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Diversity and distribution trends of bats along elevation and habitat gradients in Mount Tuminungan, Bukidnon, Philippines

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Abstract. *Lama JMN, Caballero EB, Maceda JN, Omandam JE, Mondejar EP. 2024. Diversity and distribution trends of bats along elevation and habitat gradients in Mount Tuminungan, Bukidnon, Philippines. Biodiversitas 25: 3728-3738.* Chiropterans are considered as bioindicators due to their sensitivity to changes in their immediate environment. With climate change threats getting more severe, data on how elevation and different habitats affect bat diversity is very important in predicting and monitoring the probable upslope relocation of bat species. Hence, this study aims to examine the species diversity of bats at various elevations and habitat gradients in the Daraghuyan ancestral domain at Sitio Damitan in Barangay Dalwangan, Malaybalay City, Bukidnon, Philippines. Mist netting was used to sample bats in five sampling sites within the area, covering an elevation spectrum from 1525 to 1796 masl and habitat ranging from a mixed agroecosystem (MAE), forest patches within the agroecosystem (FPA), secondary montane forest to mossy forest. This study recorded six species of bats (*n*=392 individuals), predominantly Pteropodidae, with the additional record of population size, distribution and extent of occurrence of *Alionycteris paucidentata* Kock 1969 within Mount Kitanglad Range Natural Park (MKRNP). Sampling site 1b (FPA) had the highest relative abundance (33.42%) and bat diversity (H'=1.346) while Site 2, an intact lower montane forest (LMF), had highest species richness (n=5). Canonical Correspondence Analysis (CCA) and GIS mapping showed several variables (i.e., elevation, vegetation, and geographical characteristic) with significant associations with bat occurrence and abundance. This study emphasizes the role of the Daraghuyan ancestral domain as one of the important habitats for bats in Mount Kitanglad Range Natural Park.

Keywords: Agroecosystem, Chiroptera, conservation, habitat selection, Mindanao

INTRODUCTION

Elevational gradients in the tropics contribute to significant species turnover and diversity, with species exhibiting restricted ecological ranges (Betz et al. 2020). For instance, the biota in tropical montane forests is extremely diverse, with the occurrence of several endemic species (Jankowski et al. 2021). However, these ecosystems are also among the most vulnerable globally due to deforestation and were estimated at million hectares per year between 2015 and 2020 (Food and Agriculture Organization of the United Nations 2020; Mata-Guel et al. 2023). Deforestation is also one of the problems in several islands in the Philippines.

The Philippine archipelago is home to a high diversity and endemism of forest flora and fauna (Conservation International 2024) which are mostly threatened by continued human activities such as unsustainable logging and illegal timber trade (Hughes 2017) which could lead to a decline in their number (Murphy and Romanuk 2014) and, mostly likely, extinction (Hughes 2017). An analysis of the regional pattern of forest cover change in Southeast Asia (Stibig et al. 2007) shows that forest conversion by small-holder agriculture is still occurring in the Philippines' higher mountain forests, with concession logging identified as a driver of forest loss in Mindanao, followed by encroachment by shifting cultivators and small-holder farming. The continued disappearance of habitat, rising human population, and loss of vital ecosystems are some of the of the most concerning crises today (Shivanna 2022), making the Philippines one of the hottest hotspots and a top priority for global conservation (Conservation International 2024).

Bats are among the most diverse and widely distributed mammals that greatly depend on natural forests (Meyer et al. 2016). In the Philippines, bat fauna is quite diverse, with 78 species, 53 of which are known in Mindanao (Heaney et al. 2010). A substantial proportion of Philippine bats occur in forest ecosystems, with 25% of the species being forest-dependent (primary to mossy montane forest) (Heaney et al. 2010). Forest degradation can impact bat species, particularly those that rely on intact and primary forests for roosting and feeding (Heaney et al. 2006; Nuñeza et al. 2015; Tanalgo and Hughes 2019). However, in Mindanao, where tree cover loss is greater, fewer bat surveys have been conducted, which has critical implications for the understanding of the impacts of deforestation to bat biodiversity (Tanalgo and Hughes 2019). Climate change exacerbates habitat degradation by causing favored niches to relocate upslope (Shen 2017). The shift might be dangerous for bats, are effective bioindicators since they are very sensitive towards changes in environmental conditions (Scherrer et al. 2019). For example, because of their high trophic level, bats are particularly helpful in monitoring the presence of pollutants like pesticides and heavy metals (Russo et al. 2021). Despite this urgent warning, bat conservation and lawful protection have rarely been a priority (Tanalgo and Hughes 2019). Anthropogenic threats are not the sole reason why this order of volant mammals merits scientific study. Fruit bats pollinate and disperse a variety of fruit trees, including Philippine fig species, some of which are keystones (Relox et al. 2014). Insectivorous bats, in their own sense, reduce insect population while also managing agricultural pests (Tuneu-Corral et al. 2023; Wilson 2024).

This study focuses on the assessment of bats on Mt. Tuminungan, Bukidnon, one of the peaks of Mount Kitanglad Range Natural Park (MKRNP), which was declared by The Association of Southeast Asian Nation (ASEAN) a Heritage Park in October 2009 and is regarded as the first and most successfully managed protected area in the country. MKRNP covers multiple forest types due to the variation in altitude. The study by Amoroso et al. (2011) three vegetation types in MKRNP: agroecosystem (1,200-1,700 masl), montane forest (1,700-2,100 masl) and mossy forest (2,100-2,900 masl). Several studies were conducted on the bats of MKRNP (e.g., Heaney et al. 2006; Mohagan et al. 2015); however, some isolated areas are still unexplored. To narrow the gap, this study aims to uncover the trends in bat diversity and distribution at different habitat gradients of Mount Tuminungan, Bukidnon, Philippines based on mist netting at different sampling sites. The findings of this study will be useful in long-term monitoring in this era, particularly in spotting niche range-shifting by contrasting it with future data.

MATERIALS AND METHODS

Study area

This study was conducted at the Daraghuyan ancestral domain at the foot of Mount Tuminungan, Bukidnon, Philippines (8°18'11.88" N, 125°0'2.8794" E) where five sampling sites were established (Figure 1). Each sampling site was selected through ocular inspection taking into considerations the presence of fruit trees, the existence of water systems, caves and other areas that are known to be foraging and roosting sites of bats. In each sampling site, brief descriptions (e.g., elevation, coordinates, vegetation, localities) and anthropogenic disturbances were recorded (Table 1). Throughout the entire sampling period, we covered a total of four habitat types: mixed agroecosystem (MAE), forest patches within agroecosystems (FPA), lower montane forests (LMF), and lower montane forests transitioning to mossy forests (LMMF).

Table 1. Coordinates, elevation and habitat type of sampling sites

Sampling sites	Coordinates	Elevation	Habitat sype
1A	08° 9' 0.54" N, 124° 58' 23.4012" E	1525 masl	MAE
1B	08° 8' 40.3188" N, 124° 58' 5.4012" E	1641 masl	FPA
2	08° 8' 29.1012" N, 124° 58' 1.9812" E	1701 masl	LMF
3	08° 8' 20.2812" N, 124° 58' 0.9588" E	1730 masl	LMF
4	08°8'10.6188" N, 124°57'54.9" E	1796 masl	LMMF

Notes: MAE-Mixed Agroecosystem; FPA-Forest Patches along Agroecosystem; LMF-Lower Montane Forest; LMMF-Lower Montane to Mossy Forest

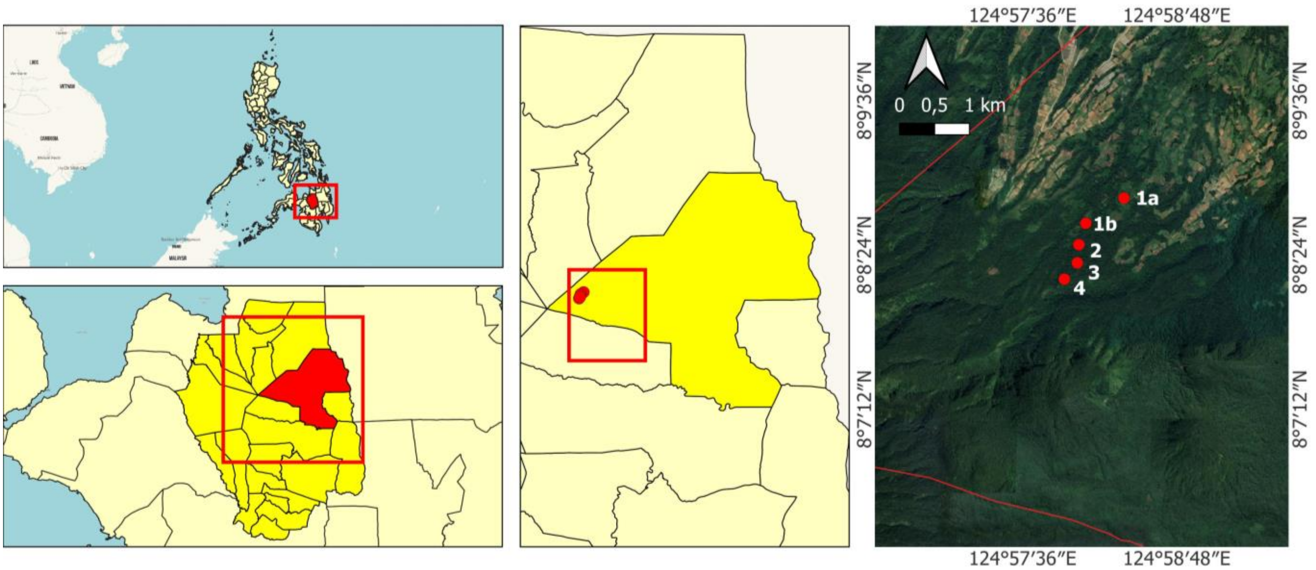

Figure 1. Map of Mt. Tuminungan in Malaybalay City, Bukidnon Province located on the Mindanao Island, Philippines

Site 1a (MAE) is situated at an elevation of 1,525 masl is a mixed agroecosystem where there is a presence of coffee plantation (*Coffea arabica* L.). The area is an open canopy with an emergent tree of *Falcataria falcata* (L.) Greuter & R.Rankin and canopy tree of *Trema* spp. The area is highly disturbed dominated by invasive species in the area such as *Galinsoga parviflora* Cav., *Lantana camara* L., *Sida* spp., and grasses. Notable plant species such as tree ferns (Cyatheaceae) were also observed in the area and epiphytes such as *Decaisnina cumingii* (Tiegh.) Barlow, *Amyema seriata* (Merr.) Barlow and *Aeschynanthus crassifolius* (Elmer) Schltr. The terrain is almost flat for the plantation but 45° slope at the western side approximately 10 meters away from stream and a spring at the east side.

Site 1b (FPA) is a remnant of a secondary growth lower montane forest within an agroecosystem with coffee plantation and has an elevation of 1641 masl. The area is a semi-open canopy with emergent trees of *F. falcata* and several canopy trees such as *Lithocarpus apoensis* (Elmer) Rehder (Ulayan), *Pterospermum niveum* S.Vidal (Bayok) and *Terminalia microcarpa* Decne. (Kalumpit). Fig trees (*Ficus* spp.) and *Pandanus* spp. were abundant around the area and trees were covered with mosses, epiphytic ferns (*Asplenium* spp., *Lindsaea* spp.) and orchids (*Coelogyne cantonensis* (Rolfe) R.Rice, *Appendicula* spp.). The terrain is flat near a stream which fern species of family Thelypteridaceae (*Sphaerostephanos latebrosus* (Kunze ex Mett.) Holttum; *Chingia ferox* (Blume) Holttum) and aroids (*Schismatoglottis* spp.) are common. Patches of wild banana (*Musa* spp.) were also observed. The site is approximately 5 meters away from a stream before entering to Site 2, and a larger stream occupying the east side of the area.

Site 2 (LMF) is a secondary growth lower montane forest with an elevation of 1701 masl. The area is flat to rolling (<45°) and was a slightly closed canopy (>60%) with an emergent tree of *Lithocarpus* spp. and canopy trees of *Trema eurhynchum* (Miq.) Byng & Christenh. (Anabiong) and *Pterocymbium tinctorium* (Blanco) Merr. (Taloto). Trees such as *Ficus* spp. and *Saurauia* spp. were also common in the area covered with mosses, epiphytic ferns (*Asplenium* spp., *Microsorum* spp.), orchids (*Appendicula* spp., *Bulbophyllum* sp.), and climbing aroids (*Amydrium* spp., *Raphidophora* spp.). *Medinilla* spp. and *Hymenophyllum* spp. were also common in the area. A few meters away from the site is a three-meter stream which separates it from a coffee plantation approximately 50 meters from the stream with little to no anthropogenic (e.g., trail).

Site 3 is also classified as a secondary growth lower montane forest with a slightly closed canopy (>60%). It has an elevation of 1730 masl and dominated by *Lithocarpus* spp. and some species of canopy trees such as *Agathis philippinensis* Warb. (Almaciga), *Dacrycarpus imbricatus* (Blume) de Laub., and *Pterocymbium tinctorium* (Blanco) Merr. (Taloto). Understory trees under family Lauraceae (*Actinodaphne apoensis* (Elmer) Kosterm. ex Brambach and Pelser, *Cinnamomum mercadoi* S.Vidal, *Litsea glutinosa* (Lour.) C.B.Rob.) and family Moraceae (*Artocarpus lamellosus* Blanco, *Ficus* spp.) were abundant in the area. The site has an undulating terrain and approximately 100 meters away from the stream with little to no anthropogenic disturbances (e.g., trail).

Site 4 (LMMF) was established as a Biodiversity Monitoring Sites (BMS) at 1796 masl. The sites were classified as lower montane forest transitioning to upper montane forest (mossy forest) dominated by gymnosperms under family Podocarpaceae such as *D. imbricatus*, *Phyllocladus hypophyllus* Hook.f., and *Podocarpus* spp. which is semi-closed to closed canopy. Thicker mosses were observed mostly on trees and several species of *Lycopodium* spp. (*Ikog sa unggoy*), and orchids (*Appendicula maquilingensis* Ames, *Dendrochilum* spp.). Presence of *Nepenthes* sp. (pitcher plant), *Dawsonia superba* Grev. (giant moss), and *Medinilla* spp. were observed in the area with little to no anthropogenic disturbances (e.g., trail).

Bat sampling

Under the Wildlife Gratuitous Permit No. R10-2022-39 was issued by the Office of the Regional Executive Director of DENR, Malaybalay City, sampling was conducted between November 14-25, 2022. Mist nets with a length of 6 meters were used to sample bats and were placed at 1 to 1.5 meters above the ground (the lower portion of the net) along possible flyways, left open from 1800 H to 2200 H. The mist nets were checked regularly at least every half-hour interval to avoid pre-mature death due to strangling and bats escaping by chewing, particularly in mist nets. Then, the mist nets were checked every hour for the rest of the night up to the early morning (0500 H to 0530 H). The mist nets were then closed during the day to avoid trapping aves. One net night is equivalent to one 6-meter net open from dusk to early the next morning (Sedlock et al. 2008). Bats were carefully removed from the net and placed in a separate cloth bag, which was large enough for a bat to move freely and hang upside down. All captured bats were marked with indelible ink before release to avoid recounting. Recaptured bats were disregarded and released. Mist netting was done separately on each site, with 3-5 sampling days. Overall, the sampling effort accounted for a total of 150 net-nights across five sampling sites. The adequacy of sampling efforts was evaluated through the examination of a species accumulation curve (Figure 2). A plateau in the species accumulation curve signifies that the majority of bat species have been documented, and further sampling endeavors are unlikely to yield additional bat records.

Measurement and identification

Captured bats were identified up to the species level using the Key to the Bats of the Philippines by Ingle and Heaney (1992). The sex, age, reproductive condition, and biometrics such as body weight, length of forearm, hindfoot, ear, tail vent, and total length were recorded. Bat species identified and examined were marked using indelible ink on their wing membranes, after which they were released back into the forest. Representatives of each species were kept as vouchers for confirmation of their names in the Terrestrial and Freshwater Ecology Laboratory at the Premiere Research Institute of Science and Mathematics, Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines.

Determination of conservation status and endemicity

The species' conservation status and endemicity were determined using the most present database from the International Union for Conservation of Nature Red List version 2023-1 (IUCN 2023).

Data analysis

Relative Abundance (RA%) was computed by dividing the number of individuals captured for each species by the total number of individuals for all species multiplied by 100. The dominance and species diversity index of each sampling site was calculated using the PAleontological STatistics (PAST) software. Furthermore, the data were grouped into clusters and measured for resemblance (similarity) using PRIMER 7 software with 999 permutations in all cases at a significance level of 5%. Similarity matrices were constructed using the Bray-Curtis index in PRIMER 7 software. To minimize the bias of this index on species with the largest differences in abundance, a log+1 transformation was performed on capture rates prior to the construction of the similarity matrices (Avila-Cabadilla et al. 2012). While, Canonical Correspondence Analysis (CCA) using PAST software was done to determine the relationship between the different bat species in different habitat gradients. Lastly, Q-GIS software was used to map the species assemblages occurring in varying habitat gradients in the area based on the data on the captured population, the World Geodetic System (WGS) and the Environmental Systems Research Institute, Inc. (ESRI).

RESULTS AND DISCUSSION

Species composition and relative abundance

A total of 392 individuals representing six species, six genera, and two families were recorded in the five substations surveyed (Table 2, Figure 3). Of the six species, five belong to the family Pteropodidae (fruit bats), namely: Mindanao Pygmy fruit bat (*Alionycteris paucidentata* Kock 1969), Lesser Dog-faced fruit bat (*Cynopterus brachyotis* Müller 1838), Philippine Pygmy fruit bat (*Haplonycteris fischeri* Lawrence 1939), Dagger-toothed long-nosed fruit bat (*Macroglossus minimus* E.Geoffroy 1810), Greater Musky fruit bat (*Ptenochirus jagorii* Peters 1861), and one species under the family Verpertilionidae-the Wooly bat (*Kerivoula* sp.). The endemism of bat assemblage in the area scores 66.6%, with three Philippine endemic species and one Mindanao faunal region endemic. Endemic bat species are known to be highly sensitive to disturbances (Phelps et al. 2018).

The highest species composition was observed in Site 2 (*n*=5) at 1701 masl, while the remaining sites, Site 1a, Site 1b, Site 3 and Site 4 had the same number of species (*n*=4). These sites varied in elevations. In Site 3, one individual of *Kerivoula* sp. was captured. This species has a broad tolerance of vegetation types and elevations, from highly disturbed and fragmented lowland forest near sea level, to pristine montane forest at 1465 masl (Sedlock et al. 2008, 2014; Heaney et al. 2016).

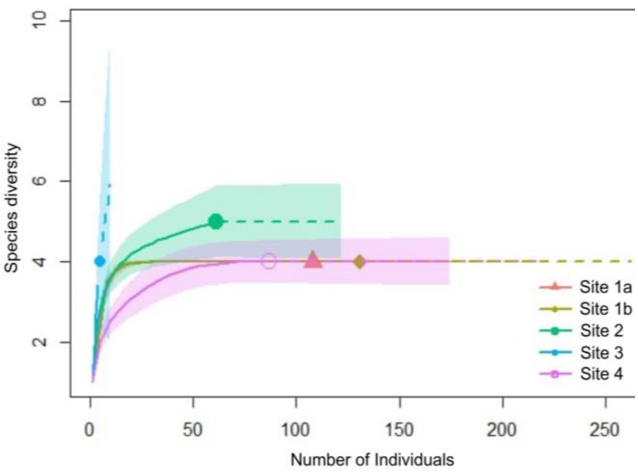

Figure 2. Species accumulation curve in five sampled sites

Table 2. Species composition, abundance, distribution and conservation status of Bats in Mt. Tuminungan, Bukidnon, Philippines

Taxa	IUCN Conserv. status (2023)	Distribution status	Sampling Sites										Total	(RA%)
			S1a	(RA%)	S1b	(RA%)	S2	(RA%)	S3	(RA%)	S4	(RA%)		
Pteropodidae														
Alionycteris paucidentata	LC	ME	-	(0.00)	-	(0.00)	5	(8.20)	1	(20.00)	3	(3.45)	9	(2.30)
Cynopterus brachyotis	LC	NE	19	(17.59)	33	(25.19)	10	(16.39)	1	(20.00)	-	(0.00)	63	(16.07)
Haplonycteris fischeri	LC	PE	23	(21.30)	30	(22.90)	24	(39.34)	2	(40.00)	64	(73.56)	143	(36.48)
Macroglossus minimus	LC	NE	17	(15.74)	21	(16.03)	1	(1.64)	-	(0.00)	3	(3.45)	42	(10.71)
Ptenochirus jagorii	LC	PE	49	(45.37)	47	(35.88)	21	(34.42)	-	(0.00)	17	(19.54)	134	(34.18)
Vespertilionidae														
Kerivoula sp.	LC	PE	-	(0.00)	-	(0.00)	-	(0.00)	1	(20.00)	-	(0.00)	1	(0.26)
Total			108	(27.55)	131	(33.42)	61	(15.56)	5	(1.28)	87	(22.19)	392	100

Note: S1a-MAE; S1b-FPA; S2 & S3-LMF; S4-LMMF; LC-Least Concern; NE-Non-Endemic; PE-Philippine Endemic; ME-Mindanao Endemic

Figure 3. The six species of bats recorded in Mt. Tuminungan, Bukidnon, Philippines, in which A. *Alionycteris paucidentata*; B. *Cynopterus brachyotis*; C. *Haplonycteris fischeri*; D. *Macroglossus minimus*; E. *Ptenochirus jagorii*; F. *Kerivoula* sp. Photos by J. M. Lama

Furthermore, the high species composition in the secondary montane forest (Sites 2, 3 and 4) as well as in the mixed agroecosystem (Sites 1a and 1b) might be influenced by the various food plants abundantly available in the sites. For example, the Philippine endemic *P. jagorii*, has a diverse fruiting tree on its diet. According to Heideman and Heaney (1989), their diet heavily includes figs (Moraceae: *Ficus* spp.) which are abundant in most sampling sites, fruits of at least one unidentified plant in the faimly Lauraceae; and cultivated or wild bananas (*Musa* spp.) which are observed to be present in Sites 1a and 1b. This species was apparently feeding also on the sweet coffee fruits (Heideman and Heaney 1989), which also explains its abundance in Site 1a and Site 1b where plantation of coffee (Rubiaceae: *C. arabica*) were established.

Relative abundance was found the highest at Site 1b (33.42%). This could be due to the variety of vegetation specifically indigenous tree species, fruiting trees, and coffee plantation found in the area. The site is composed of patches of secondary montane forest along an agroecosystem. The abundance of fruit bat in the area can be explained by the presence of wild banana trees (*Musa* spp.). Musaceae, irrespective of species, provide resources to fruit bats in the form of fruit and flower (Aziz et al. 2021). Additionally, a study by Phillipps and Phillipps (2016) have hypothesized that bats rely on wild bananas as a backup source of food during times of scarcity.

The most frequent netted species were *P. jagorii* and *H. fischeri*. However, in each sampling site, as the elevation and habitat gradient changes, there is a transition of the highest individuals caught. For instance, Sites 1a and 1b (1525-1641 masl) were dominated by *P. jagorii*. While from Site 2 to Site 4 (1701-1796 masl), which is a secondary montane forest transitioning to mossy forest, is dominated by *H. fischeri*. This species is known to be a high-altitude specialist, is common in primary forest, especially at middle elevations, and is rare in secondary forest (Deligero et al. 2016; Tanalgo et al. 2017). The observed decrease in population of *P. jagorii* as the elevation increases and transitioning habitat to a less disturbed areas contrasts the results of the study of Fidelino et al. (2020), which found that generalist bat species, like *P. jagorii*, do not show a distinct difference in abundance between habitat types, suggesting that it may not be appropriate to use it as metrics for restoration success in reforestation areas in the Philippines. Furthermore, the small fruit bat, *M. minimus*, may not be highly abundant but can be found present in all sampling sites, except in Site 3, as it also utilizes a wider range of habitats than any other fruit bat species in the Philippines, from urban orchards at sea level to mossy forests (Heaney et al. 1989; Mohagan et al. 2018).

The presence and abundance of *A. paucidentata* from Sites 2, 3, and 4 could be attributed to the elevation, low anthropogenic disturbance and vegetation of the sites consisting of secondary growth forest with unique flora compositions. Most records of this species are from primary montane mossy forests; it is also present in secondary and primary montane forests but absent in lowland forests (Heaney et al. 2006; Mildenstein 2016). This species is the most abundant bat in the mossy forest of MKRNP and has not been recorded below 1,500 masl, uncommon at 1,500-1900 masl and abundance at 2,250 masl and potentially higher (Heaney et al. 2006). Also, during the surveys on MKRNP, *A. paucidentata* always occurred with *H. fischeri* (Heaney et al. 2006). It was previously considered as Vulnerable in 1996 but was listed as Least Concern during the assessment in 2008. Although its extent of occurrence is probably less than 5,000 km², it is common, but only occurs in montane mossy forest habitat that is not significantly threatened, and does not appear to be in decline (Mildenstein 2016). With its rarity, this recent study provides a new record on the population size, distribution and extent of occurrence of the species inside MKRNP. Hence, strengthening the protection of the quality of habitat in the area is necessary to prevent the continuing population decline. The greater amount and wide variety of food resources in the area are probably a factor that makes it a favorable foraging site for the bats. The low number of insect bats captured in the area may be due to the lack of caves seen there and the usage of mist nets (Tanshi and Kingston 2021). Furthermore, insect bats may escape by cutting the nets with their sharp teeth when trapped or their sensory abilities allowing them to detect and avoid the nets (Jose et al. 2021). The areas also had differences in their elevation and vegetation, hence, bats being mobile can easily move from one area to another. The higher or lower number of individuals and number of bat species in the five sampling sites could be attributed to the availability of suitable places to forage and the presence of food available (e.g., fruit or insects) in the area. Species abundance however was found to be decreasing with increasing elevation. This corresponds to the observations in previous studies (Heaney et al. 1998; Coelho et al. 2018; Chakravarty et al. 2021), particularly that bats have a certain elevation range in which their activity peaks and then declines upon reaching a certain elevation point.

Diversity, similarity and distribution in different habitat gradient

A higher value of the Shannon-Weiner index indicates greater diversity. When the value of the computed diversity is 1-3, it represents moderate diversity; less than 1 indicates low diversity, and values greater than 3 indicates high diversity (Colwell 2009). All sampling sites have moderate bat species diversity except for Site 4, which has low diversity. Of the five sampling sites, Site 1b recorded the highest diversity index H'=1.346, while Site 4 had the lowest H'= 0.777 (Table 3). The Philippine Pygmy fruit bat (*H. fischeri*), being a high elevation specialist (Deligaro et al. 2016) dominated the population of bat in Site 4 (RA=73.56%). The absence of some species of bats influenced the overall diversity index value. Hence, the computed diversity index of sampling site 4 is low due to the presence of dominant species.

The differences in chiropteran diversity can be explained by the differences in their vegetation structures and elevation. The high diversity in Site 1b (FPA) might be attributed to the large variety of food available in the area ranging from agricultural crops such as *C. arabica*, wild *Musa* spp., forest fruits like *Ficus* spp. and *Pandanus* spp. In addition, this site has lower elevation compared to Sites 2, 3 and 4. The area also has numerous open areas and is near streams, which serve as pathways for bats when foraging. Native plant species of *Pandanus*, *Litsea*, *Ficus*, *Musa*, *Syzygium* and *Artocarpus* are known to be consumed by frugivorous and nectarivorous bats (Heaney et al. 2010; Aziz et al. 2021). There are many cases of declining diversity with increasing elevation among bats (Heaney et al. 1989; Patterson et al. 1996). According to a study by Bogoni et al. (2021), the latitudinal gradient was the main determinant of overall bat distribution, whereas elevation appears to apply an additional local filter to the regional pool wherever tropical mountains are present, thereby shaping the structure of montane bat assemblages. Consequently, all these add up to stable food resources, an assortment of niches and a foraging guild, thus supporting a diverse range of bats.

Furthermore, the findings of Bray-Curtis Similarity (Figure 4) revealed that Sites 1a and 1b had the highest similarity (97.92%), followed by Sites 2 and 4 (80.92%) and lowest similarity was observed between Sites 1b and 3 (30.51%). The abundance of *P. jagorii* contributed to the high similarity between Sites 1a and 1b (27.59%), whereas, for Sites 2 and 4, it was the *H. fischeri* (34.32%). These species are both endemic in the country, but one is a generalist and the latter is a high-elevation specialist which explains their abundance at the sites mentioned (Deligero et al. 2016). The *P. jagorii* is most common in lowland forest, uncommon in montane forest, and absent in mossy forest (Heaney et al. 1998), which explains it high abundance in Sites 1a and 1b. Whereas, the high abundance of *H. fischeri* in both Sites 2 and 4 could be attributed to their elevation, low anthropogenic disturbance and similar vegetation structure. In a study by Relox et al. (2014), *P. jagorii* and *H. fischeri* along with *P. minor* exhibited a high preference for *Ficus* species and made up the majority of the fruit dispersers, meaning these fruit bats are capable of dispersing seeds of different plant species that could help maintain the ecological balance and aid in forest regeneration in degraded habitats.

Table 3. Biodiversity indices recorded in Mt. Tuminungan, Bukidnon, Philippines

Sampling sites	Elevation (masl)	Habitat type	Net-nights	Richness (S)	Diversity (Shannon_H')	Evenness_$e^{H/S}$	Dominance_D
1a	1525	MAE	30	4	1.285	0.9034	0.3069
1b	1641	FPA	30	4	1.346	0.9606	0.2703
2	1701	LMF	30	5	1.303	0.7361	0.3072
3	1730	LMF	30	4	1.332	0.9473	0.28
4	1796	LMMF	30	4	0.777	0.5438	0.5817

Notes: MAE-Mixed Agroecosystem; FPA-Forest Patches along Agroecosystem; LMF-Lower Montane Forest; LMMF-Lower Montane to Mossy Forest.

In addition, the low similarity between Sites 1b and 3, was attributed to the differences between these sites in species and number of individuals captured and could also be influenced by the variation of each site in terms of vegetation, disturbance, elevation and canopy cover. For example, the *H. fischeri* favors a forest where canopy cover is dense and tree height decreases with increasing elevation (Heaney et al. 1998). This may confirm that differences in vegetation and disturbance affect the number and abundance of species in a specific area.

This study also visualized the spatial habitat preference of bats on Mt. Tuminungan, Bukidnon, Philippines. Results based on mist netting indicated that streams, forested areas, edge habitats, and patches of tree cover are important areas for bats in a typical Philippine forest landscape. Although bat activity was high along FPA areas, a notable number of bats were still present at different habitat types. Bat activity between forest and agroecosystem habitats was higher than in a more forested area. This might be due to the variety of food available in-and-between these sites, ranging from native fruit trees, plantations and favorable habitats for the entomological population.

Figure 5 shows the distribution pattern of bats in each sampling sites in Mt. Tuminungan, Bukidnon. The results demonstrated that areas near streams, intact secondary montane forest and higher elevations harbors rare species of bat, like the *A. paucidentata*. While other species like *C. brachyotis* and *H. fischeri* occurs in different land use types, despite the high differences in biological or environmental factors and anthropogenic disturbances. This behavior demonstrates that even agriculturally converted landscapes are important refuges for wildlife.

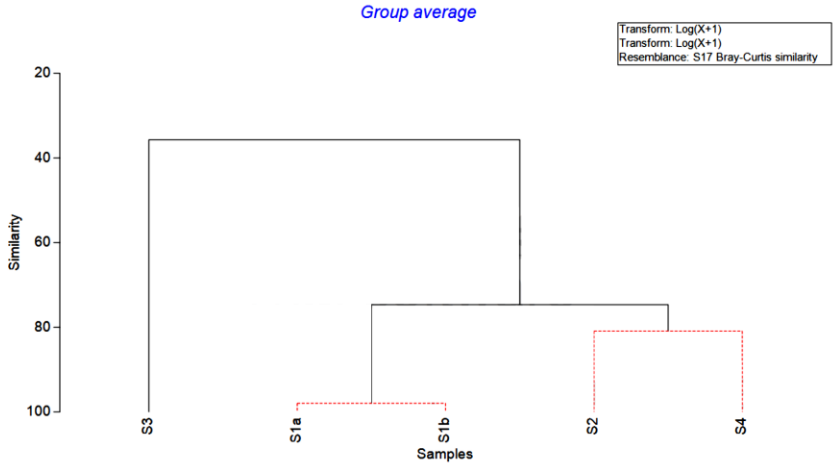

Figure 4. Bray-Curtis Similarity of bat species in 5 sampled sites

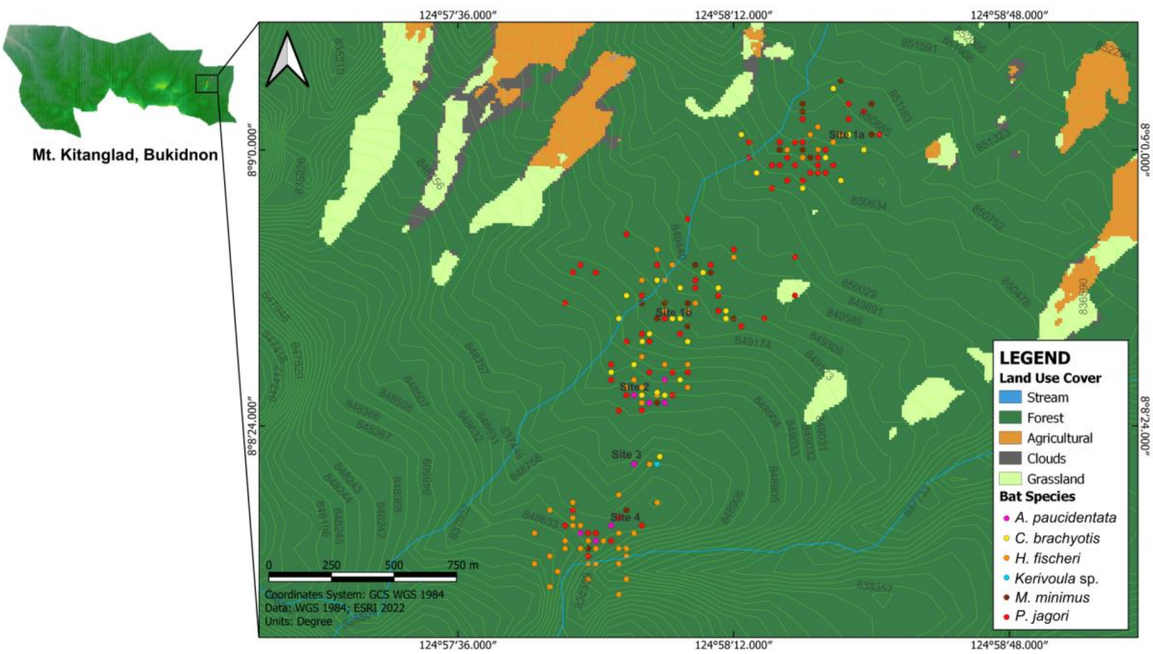

Figure 5. Map showing the bat species richness patterns in Mt. Tuminungan, Bukidnon, Philippines and its complex relationship with different land use types

Figure 6 shows the ordination diagram, which provides a graphical display of the possible relationship among bat species and habitat gradients as well as topography-related variables such as elevation, vegetation and geographical characteristics. This was based upon the given period of sampling duration. Using the two axes of the Canonical Correspondence Analysis (CCA), a bi-plot visualization shows the distribution of species within the four identified habitat gradients in five sampling sites on Mt. Tuminungan. The test for F1 and F2 axis was not statistically significant at p=0.56 and p=0.684, respectively. The first two CCAs accounted for 77.17 and 19.47% variation in taxon composition.

Based on CCA, the bat assemblages were strongly influenced by elevation, distance from the water body, and vegetation present in the area, specifically the presence of fruit trees from the families Moraceae, Musaceae and Pandanaceae. Bats like the *C. brachyotis*, *P. jagorii* and *M. minimus* are strongly correlated with MAE and FPA because these species are generalist and have the ability to thrive even in disturbed areas (Heaney et al. 2010). While forest-dependent species like the *H. fischeri* prefer a high-elevated, montane habitats (LMMF). Elevation affects species richness such that with increasing elevation, species richness declines steadily (Linden et al. 2014). Except for a few species, most of the bat species were recorded within their known specific elevation ranges (Heaney et al. 1989). In a study by Monadjem et al. (2023), there was a continent-wide pattern of rapid decline in bat species richness above 1000 meters above sea level in Africa. The results in this study is similar to distributional studies conducted in other areas, like in Afrotopical mountains (Linden et al. 2014; Herkt et al. 2016; Katunzi et al. 2021; Vogeler et al. 2022) South America (Patterson et al. 1996; Lim and Lee 2018), Papua New Guinea (Sivault et al. 2022), and in the Philippines (Heaney et al. 1989; Nuñeza et al. 2015; Deligero et al. 2016; Heaney et al. 2016). While the number of bats did not differ significantly between the habitat types, there was a higher proportion of bat species in the disturbed habitat than in the undisturbed habitat. This can probably be explained by the presence of forest tree species and fruiting tree species planted by humans. Between 50-90% of tropical trees and shrubs produce fleshy fruitsadapted for vertebrate consumption (Wandrag et al. 2017). Additionally, research indicates that lower intensity agricultural systems—organic farming and shaded agroforestry in particular-benefit bat populations (Park 2015). These systems are linked to increased bat abundance, species richness, and variety, and are more frequently used by foraging bats. However, bats show highly variable responses to habitat conversion, with no significant change in species richness or measures of activity or abundance (Williams-Guillén et al. 2016; de Oliveira et al. 2017). In contrast, intensification within agricultural systems had more significant negative effects on abundance and species richness (Cleary et al. 2016). Whereas, organic farming and shaded agroforestry appear to mitigate the negative consequences of habitat conversion and intensification, often having higher abundances and activity levels than natural areas (Williams-Guillén et al. 2016).

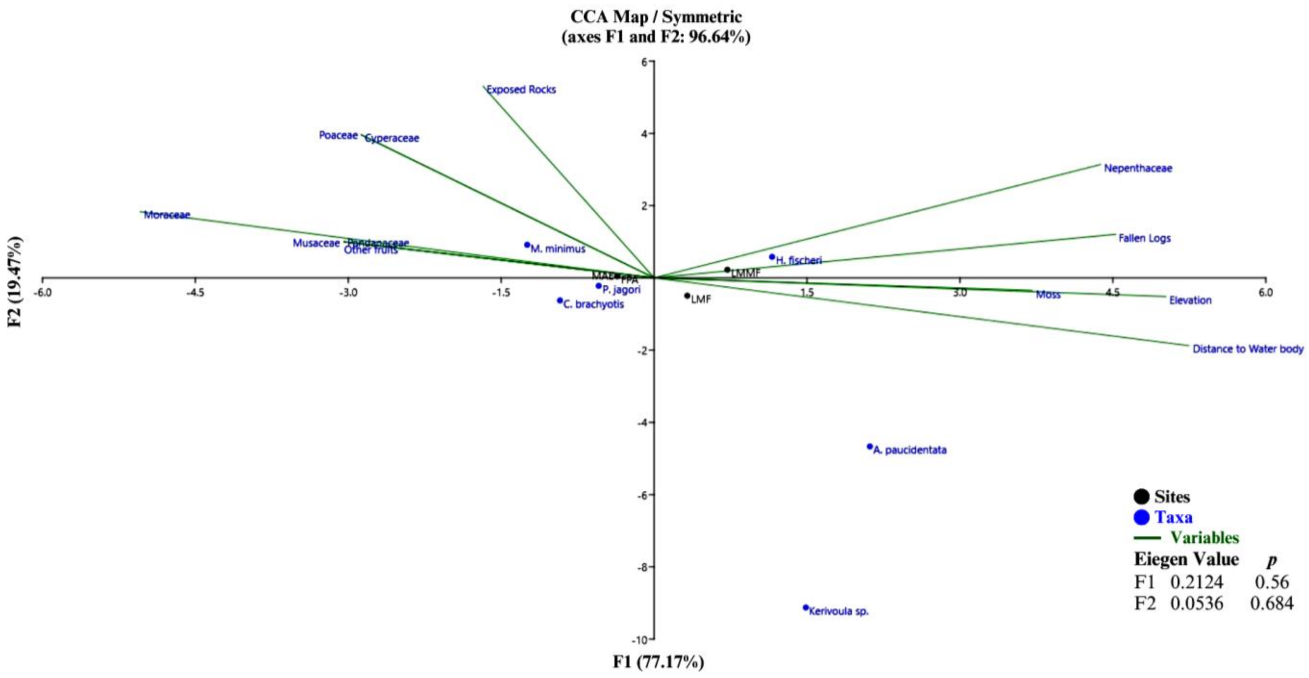

Figure 6. Ordination diagram of bat species distribution and its possible correlation to different habitat gradient and environmental variables in Mt. Tuminungan, Bukidnon, Philippines. Environmental variables are visualized as green arrows. The arrows point in the direction where the environmental variable has its highest values in the habitat gradient. The lengths of the arrows are proportional to their importance in explaining the variation in the species composition

Oftentimes, natural disturbances occurring in forest ecosystems increase habitat heterogeneity, which leads to an increase in species richness in various taxa, including bats (Regnery et al. 2013; Piksa et al. 2022). In contrast, anthropogenic disturbances are often chronic, causing a relatively weak but continuous impact that may strongly affect species richness and composition, functional diversity, ecological processes, and ecosystem services (Leal et al. 2014; Ribeiro et al. 2015, 2016). Consequently, the planted fruiting trees, along with the existing forest trees in sampling sites 1a and 1b, influenced the occurrence of a high number of bat species, which also led to an increase in the feeding activity of bats, especially those hunting in open spaces (Froidevaux et al. 2022). In this study, one fruit bat (*Alionycteris paucidentata* Kock 1969) and one insect bat species (*Kerivoula* sp.) showed weak or no correlation with the examined. This is possibly due to the limited number of samples collected, which limits the ability to correctly assess their preferences. Moreover, weather conditions may also affect the richness of bat species in disturbed areas. According to McCain (2007), the harsher weather conditions occurring at higher elevations are an important factor limiting the presence of bats. There is rising evidence that weather conditions are increasing globally, which threatens the terrestrial flora and fauna (IPCC 2018), and identifying the most at-risk populations is vital since such occurrences can have a catastrophic impact on small populations, especially for species with poor reproductive and population growth rates, like bats (Festa et al. 2023). Müller et al. (2012) found that temperature and wind speed were more variable in tree stands compared to forest edges and open areas. BakwoFils et al. (2021) suggested that insectivorous bats in less disturbed habitats may exhibit different echolocation call behaviors, potentially due to the varying environmental conditions. On the other hand, species that utilize low-intensity, high-frequency echolocation sounds with low wing loadings are suitable for feeding and commuting in crowded environments close to vegetation (Law et al. 2011). As a result, increased anthropogenic disturbances can drastically diminish resource availability for these species (Threlfall et al. 2012), and sensitive and tolerant species differ in the type, frequency, and bandwidth of echolocation calls and roost use. For instance, species that are sensitive to coffee use broadband and high-pitched frequency-modulated calls, which are efficient at detecting insects in complex vegetation, and roost in plant structures that may be lost as vegetation is simplified. In contrast, tolerant species used lower-pitched constant-frequency calls and roosts in caves (Huang et al. 2019). Although disturbed vegetation promotes a higher diversity of bats, the transition from pristine forests to human-dominated landscapes may harm forest specialists who are sensitive to human disturbances. Understanding species' habitat needs and how human-caused disturbance affects the pattern of species diversity and abundance is critical in determining the degree of sensitivity to fragmentation and local extinction risk, which may be required for developing effective species-specific conservation strategies.

In conclusion, the observed bat assemblages across different habitat gradients in Mt. Tuminungan are influenced by elevation, vegetation, and geographical characteristics, which play crucial roles in the diversity and distribution of bats in specific habitat gradients. The availability of food, water, and suitable roosting sites also influenced the pattern of bat diversity. Ecological generalist species are likely to adapt to environmental changes, whereas forest-dependent specialists that prefer high-elevation montane forests are more susceptible to threats from ongoing climate change and habitat degradation. Thus, studies on the interactions between bats and environmental parameters are important to understand the ecological processes shaping bat diversity, which is also crucial for the effective formulation of conservation and management strategies for mountain ecosystems.

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