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Cave-dwelling bat assemblage of Polillo Island, eastern Philippines

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ABSTRACT

Almost half of Philippine bat fauna (35 species) are known to use caves as roosting sites. Caves in the Philippines are significant livelihood source, from extractive utilization to ecotourism ventures, and as a result, bat populations have been adversely affected and are probably declining. We contributed to a nationwide initiative to assess the status of cave bats by conducting rapid surveys on Polillo Island in May 2009. We also measured cave attributes (length, entrance size, and microclimate), and documented human disturbances present. Sixteen bat species were recorded in 21 of 22 caves surveyed. Seventeen caves had 1-2 species, whereas one cave had nine species; only five caves have sizeable bat populations (>1,000 individuals). Most surveyed caves experienced on-site or historical disturbances (73%), primarily from swiftlet nests harvesting and guano collection. Bat reproductive data indicated that: significantly more females were captured (408 vs 174), 13 species had pregnant bat individuals, and these reproductively active bats account for 62% of captured females. Lastly, Spearman's rank-order correlation analysis showed significant correlation for species richness with cave length (r_s= 0.76, p<0.001), entrance size (r_s = 0.54, p<0.01), and cave microclimate (temperature r_s = -0.80, p<0.001; relative humidity r_s = 0.65, p<0.05). In summary, a comparatively high bat species richness in some caves (with rare and threatened endemics), presence of large colonies, and prevalent human disturbances all point to the importance of Polillo Island as a significant conservation priority for cave-roosting bats in the Philippines.

INTRODUCTION

Karst and its associated caves are some of the most ubiquitous landscapes in the Philippines, covering approximately 10% of the total land area of the country (Restificar et al. 2006). The Philippine Department of Environment and Natural Resources (DENR) has identified more than 1500 caves present (PAWB 2008) and at least 25 cave systems are under protected area status (PAWB 2004). Karst areas in the Philippines also support a diverse assemblage of terrestrial vertebrates that are adapted to caves including several species of swiftlets (Kennedy et al. 2000), amphibians (Brown and Alcala 1982; Siler et al. 2009), reptiles (Brown and Alcala 1978; Linkem et al. 2010) and bats (Rabor 1952; Heaney et al. 2010). Bats are the most species rich among Philippine cavernicolous vertebrates and at least 35 species are known to utilize caves as roosts (Sedlock et al. 2014), representing almost half of the country's bat fauna (Heaney et al. 2010). Bats are widely known to provide valuable ecosystem services (Kunz et al. 2011) such as seed dispersers (Corlett

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1998), pollinators (Corlett 2004), and consumption of herbivorous insect pests (Leelapaibul et al. 2005; Srilopan et al. 2018). In addition, cave-roosting bats produce guano that is important in a cave ecosystem by providing an abundant food source especially for arthropods (Emerson and Roark 2007; Gnaspini and Trajano 2000; Smrz et al. 2015), as habitats for guanobionts (Deharveng and Bedos 2000), as well as influencing trophic interactions among cave-dwelling organisms (Ferreira and Martins 1999).

There have been a rapidly increasing number of researches done on Philippine cave-dwelling bats in recent times (mostly synthesized by Tanalgo and Hughes 2018), primarily on surveys and inventories (Alviola et al. 2015; Mould 2012; Nuneza and Galorio 2014; Quibod et al. 2019; Sedlock et al. 2014; Tanalgo and Tabora 2015), on-site threat description and quantification (Quibod et al. 2019; Phelps et al. 2016; Tanalgo et al. 2018), and ecological requirements and roost preferences (Dimaculangan et al. 2019; Phelps et al. 2016). These studies represented a significant leap in the amount of information currently known for cave-dwelling bats in terms of species distribution, ecology, and conservation (Tanalgo and Hughes 2019). On the other hand, cave communities and karst ecosystems in the Philippines have experienced substantial human-led disturbances such as from guano mining (Urich 1993), swiftlet nest collection (Alviola et al. 2015; Sedlock et al. 2014), tourism (Alcala et al. 2007), treasure hunting (Sedlock et al. 2014) and bat hunting (Mould 2012). The magnitude and extent of these disturbances dm and its effects on bats remain poorly known (Sedlock et al. 2014). As a result, the inventory and conservation of cave bats and their associated ecosystem have been identified as a research priority in Southeast Asia including the Philippines (Kingston 2010). In a recent synthesis of available publications on Philippine bats, Tanalgo and Hughes (2019) reported that more than half of known cave-dwelling bat species in the country are continually being threatened from various anthropogenic activities, most primarily from cave tourism and visitation, and mining and quarrying. This raises the importance of setting up an effective scheme to survey and monitor cave-dwelling bats and their vulnerability to human-caused threats (Tanalgo et al 2018; Tanalgo and Hughes 2019).

As such, we contributed to this recommendation by providing the results of our rapid surveys of cave bats on Polillo Island, in eastern Philippines. Polillo Island (761 km^2) belongs to a group of 24 islands and islets that lie off the east coast of Luzon. Much of the island has been converted to coconut plantations for harvesting of *copra* to extract oil, which is the island's major industry (Mallari et al. 2001). Extensive karst areas are very much confined to the eastern side of the island, and mostly situated along coastlines (MGB 1981; MMAJ 1985). Heaney et al. (2010) reported eight species of bats present in the island based on a few incidental collections deposited at the Field Museum, USA. This paper constitutes the first purposive bat survey on caves for Polillo Island.

Our foremost objective was to assess species composition and population size of bats in caves. In doing this, we also performed measurements of various cave physical attributes (maximum horizontal length, entrance size, and microclimatic conditions), and documented human disturbances present through visual inspection or community interviews. Corollary to our first objective, we also determined the presence of relationship between species richness and measures of cave physical attributes through correlation analysis. Lastly, we also gathered information on the reproductive status of captured bat species, specifically on sex-ratios, age class, and frequency of pregnant and lactating bats.

MATERIALS AND METHODS

Study Site

Polillo Island, which lies ca. 25 km east of Luzon Island (Figure 1), is the largest among the 24 scattered islands and islets that 4h along the eastern seaboard of Polillo Island (MGB 1981; MMAJ 1985). Virtually all the caves we surveyed were located along the eastern portion of the island.

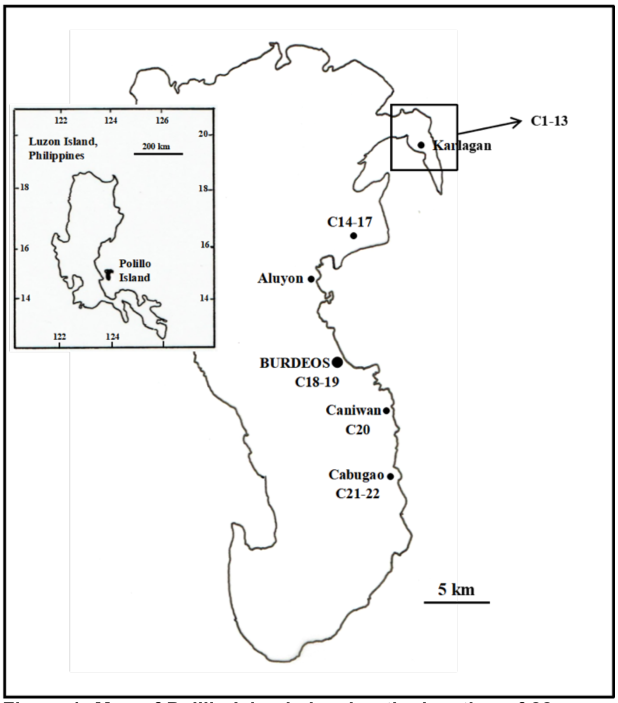

Figure 1: Map of Polillo Island showing the location of 22 caves (C1-22) and the municipality of Burdeos with the baranggays where all cave surveys were done. See Table 1 for corresponding cave name and number. Inset map shows location of Polillo Island relative to Luzon Island.

Polillo Island is dominated by coconut plantations and scrub vegetation, and the remaining scattered patches of intact forests accounts for 19% of the total land area (Mallari et al. 2001; PIBCFI 2008). A substantial portion of these forest patches, estimated at ca. 7500 hectares (~10% of island area), have been declared as Local Conservation Areas (LCAs) under the administrative jurisdiction of municipal government units (PIBCFI 2008). Sizeable forest patches have been identified, notable of which include the Kalawakan Forest Block in Panukulan (northernmost municipality of Polillo Island); the contiguous watersheds of Aluyon, Burdeos, Binibitinan, and Taluong which is shared between the municipalities of Polillo and Burdeos; and the Macnit-Lumpag forest patch located at the southern portion of the island. Polillo Island is included as an Important Bird Area (Mallari et al. 2001) and Conservation Priority Area (Ong et al. 2002) due to presence of several island-endemic and threatened land vertebrates such the Polillo Tarictic (*Penelopides manillae subnigra*) and the Gray's Monitor Lizard (*Varanus olivaceus*).

Cave Surveys

We conducted our cave bat surveys from May 28 to June 15, 2009 in the municipality of Burdeos, Polillo Island. Information on cave locations, especially those which contain bats, was solicited from local residents, local government officials and agencies. A total of 22 caves were visited and sampled for bats for the duration of the survey (Table 1). Each cave was surveyed during daytime, and the location of each cave was determined using a hand-held Global Positioning Unit (GPS); coordinates were taken at cave entrances (latitude and longitude, and elevation data are not provided in this paper to protect cave

Table 1: **Attributes of 22 caves surveyed for bats in Polillo Island, eastern Philippines. Attributes expressed as: cave length (m), entrance size (m^2), temperature (°C), relative humidity (RH, mean and SD). Abbreviations for cave disturbance (bh- bat hunting, gc- guano collection, gd- garbage dumping, gr- graffiti, sp- speleothem collection, sw- swiftlet nest collection, to- tourism, tr- treasure hunting,). Refer to Methods for scientific name abbreviations.**

Cave name/number	Cave length	Entrance size	Temp.	RH	Disturbance type/s	No.of bat species	Bat species present	Bat population estimate
Unnamed Cave 1 (C1)	9.2	2.86			none	1	*Em. ale.*	<20
Unnamed Cave 2 (C2)	5.9	24.32			none	2	*Em. ale.*	<20
Unnamed Cave 3 (C3)	8.5	1.12			none	1	*Me. spa.*	<10
Lumimpad 1 (C4)	10.2	6.46	29.3 (0.08)	87.5 (1.05)	gr, sw	0	none	0
Lumimpad 2 (C5)	8.7	2.03			sw	1	*Em. ale.*	<15
Togawe 1 (C6)	41.3	2.94	29.8 (0.11)	86.5 (0.55)	sw	1	*Em. ale.*	<30
Togawe 2 C7)	44.5	95.30	27.8 (0.18)	89.0 (0.89)	sw	2	*Em. ale., Mi. pau.*	<30
Dita 1 (C8)	55.3	10.08	29.6 (0.13)	88.5 (1.05)	sp, sw	2	*Em. ale., Mi. pau.*	<30
Dita 2 (C9)	46.4	8.64			sp, sw	2	*Em. ale., Mi. pau.*	<30
Dita 3 (C10)	42.1	4.94			sp, sw	2	*Em. ale., Mi. pau.*	<30
Boulevard (C11)	15.3	0.32	30.9 (0.17)	83.2 (0.41)	gd, gr	1	*Em. ale.*	<20
Kahapunan 1 (C12)	30.1	3.64	29.0 (0.18)	90.7 (0.52)	gc	2	*Em. ale., Mi. pau.*	~200
Kahapunan 2 (C13)	20.5	11.40	29.1 (0.21)	89.7 (0.82)	gc	1	*Em. ale.*	~100
Puting Bato 1 (C14)	85.5	255.84	28.1 (0.07)	89.0 (1.26)	gc, sw, to	2	*Eo. spe., Hi. dia.*	>1000
Puting Bato 2 (C15)	76.3	164.3	28.4 (0.11)	88.3 (1.03)	gc, gr, sw, tr, to	2	*Ro. amp., Hi. dia.*	>1000
Puting Bato 3-4 (C16)	247.1	124.74	28.3 (0.07)	88.5 (0.84)	gc, gr, sw, to	4	*Ro. amp., Hi. dia., Hi. pyg., Rh. ruf.*	>1000
Puting Bato 5 (C17)	51.2	2.66	28.2 (0.11)	89.2 (0.41)	none	5	*Hi. cor.,Hi. dia.,Mi. pau., Mi. esc., My. mac.*	<500
Bulalon (C18)	207.8	17.46	26.6 (0.05)	92.8 (0.75)	bh, gc	7	*Eo. rob., Hi. pyg., Rh. arc., Rh. ruf., Mi. pau., Mi. esc., My. mac.*	>1000
Mapanghi (C19)	238.5	379.44	27.0 (0.26)	89.9 (0.98)	gc, sw, to	9	*Eo. spe., Ro. amp., Hi. ant., Hi. dia., Hi. obs., Hi. pyg., Rh. arc., Rh. ruf., Mi. pau*	>1000
Fortun (C20)	55.2	2.31			gc	2	*Rh. arc., Rh. phi*	~200
Kabag (C21)	18.4	0.72			none	1	*Me. spa.*	<20
Rocky Mountain (C22)	19.2	1.82			none	2	*Em. ale.*	<30

Species name abbreviations: *Eonycteris robusta- Eo. rob.; Eonycteris spelaea- Eo. spe.; Rousettus amplexicaudatus- Ro. amp.; Emballonura alecto- Em. ale.; Megaderma spasma- Me. spa.; Hipposideros antricola- Hi. ant.; Hipposideros coronatus- Hi. cor.; Hipposideros diadema- Hi. dia.; Hipposideros obscurus- Hi. obs.; Hipposideros pygmaeus- Hi. pyg.; Rhinolophus arcuatus- Rh. arc.; Rhinolophus philippinensis- Rh. phi.; Rhinolophus rufus- Rh. ruf.; Miniopterus paululus- Mi. pau.; Miniopterus eschscholtzii- Mi. esc.; Myotis macrotarsus- My. mac.*

resources from exploitation, as stipulated by Philippine law, Republic Act 9076). At each cave, data on several parameters, namely length, entrance dimensions (maximum height and width), human disturbance types present, and microclimatic conditions (temperature and relative humidity) were measured. All cave measurements began at the entrance (survey station 1) and measured its height and width (at its widest and highest point). From station 1, the distance to station 2 was taken, the location of which was determined by a change in the passageway direction. This method was continued until reaching the entire length of the cave; all linear measurements were taken either with a laser range finder or a meter tape. Temperature and relative humidity measurements were taken mostly at bat-occupied chambers, although some caves were not measured due to difficulty in terrain which greatly hampered movement especially during the conduct of bat capture. Evidence of human disturbances such as garbage, graffiti, bamboo poles of switlet nest collection, torches and nets used in hunting bats, rice sacks for collecting guano, diggings by treasure hunters, and hacked speleothems, were noted for each cave.

Bat Capture

We measured cave species richness based on the count or number of species recorded in a single cave system. For this, we went inside the cave during daylight to capture bats using either mist nets or hoop nets. In some instances, nets were also set at cave entrances. In large caves such as in Puting Bato 3-4, Bulalon, and Mapanghi, bat surveys usually took four to five hours to complete whereas smaller caves (< 20 m) took less time, usually lasting 30 minutes to one hour. Nevertheless, all 22 caves we surveyed for bats were sampled only once.

Upon capture, bats were individually placed in cloth bags and processed immediately after the entire length of the cave has been explored. The number of bats in each cave surveyed was estimated visually. It was difficult to accurately estimate the number of bats since most take flight as soon as we get near or some bats roost at high ceilings and exact numbers are difficult to ascertain. As such, bat population numbers presented herein are rough – likely underestimates at best. We also took note for presence of bat stains (dark marks left by bat feet) on cave walls and ceilings.

Standard external measurements (total length, forearm length, tail length, ear length and hindfoot length, all in millimetres), and body weights (in grams) were taken on all captured individuals. Age class, sex, and reproductive condition were also determined. Special attention was given to reproductive status of females, and we took note of each female whether as pregnant and/or lactating. Age class of each bat captured was assessed either as adults (fused joints), weaned juveniles (unfused joints with cartilage, non-nursing and capable of flight), or unweaned juveniles (non flying pups attached to mother bats). All captured bats were identified using bat key in Ingle and Heaney (1992). Recent taxonomic changes were also applied in several species particularly for *Hipposideros antricola* (Philippine populations previously identified as *Hi. ater*), and *Miniopterus paululus* and *Mi. eschscholtzii* (previously for *australis* and *schreibersii,* respectively) (Heaney et al. 2016; MDD 2020; IUCN 2021). We collected 7-10 individuals of each species captured per cave, preserved in 10% formalin and then transferred to 70% ethanol upon arrival at the UPLB Museum of Natural History where voucher specimens were deposited and catalogued.

Statistical Analysis
Prior to statisticalA1 test, all variables (species richness, cave length and entrance size, temperature, and relative humidity) were data transformed ($\log_{10}$) to stabilize the variance of measured data (Box et al. 1978). Shapiro-Wilk normality test indicated that species richness and cave entrance size were not normally distributed. As such, we used the non-parametric test Spearman's rank-order correlation analysis to test for associations between species richness and cave physical characteristics (cave length, entrance size, temperature and relative humidity). Normality test and correlation analyses were performed using the program PAST (Paleontological Statistics Software) ver. 1.68 (Hammer et al. 2001). Chi-square goodness of fit test was used to determine significance in sex ratios for each bat species. For this, we followed the convention of conducting tests only for species with a combined (both males and females) sample size of 20 or more individuals, and with at least five individuals per sex. A pre-programmed Excel spreadsheet in *Handbook on Biological Statistics,* 3rd edition (Macdonald, 2014), an online freeware, was used to perform linear regression and Chi-Square analyses. All statistical tests were evaluated at a minimum 95% significance level ($P < 0.05$).

RESULTS AND DISCUSSION

Cave Characteristics
A total of 22 horizontal caves were surveyed between May 28 to June 15, 2009 (Table 1, Figure 1 for location map of caves, and Figure 2 for representative caves).

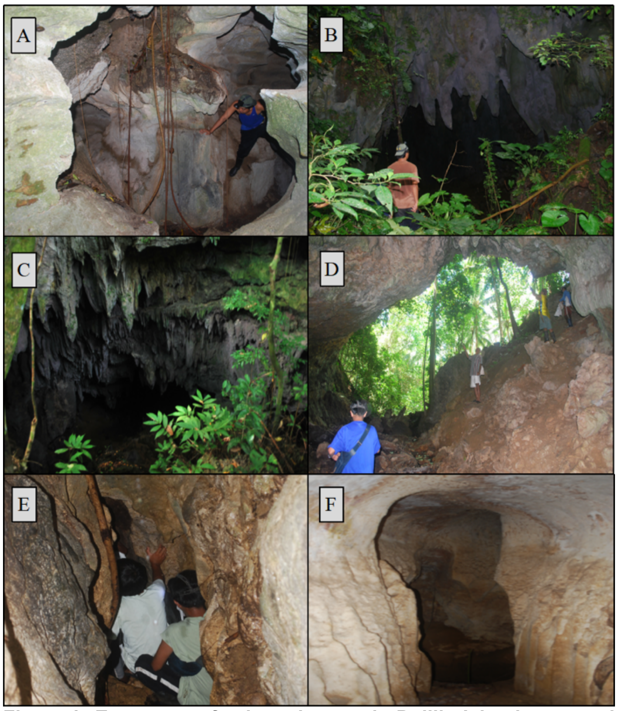

Figure 2: Entrances of selected caves in Polillo Island surveyed for cave-dwelling bats. Shown cave are as follows: A- Kahapunan 1, B- Puting Bato 1, C- Puting Bato 3-4, D- Mapanghi, E- Fortun, F- Rocky Mountain.

Almost 60% (13 caves) are situated in Brgy. Karlagan, whereas four are in Brgy. Aluyon (where Puting Bato cave complex is situated); two caves each were surveyed in baranggays Poblacion (near Burdeos town center) and Caniwan, and one cave in Brgy. Cabugao (Figure 1).

Cave lengths among the 22 caves ranged from 5.9 to 247.1 meters, with an average length of 60.78 m (± 73.03) (Table 1). A substantial majority (14 caves) were relatively short caves (<50 m), whereas only three caves exceeded more than 200 m in length. Cave entrance sizes ranged from as small as 0.32 m^2 (Boulevard cave) to as large as 379.44 m^2 in Mapanghi cave, and the mean entrance size was 51.06 m^2 (± 98.80 m^2). At least half of the 22 caves have entrance sizes smaller than 5 m^2. All caves were warm and humid, with temperatures of 26.6–30.9 °C and relative humidity values of 83.2–92.8%.

Diversity of cave bats in Polillo Island
A total of 582 bat individuals belonging to 16 species and representing 7 families were captured in the 22 caves surveyed (Tables 1-2, and Figure 3 for representative bat species); six species are new records for Polillo Island (38% of total species captures) based on a comparison with existing vouchered records published in Heaney et al. (2010). In addition, seven species captured in this study are Philippine endemics, representing 44% of total species captures. Of the 16 species of bats captured, these comprised of 3 fruit bats (Pteropodidae) and 13 insectivorous bats. Fruit bats (Family Pteropodidae, *Rousettus amplexicaudatus, Eonycteris robusta and Eo. spelaea*) were present in five caves, all of which had colonies exceeding 1000 individuals (represented mostly by *Rousettus amplexicaudatus* or *Eonycteris spelaea*), whereas insect-eating bats (represented by families Emballonuridae, Megadermatidae, Rhinolophidae, Hipposideridae, Miniopteridae, and Vespertilionidae) were recorded in 21 caves (Table 1). The most frequently encountered bat species was *Emballonura alecto* (a species present in 13 caves). Two bats, *Mi. paululus* and *Em. alecto*, were the most frequently captured species (116 and 113 bats, respectively), representing almost 40% of the total bat captures. On the other hand, five species (*Eonycteris robusta,*

Table 2: Sex ratio, age-class, and reproductive condition (for females) of 16 bat species captured during the cave survey in Polillo Island, eastern Philippines. Sex ratio with asterisks indicates significant difference. Species in boldface and with + are Philippine endemics and new Polillo Island record, respectively.

Species	♀	♂	Sex-ratio (♀:♂)	Pregnant	Lactating	Age-class		
						Adult	Weaned Juveniles	Unweaned Juveniles
Eo. robusta+	1	1	1:1	1		2		
Eo. spelaea	48	21	2.3:1**	33	1	66	3	
Ro. amplexicaudatus	42	13	3.2:1**	28	3	50	5	
Em. alecto+	80	33	2.4:1 **		43	68		45
Me. spasma	12	2	6:1		4	10	1	3
Hi. antricola+	2	4	1:2		1	6		
Hi. coronatus+	4	4	1:1			7	1	
Hi. diadema	49	21	2.3:1**	38		64	6	
Hi. obscurus+		1	-			1		
Hi. pygmaeus	25	13	1.9:1*		14	24		14
Rh. arcuatus	28	18	1.6:1	16	2	41	5	
Rh. philippinensis+		1	-			1		
Rh. rufus	3	11	1:3.7		1	14		
Mi. paululus	92	24	3.8:1**		53	105	11	
Mi. eschscholtzii	16	5	3.2:1*	9		21		
My. macrotarsus	6	2	3:1	5		7	1	
Total	408	174	2.3:1**	131	122	487	33	62

**- p< 0.05; **- p<0.01*

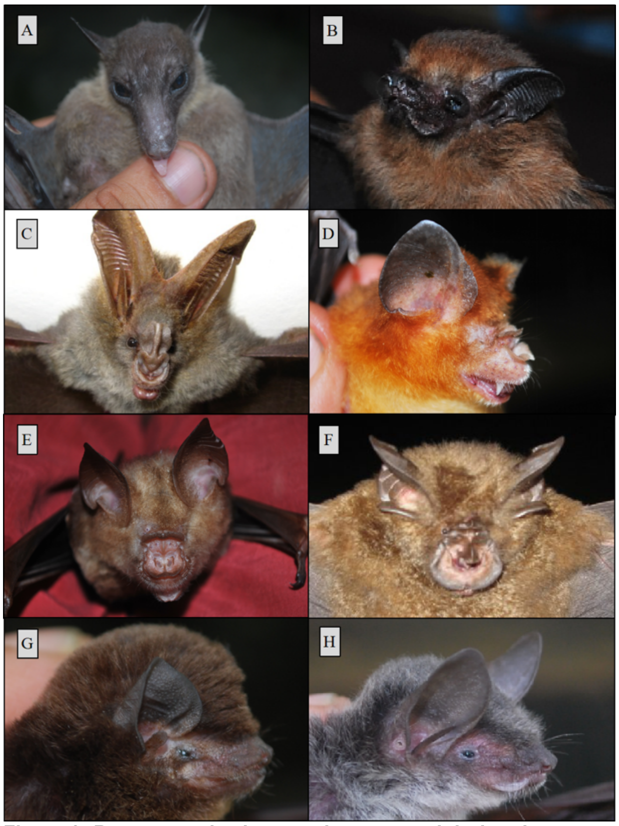

Figure 3: Representative bat species captured during the survey of Polillo Island for cave-dwelling bats. A- *Eonycteris robusta,* B- *Emballonura alecto,* C- *Megaderma spasma,* D- *Hipposideros coronatus*, E- *Hipposideros diadema*, F- *Rhinolophus rufus,* G- *Miniopterus eschscholtzii,* H- *Myotis macrotarsus*.

Hipposideros antricola, Hi. coronatus, Hi. obscurus, and *Myotis macrotarsus*) had captures of less than 10 individuals (Table 2). Six species captured in this study had not been previously recorded on Polillo Island (Heaney et al. 2010) including *Hi. coronatus* which is a poorly known species previously recorded only within the Mindanao Faunal Region (Heaney et al 2010; Sedlock et al. 2014). These additional records now bring the total for the island to 21 species, and also include bats that are not cave-dwellers (e.g. *Macroglossus minimus* and *Pteropus hypomelanus*). This is likely an underestimate given that some species were not captured in the study that are commonly reported in caves in other parts of the Philippines such as *Taphozous melanopogon, Rhinolophus virgo,* and *Miniopterus tristis.* Nevertheless, the 16 species we captured comprised 76% of the bat fauna known for Polillo Island and possibly points to the high importance of caves as a significant source of bat diversity on islands. Similarly, Phelps et al. (2016) recorded almost 70% of the total Bohol Island bat fauna in caves, and Alviola et al. (2015) captured almost two thirds of the known Marinduque Island bat fauna. In addition, our tally of 16 species is comparable to other published cave surveys done in the Philippines such as in Palawan with 15 species (Esselstyn et al. 2004) and Southern Mindanao with 14 species (Tanalgo and Tabora 2015), but less species-rich compared to Bohol with 23 (Phelps et al. 2016). In a regional context, our result fares poorly (as with other cave systems in the Philippines) with other surveys in different parts of Southeast Asia (e.g. East Kalimantan, Indonesia, 38 species — Suyanto and Struebig 2007; northern Vietnam, 31 species — Furey and Racey 2007).

Bat species richness per cave

Species richness per cave varied from no bats in Lumimpad 1 to nine species in Mapanghi cave; a total of 21 caves had bats (Table 1). On the other hand, 17 caves had only one or two species of bats recorded and only four caves had more than two species of bats. This low per-cave species richness was also reported in some islands in the Philippines: Bohol (median = 2, Sedlock et al. 2014), Marinduque (median= 4, Alviola et al. 2015), Panay (median= 2, Mould 2012). On the other hand, one of the caves we surveyed in Polillo Island, Mapanghi, ranks among some of the most species-rich cave in the Philippines, with nine species. Prior to this study, among the islands in the Philippines with reported highest species richness in one cave were in Bohol (10 species, Phelps et al. 2016), Palawan (10 species, Esselstyn et al. 2004), and Negros (nine species, Alcala et al. 2007). However, some caves in Southeast Asia are more species-rich such as in An Tinh Cave, Vietnam with 21 species (Furey et al. 2011), and in Tam Houay Si Cave, Laos with 20 species (Robinson and Webber 2000).

Cave disturbance and bat population

Based from bat surveys and informal interviews with local guides, we documented physical and anecdotal evidence of eight types of human disturbances (Table 1 and Figure 4). Evidence

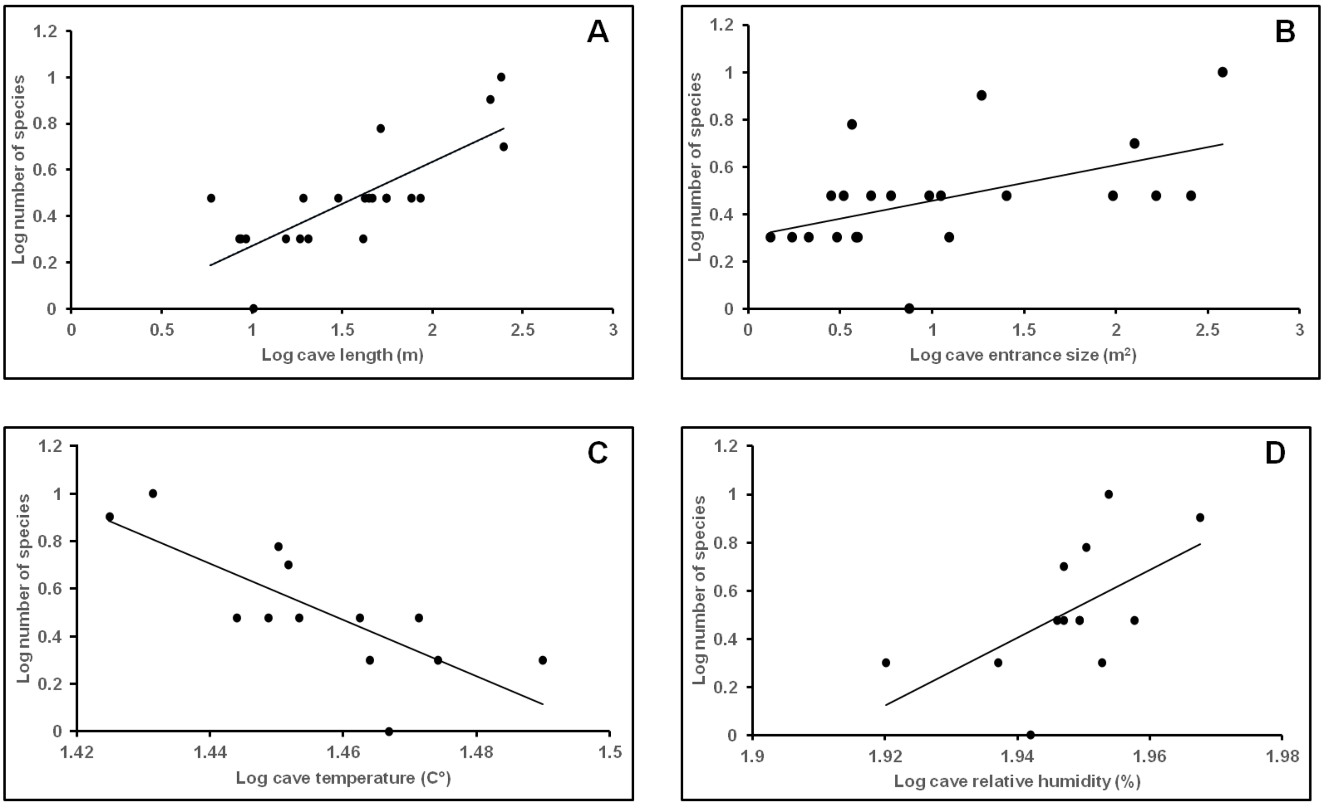

Figure 4: Scatter plots and trend lines for cave species richness and measured cave physical attributes, A- cave length, B- size of largest entrance, C- cave temperature, and D- cave relative humidity.

of human disturbances were present in 16 of the 22 caves. Puting Bato 2 had the greatest number of disturbance types with five. Collection of swiftlet nests was the most prevalent, being present in 10 caves. Signs of guano collection were documented in eight caves whereas tourism-related visits were documented in three caves. From interviews with local guides, bat hunting only occurred in Bulalon cave.

Large bat populations (>1000 individuals) were recorded in five caves, one cave (Puting Bato 5) harbored close to 500 bats, and two caves (Kahapunan 1 and Fortun) had populations reaching 200 individuals (Table 1). The low frequency of caves with large colonies is also reported in other areas across the Philippines such as in Panay Island (4/21 caves- Mould 2012), Bohol (3/25 caves- Sedlock et al. 2014), and Marinduque (5/11 caves- Alviola et al. 2015). Our study also documented possible bat population decline in Polillo Island through the presence of extensive bat stainings in caves with very low bat numbers (Lumimpad 1-2, Togawe 1-2, and Dita 1-3). Interviews with local guides indicated that these caves were heavily collected for swiftlet nest, with reported collection rates reaching as high as 10 times a year in Lumimpad 1. This condition may possibly point to bat abandonment similar to what has been documented in the islands of Bohol (Sedlock et al. 2014) and Siquijor (Sedlock, pers. comm.).

Moreover, fruit bat colonies in caves might be susceptible to population decline possibly because of their apparent rarity (caves containing fruit bats appear to be relatively less common) and high concentration of human activities in caves where they are present. In this study, we only recorded fruit bats in caves with large dimensions (i.e. Puting Bato 1, 2, 3-4, Bulalon and Mapanghi) suggesting a roosting preference for big caves. Published cave bat surveys in the Philippines indicate that large caves (>100 m in length) are uncommon (Vinarao and Cabauatan 2011; Mould 2012; Nuneza and Galorio 2014; Sedlock et al. 2014; Alviola et al. 2015), and presence of fruit bat colonies coincided with such large caves. In addition, our results indicate that large caves with large fruit bat populations had the highest concentration of various human disturbance types. Such caves in Polillo Island had at least three types of human disturbances, with as high as five in Puting Bato 2. Large caves can potentially offer a variety of resources such as guano (from large bat colonies, especially fruit bats), food (bat hunting), swiftlet nest, and recreational areas for visiting tourists, the utilization of which can drastically affect bat populations as documented in numerous Philippine caves (Mould 2012; Sedlock et al. 2014; Alviola et al. 2015; Tanalgo and Tabora 2015) and other parts of Southeast Asia (Robinson and Webber 2000; Clements et al. 2006; Furey et al. 2011).

Sex-ratio, age-class, and reproductive condition

Significantly more female bats were captured compared to males (χ^2= 94.82, p<0.001) for an overall sex ratio of 2.34: 1 (Table 2). At least ten species had sex-ratios that are female-skewed with a mean ratio of 2.97:1. In addition, seven of these species had statistically significant disproportionate sex ratios. In terms of age-class (Table 2), adult bats comprised 84% of the total captures, and there were more unweaned juveniles (still attached to mother bats) than weaned juveniles (independent of mother bats, capable of flight). A substantial majority of weaned juveniles were recorded in *E. alecto* (45 individuals) where it accounted for 73% of the total captures of weaned juveniles. Factors that can influence biased sex-ratios in caves can include dispersal of adult males and weaned juveniles during breeding season (Ransome 1971; Kunz 1982; Perry et al. 2010), or seasonality of cave occupancy by females to form maternity roosts (Kunz and Lumsden 2003). While sexual segregation during breeding season is common in temperate countries, it is poorly known in the tropics (Dimaculangan et al. 2019). In addition, published accounts of tropical bat aggregations in caves have documented both males and females during the reproductive season (Furey et al. 2011; Alviola et al. 2015; Phelps et al. 2016). On the other hand, the low number of males (30% of total captures) and weaned juveniles (just 5% of total captures) in our study may point to an on-going process of dispersal in the course of the breeding season. In addition, the relatively high number and prevalence of pregnant and lactating bats documented in this study, 131 and 122 bats respectively (for a combined 62% of all females, see Table 2), are a strong indication of presence of maternity roosts. Such aggregations have been documented in different parts of the Philippines (Palawan- Esseslstyn et al. 2004; Bohol- Sedlock et al. 2014; Marinduque- Alviola et al. 2015; Luzon Island- Dimaculangan et al. 2019). As such, bats during the breeding season can be particularly vulnerable because reproduction is energetically expensive, and disturbance, especially at actual roost sites, during this period (either at pregnancy, lactation, or weaning stages) can prove detrimental to population recruitment (Racey 1982; Furey et al. 2011). Because of this, data on bat reproductive patterns has conservation relevance and can be used in formal management of caves and their bat populations especially in the light of growing interest among local communities, especially in the Philippines, to open caves for eco-tourism.

Bats Species Richness and Cave Characteristics

Spearman's rank-order correlation analysis of the 22 caves (see scatter plots in Figure 4) indicated a highly significant, positive correlation between species richness and cave length (r_s= 0.76, p<0.001) and entrance size (r_s = 0.54, p<0.01). In addition, microclimate parameters exhibited opposing but significant relationships: species richness was negatively correlated with temperature (r_s = -0.80, p<0.001), whereas a positive correlation was observed with relative humidity (r_s = 0.65, p<0.05).

Our data suggests that long caves tend to harbor more species of bats and this has been documented in several cave areas around the world (Yucatan, Mexico- Arita 1996; central Mexico- Brunnet and Medellin 2001; Bolivia- Siles and Aguirre 2007; Henan, China- Niu et al. 2007; Bohol Island, Philippines- Phelps et al. 2016). Large caves are usually structurally complex which can offer roost site diversity and accommodate high bat species richness (Brunnet and Medellin 2001). Similar significant and positive correlation between species richness and entrance size indicates caves with large entrance size also tend to accommodate more species of bats. This aspect of cave structure has not been investigated although Niu et al. (2007) used number of entrances as a measure of possible correlate with bat species richness. Entrance size may act as a selective barrier as narrow cave entrances can physically restrict and limit number of colonizing bats (Rodriguez-Duran and Lewis 1987). In addition, small entrance size may also deter crudely echolocating bats (e.g. *Rousettus)* from entering such caves. Our data support this and show that all species of fruit bats (three species), which can add considerably to the species pool in each cave, were exclusively roosting in caves with large entrances (> 124 m^2).

Microclimate has been identified as an important factor in a bat's roosting preference as it influences selection of roost sites with optimal temperature and humidity in order to minimize energy expenditure and water loss (Brunnet and Medellin 2001; Kunz 1982; McNab 1982; Nagy and Postawa 2010). Several studies reported influence of cave microclimate on bat distribution and species composition (Nagy and Postawa 2010; Paskuz et al. 2007; Ulrich et al. 2007). A combined regime of relatively low temperature and high relative humidity in a cave can be an important factor especially in tropical environments as these can facilitate water loss mitigation in bats especially during periods of warm temperatures (i.e. summer months) (Brunnet and Medellin 2001).

Bat Species' Cave Preference

Our results also offer some preliminary ecological information, especially on species' cave preference and possible relationship between cave structural complexity and species richness. The two most encountered bat, *Em. alecto* (13 caves) and *Mi. paululus* (seven caves), tend to be present in caves of variable dimensions and disturbances (see Table 1). These data could suggest that (1) *Mi. paululus* can adapt to wide-ranging cave architecture, (2) a specific preference for small caves for *Em alecto,* or (3) a wide tolerance to disturbances for both species. *Miniopterus paululus* was recorded in caves of varying lengths (from 30.1 m to 238.5 m) and different combinations of disturbance types; collectively, all caves where it is present had all disturbance types. This species was also one of the most frequently encountered in Bohol (Sedlock et al. 2014; Phelps et al. 2016) and Palawan (Esselsyn et al. 2004). *Emballonura alecto* was present almost solely in small caves (<50 m) including those that were repeatedly collected for swiftlet nests. However, this species was seldom encountered on Bohol Island which was present only in six of the 62 caves surveyed (Phelps et al. 2016), or in Panay Island with three out of 21 caves (Mould 2012). Interestingly, fruit bats and all hipposiderids and rhinolophids were present in long caves (at least 75 meters, and all caves with >200 m) with large entrances (>120 m^2). As such, these data offer preliminary insights to the specific cave structure requirements at various taxonomic levels. Cave bat surveys incorporating measures of cave structural complexity have yielded valuable information on species-specific microhabitat associations.

Cave Bat Species in the IUCN Red List

Three bat species recorded in this study, namely *Eonycteris robusta, Hipposideros coronatus,* and *Rhinolophus rufus,* are categorized as Vulnerable, Data Deficient, and Near-Threatened, respectively in the 2021 IUCN Red List (Phelps et al. 2016; Alviola et al. 2019; Waldien and Carino 2020). We captured relatively few individuals of *Eo. robusta* (two individuals) and *Hi. coronatus* (eight individuals), and they were documented only in Bulalon and Puting Bato 5, respectively. On the other hand, fourteen individuals of *Rh, rufus* were captured in Puting Bato 3-4, Bulalon, and Mapanghi caves. Our captures of these species would indicate an apparent rarity in terms of numbers and distribution, especially for *Eo. robusta* and *Hi. coronatus,* but we like to emphasize that our surveys were rapid assessments (one-time sampling per cave) and a more intensive sampling may reveal presence of these bat species in other caves in Polillo Island. On the other hand, our documentation of disturbances revealed that bat hunting was present in Bulalon cave, whereas guano collection, swiftlet nest collection, and tourist visitations have been recorded in Puting Bato 3-4 and Mapanghi caves. We are uncertain if these human activities have directly affected the population of these IUCN Red List species in the caves we surveyed, but such activities have had documented negative impacts on bat populations elsewhere in the Philippines (Mould 2012; Sedlock et al. 2014; Tanalgo and Tabora 2015; Quibod et al. 2019). As this study was conducted in 2009, it is important to conduct a resurvey of the caves in Polillo Island and fully assess the disturbances that are present and its impact to bat populations.

CONCLUSION

Research on cave dwelling bats in the Philippines is in its infancy, and the results presented herein represent one of only few published cave bat surveys done in the country. Cave surveys employing bat inventories across a wide landscape (island- or province-wide scale) and incorporating measurements of cave characteristics, and disturbance assessment can provide various types of information that is valuable to management and conservation. Some examples of these information are: (1) a highly augmented bat species list, as this study has demonstrated that caves can be a major source of bat diversity on islands, (2) magnitude, extent, and effect of cave disturbance to bats, (3) bat population, which can be used to monitor response of bats to disturbances, (4) possible correlates of bat species richness, which can be applied to categorizing and prioritization of caves for management and conservation, and (5) natural history data such as reproductive condition which has significant implication to bat conservation in caves. As the Philippine government is mandated by law to conduct detailed assessment and classification of caves for management and conservation (DENR Administrative Order #29 2003), we believe systematic and purposive cave bat surveys can contribute significantly to its implementation.

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CONTRIBUTIONS OF INDIVIDUAL AUTHORS

PA Alviola is the principal author and conducted the sampling and the statistical analyses. EA Cosico and EG Eres contributed in the conceptual design of study, acquisition of data, and review of manuscript. LE Afuang and IL Lit, Jr. also contributed to conceptual design as well as review of manuscript. The latter is also the overall advisor of the study.

CONFLICT OF INTEREST

The authors have no conflicts of interest.

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