratories, total organic carbon is frequently used instead. When converting organic carbon to organic matter, a conversion factor of 1.72 is usually utilized. This conversion factor assumes that organic matter has a carbon content of 58% (What is soil organic carbon?, 2022). In line with this, in the study site, the organic matter revealed that the entrance zone had the highest percentage of soil organic matter and organic carbon with 7.06 and 4.1, respectively, with a descriptive equivalent of the medium.

Further, the three zones are determined to have a low percentage of organic matter and organic carbon; thus, the deep zone followed with 5.02% and 2.92%, the twilight zone (4.94%, 2.87%), and transition zone (3.85%, 2.24%). Lastly, all cave soils from the four zones had a sandy loam texture. The entrance zone had a medium percentage of organic matter due to its outside environment, consequently affecting the amount of organic carbon.

According to Merckx and colleagues (1985), organic amendments to the soil, such as manure and plant residues, are a major organic carbon source. Plants exude organic carbon through their roots, which helps to support microbial populations and turnover; thus, it can be inferred that the inner zones might have fewer organic carbon sources. All the collected soil samples are sandy loam congruent to Derevianko and the company's findings (2013). They determined that Chagyrskaya Cave in Altai has different-colored sandy loam soil, mainly sandy grayishbrown loam, darker and denser than the overlying strata, from the cave's entrance to the inner chamber.

In line with this, Anton and company (2011) reported that when water in the soil zone comes into contact with limestone or dolomite before entering a cave, the carbonate minerals are dissolved, and the cave becomes somewhat alkaline. Because the pressure in the cave channel is lower than in the soil zone, carbon dioxide is released from the groundwater. When carbon dioxide is removed from the atmosphere, the water becomes too alkaline to keep all of the minerals dissolved in the soil zone, and carbonate minerals (such as calcite) are slowly deposited as stalactites and stalagmites, and flowstone within the cave. As a result, the cave's rocks can dissolve and be placed within a few feet of one other.

Ladd and Amato (1985) reported that high equilibrium levels of organic matter are difficult to achieve in tropical ecosystems due to the substantially quicker breakdown rate generated by constant temperature. To maintain a sufficient labile soil organic matter pool in farmed soils, significant yearly rates of organic inputs are required. The soil organic matter is essential for several important soil activities, including nitrogen turnover. The loss of SOC is thought to have a negative impact on nutrient availability, soil water storage, and carbon storage in general (Schoknecht *et al.*, 2013). Conversely, the data revealed that the entrance zone had the highest organic matter percentage compared to the twilight, transition, and deep zones, which correlates to an increased number of different species present in the area, such as *Pheretima* sp., *Mastax philippina*, *Notagonum* sp. *Hygia* sp., *Ophrydesmus* sp., *Ctenus* sp, *Pheidole* sp., *Strumigenys* sp., *Burmoniscus* sp., *Uthina* sp., *Isolapotamon* sp., *Diestrammena* sp., *Heteropoda* sp., and *Achatina fulica*.

Table 9. pH, organic matter, and texture of the Cave soil in Asbang Fak Sol Cave

Zones	pH	Organic matter		Soil texture
		% OM	% OC	
Entrance	8.075 Slightly alkaline	3.59 Low	2.09 Low	Sandy loam
Twilight	8.03 Moderately alkaline	2.82 Very Low	1.64 Very Low	Sandy loam
Transition	8.05 Moderately alkaline	2.74 Very Low	1.59 Very Low	Sandy loam
Deep	4.86 Slightly acidic	1.91 Very Low	1.11 Very Low	Sandy loam
Average	7.254	2.765	1.608	

On the other hand, Table 9 presents the pH values, organic matter, and texture of the cave soil in the Asbang Fak Sol cave. It can be noticed that only the deep zone was classified to be slightly acidic with a pH of 4.86. Moreover, the twilight zone was moderately alkaline with a pH of 8.03, followed by the entrance zone (8.075), and transition zone (8.05), which were both slightly alkaline.

In a study, Khaziev (2011) found that the diversity of species, life forms, and physiological activities of the soil biota are linked to soil qualities, providing a foundation for biological soil diagnosis and indication approaches like zoological methods. Various characteristics, including soil organic matter content, moisture, acidity, nutrient and salt concentrations, physical features, and texture, contribute to the diversity of vegetation and microorganisms adapted to a given soil type. The species diversity in macrofaunal assemblages of various soil types are influenced by the physical and mechanical properties of soil, including particle size composition, moisture–air regime, density, and plant detritus mix, influence .

In connection, there were two sightings of earthworms identified as *Pheretima* species in the entrance and deep zones of the Asbang Fak Sol cave, which could explain the appropriateness of the average pH value in the cave support the macroinvertebrates. The cave had an average of 7.254, which is slightly alkaline. This basis is supported that earthworms were more important (in terms of species richness, population density, and biomass) in soils with a pH greater than 5.0, according to Piearce (1972). Salmon and Ponge (1999) also noted that, at least in deep layers, casts and burrow walls have more organic matter concentration than surrounding soil. Proteins and glycoproteins, urea, amino acids, vitamins, and glycosides are organic components excreted by earthworms. These are expelled as casts and directly in the environment via their nephridiae and as epidermal mucus, which is a major source of nitrogen for soil microbes and plants.

In a relevant study by Young (1976) in Canelobre cave, Spain, it was observed that the cave has a pH range of neutral to slightly alkaline due to guano-leached phosphate solutions reacting with the limestone bedrock in an environment that resulted in the occurrence of apatite and carbonate hydroxylapatite. However, although fresh guano is slightly alkaline, organic degradation gradually releases acids (nitric, sulfuric, phosphoric, and carbonic) that increase acidity as low as pH 2-4. Through interactions with organic matter, solutes from dripping, the carbonate host rock, and detrital material that provides Al, Fe, K, Mg, Mn, and other elements, this acidic environment lead to the genesis of minerals, primarily phosphates but also some sulfates and occasionally nitrates (Audra *et al.*, 2019).

In terms of organic matter, the entrance zone in the cave had the highest percentage of soil organic matter and organic carbon with 3.59 and 2.09, respectively, with a descriptive equivalent of low. Further, the three zones were determined to have a very low percentage of organic matter and organic carbon; thus, the twilight zone followed with 2.82% and 1.64%, transition zone (2.74%, 1.59%), and deep zone

(1.91%, 1.11%). Similar to Dat's cave, all cave soils from the four zones had sandy loam texture.

The cave has a low to a very low percentage of organic matter attributed to diminishing ratios of organic compounds. One of the explanations for the sudden reduction of particle organic materials in the dark inner portion was degradation. From the cave entrance to the deepest stations, the organic matter concentration of the particles dropped. Because of the organic matter's un-degradability and the cave's uniform hydrologic conditions, non-organic compound quantities were limited in the cave's dark inner part (Fichez, 1991). As the clay content in the soil rises, the organic matter in the soil rises with it. Two mechanisms contribute to this rise. For starters, the decomposition of organic matter is slowed by connections between the surface of clay particles and organic matter. Second, clay-rich soils have a higher chance of forming aggregates. Microbial attack causes increased mineralization of organic matter molecules, which macro-aggregates defend from (Rice, 2002). As seen in the laboratory result, it presented that 40% – 60% of the soil was sandy; thus, the clay soil texture was lower. This further explains why the Asbang Fak Sol cave had a lower number of observed species compared to the Dat's cave. Lastly, the entrance zone of Asbang Fak Sol cave had an average total of 100 sighted individuals because it has the highest clay percentage among other zones and the highest percentage in terms of organic matter.

Furthermore, another factor that can cause the general reduction in organic component contents with sediment depth is the classic pattern of organic matter decomposition with depth and age due to aerobic and anaerobic microbial decomposition processes (Jorgensen, 1983). In addition, the soil texture was found to be sandy loam that can be attributed to deposition by floodwaters, such as in the study of Springer and Kite (1997) in the Colluvium Breath Cave.

Conclusion

In Dat's cave, twenty genera were recorded belonging to Arthropoda, Annelida, and Mollusca. The majority of the macroinvertebrates were arthropods from class Arachnida and Insecta. The following were the recorded genera: *Nephila* sp., *Mastax philippina*, *Notagonum* sp., *Charon* sp., *Sticholotis* sp., *Hygia* sp., *Ophrydesmus* sp., *Ctenus* sp., *Pheidole* sp., *Strumigenys* sp., *Burmoniscus* sp., *Crossopriza* sp., *Uthina* sp., *Isolapotamon* sp., *Diestrammena* sp., *Heteropoda* sp., *Episinus* sp., *Achatina fulica*, *Paropeas achatinaceum*, and *Pheretima* species.

On the other hand, the Asbang Fak Sol cave has sixteen genera belonging to Arthropoda, Annelida, and Mollusca, where most of them were found similar to Dat's cave. In the same way, the majority of the macroinvertebrates were arthropods from class Arachnida, and Insecta. These are the recorded macroinvertebrates: *Ballophilus* sp., *Charon* sp., *Rhinocypha colorata*, *Pseudagrion pilidorsum*, *Ctenus* sp., *Myrmicaria* sp., *Hexatoma perennis*, *Burmoniscus* sp., *Uthina* sp., *Isolapotamon* sp., *Ptilodactyla* sp., *Diestrammena* sp., and *Opadometa fastigata*.

In Dat's cave, macroinvertebrate abundance increased with respect to distance from the entrance and the presence of leaf-litters, logs, and twigs. *Pheidole* sp. is relatively abundant, followed by *Achatina fulica*, *Charon* sp., *Strumigenys* sp., *Diestrammena* sp., and *Heteropoda* sp., *Uthina* sp., and *Isolapotamon* sp., *Burmoniscus* sp., *Pheretima* sp., *Ctenus* sp., and *Crossopriza* sp., *Nephila* sp., *Mastax philippina, Notagonum* sp., *Sticholotis* sp., *Hygia* sp., *Ophrydesmus* sp., *Episinus* sp., and *Paropeas achatinaceum.* In the second cave, the Asbang Fak Sol cave, macroinvertebrate abundance also increased concerning distance from the entrance, the presence of guano, leaf-litters, logs, and twigs. *Myrmicaria* sp. is relatively abundant, followed by *Uthina* sp., *Charon* sp., *Isolapotamon* sp., *Diestrammena* sp., *Achatina fulica*, and *Pheretima* sp., *Ctenus* sp., *Burmoniscus* sp., and *Opadometa fastigata*, *Ballophilus* sp., *Rhinocypha colorata, Pseudagrion pilidorsum, Hexatoma perennis, Ptilodactyla* sp., and *Paropeas achatinaceum.*

In terms of the Shannon diversity index, the Dat's cave an average of 1.451. Moreover, the average richness, evenness values, and effective number of species of Dat's cave were 2.097, 0.824, and 5 equally common species, respectively. On the other hand, Asbang Fak Sol cave scored an average Shannon diversity index of 1.373. The average richness, evenness values, and effective number of species of Asbang Fak Sol cave were 1.860, 0.797, and 4.006.

Finally, the physicochemical properties of the sediments obtained from Dat's cave had an average pH value of 7.475 that means slightly alkaline, an average percentage value of organic matter of 5.218, and a soil texture of sandy loam. In Asbang Fak Sol cave, the sediments collected had an average pH value of 7.254 that means slightly alkaline, an average percentage value of organic matter of 2.765, and a soil texture of sandy loam.

Based on the present study's findings, it is suggested that sampling could be done for extended periods because a longer sampling period allows for more macroinvertebrates to be documented. More macroinvertebrates will be counted and recognized, and the community's diversity will be updated as a result. One day could be dedicated to a single zone. It is also recommended to conduct a study on monitoring the flux of detritus organisms, fauna, microbial community, and a report on the characterization of dissolved organic matter in drip water and streams to understand further their cave ecology. To minimize disturbance and document the activities of the invertebrates, including their eating behavior, documentation might be done using a night-vision camera.

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