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Bats of Mount Silabur, Sarawak, and Its Potential for Conservation

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ABSTRACT

Karst landscape is recognised as one of the biologically important areas especially for bats. The limestone caves and forest within the landscape provide essential resources for the local bat fauna, albeit bat populations are severely threatened by anthropogenic disturbances occurring within and surrounding the ecosystem. In Sarawak, studies on bat diversity are biased towards protected areas, leaving aside non-protected areas including private lands such as Mount Silabur. Surveys on bat diversity were conducted at the limestone outcrop and the surrounding matrix of Mount Silabur with the primary aim of developing the first checklist of bats at Mount Silabur. A total of 27 species were recorded from 12 sampling nights representing approximately 34% of the total bat species recorded in Sarawak. The Cox's Roundleaf Bat (*Hipposideros coxi*), a rare Bornean endemic species, was recorded from the cave system, signifying an important record for the area and also Sarawak. Furthermore, this is the sixth locality record for the species in Sarawak, Borneo. Interestingly, the total number of bat species recorded from Mount Silabur represented about 72% of the total bat species recorded (27 out of 38 species) from other major touristic caves in western Sarawak; Fairy Cave Nature Reserve and Wind Cave Nature Reserve. This warrants a need to develop an action plan to protect and conserve Mount Silabur cave system and the surrounding forest for its potential to serve as a shelter for bats and other cave and forest dependent taxa. The local community should implement and adhere to guidelines for cave related activities to minimise human driven disturbances on the ecosystem and its inhabitants.

Keywords: Conservation, endemic, nature reserve, private land, species diversity, threatened

INTRODUCTION

In Southeast Asia, limestone karst is a prominent feature and area of biological importance, covering over 40 million hectares, but only about 13% is nominally protected (Day & Urich, 2000; Wong *et al*., 2003; Gillieson, 2005; Struebig *et al*., 2009). Karst landscape provide important roosting resources for bat population and the availability and distribution of the cave systems greatly influence the local bat fauna (Struebig *et al.*, 2009).

Limestone karst have always been one of the main interests for bat research in Borneo. Situated in western Sarawak, Wind Cave and Fairy Cave which is part of the Bau Limestone massif, provide important roosting resources for bats, making it one of the main sites for bat conservation (Mohd-Azlan *et al.*, 2005). Bats utilize myriads of structures for roost (Kunz & Pierson, 1994; Francis, 2008), hence the surrounding matrix of limestone karst is as important to maintain viable bat population.

Bats are highly diverse with over 1400 described species worldwide (Burgin *et al.*, 2018; Senawi *et al.*, 2020). However, many bat species are subject to threats. Over a third of bats are either threatened or listed as Data Deficient on the IUCN Red List, and over half of the species ranked with either unknown or decreasing population trends (Frick *et al.*, 2019). Overall, bat populations are severely threatened by habitat loss and logging (Jayaraj *et al.*, 2011; Kingston *et al.*, 2012). If prolonged, cave disturbance will

lead to negative impacts on bats especially cave-roosting species. Likewise, land clearing and fires around the caves, quarrying of limestones, and guano extraction and edible swiftlet nests harvesting are significant threats to the cave bat colonies (Struebig *et al.*, 2010). Forest-roosting bats show more immediate responses to forest disturbance as it affects both roost availability and their foraging success (Kingston, 2013). Therefore, protected area is essential for conserving and managing flora and fauna, maintaining natural ecosystems' functioning, acting as refuges for species, and maintaining ecological processes (Dudley, 2008; Naharuddin *et al*., 2015).

A large number of protected areas are established in attempt to conserve biodiversity hotspots (Gray *et al.*, 2016), and research efforts mostly focused on the protected areas, undermining the values of non-protected areas (Avigliano *et al.*, 2019). In Malaysia, Sarawak has 13 national parks, eight nature reserves, and five wildlife sanctuaries (Sarawak Forestry Corporation, 2022). Most studies on bat diversity in Sarawak focuses on protected areas. Protected areas historically consist of public land or a combination of both public and private lands. A large proportion of private land forest remain unprotected. These unprotected areas often assumed to have less diversity because of the continuous pressure from human led disturbances (McCune *et al.*, 2017). In Sarawak, these disturbances are associated with cultural practices and economic development. However, species diversity in private land is comparable, if not higher than protected areas (Rayner *et al*., 2014). For example, most Old World bat species from the family Pteropodidae are generalist that can be found in various habitats, including non-protected and heavily modified areas such as oil palm plantation (Kumaran *et al*., 2011; Mohd-Azlan *et al.*, 2019). Therefore, it is essential to survey non-protected areas to better understand patterns of global biodiversity, their response to human driven disturbances, and also to develop appropriate conservation management to allow long-term sustainable developments (Avigliano *et al.*, 2019).

The karst system and the surrounding matrix of Mount Silabur is a private land managed by local community. It is also one of the potential nature tourism sites managed by local community recognised by the Ministry of Tourism, Arts, and Culture of Sarawak. Although Mount Silabur offer various kinds of nature-based activities, it is not until recently that the site gained popularity among visitors.

The site's attraction derived primarily from the limestone karst landscape that can offer visitors various outdoor activities including cave exploration and hiking experiences while appreciating the plethora of biodiversity including cave inhabitants. Nevertheless, natural history information for Mount Silabur is still lacking. Previously, Khalik *et al.* (2020) had done a study on morphological parallelism of sympatric cave-dwelling microsnails at Mount Silabur. Interestingly, their study showed a degree of parallelism of a third, possibly new, cryptic *Georissa* species, diverged from its above-ground sister species, *Georissa pyrrhoderma.* This is one of the many examples of the importance of biodiversity surveys in providing valuable information that will help inform the locals on the value of their land, subsequently promoting the protection and preservation of the unique biodiversity of Mount Silabur and the surrounding landscape.

The continuous loss of forest landscape in Borneo has seen an increase in research interests on the values of secondary and regenerated forest as a potential sink for local biodiversity recovery (Senawi *et al.*, 2020). The heterogeneous landscape of Mount Silabur may provide essential roosting sites and foraging ground to support viable bat population. To assess the potential of Mount Silabur as one of the sites for bat conservation in western Sarawak, bat surveys have been conducted to document bat diversity as part of an initial step in developing a management and conservation framework for the area. Two bat surveys were conducted at Mount Silabur in 2019. The result from this study was compared to two protected caves within Bau Limestone massif in western Sarawak, Fairy Cave Nature Reserve and Wind Cave Nature Reserve. The results from this study provided insights on the bat community

and highlighted the potential of Mount Silabur and the surrounding matrix for the bat community in the area.

MATERIALS AND METHODS

Study Sites

Bat surveys were conducted at Mount Silabur (N 00°57.291′ E 110°30.223′) in Sarawak, Borneo, The map of the location was constructed using QGIS version 3.4 (Figure 1). It is located at Kampung Lobang Batu, Serian, on the eastern part of Kuching, which is about 90 km from the city center. The cave at Mount Silabur is about 40 to 50 minutes-walk away from Kampung Mawang. The average temperature in the surrounding forest during the survey period was 24 °C with 98% relative humidity (RH). Bat survey was conducted on the trail heading towards the main cave entrance at the hilltop, and Siturip Cave at the foothill. The heterogenous landscape surrounding Mount Silabur consists of a secondary forest, paddy field, oil palm and bamboo forest (Figure 2).

Field Methods and Samples Processing

Surveys were conducted in two phases. The first was carried out from 5th January 2019 until 11th January 2019, while the second survey was from 26th October 2019 until 31st October 2019. A total of 20 mist nets and four four-bank harp traps were deployed at two sites for each survey: 1) Mount Silabur Cave trail, and 2) Siturip Cave trail. Mist nets were set randomly along narrow pathways, trails, cleared areas, and forest edges (Khan *et al.*, 2007), including at cave entrances (approximately 100 m from the entrance) (Figure 3). Deployed mist nets and harp traps were checked every 15-20 minutes, from 1830 hours to 2200 hours. Harp traps were kept open until the following morning and checked again at 0630 hours and closed during heavy rain.

Bats Identification

Captured bats were identified following Payne *et al.* (1985) and Phillipps and Phillipps (2018). The forearm length (FA), hindfoot (HF), ear length (E), tibia (TB), tail (TV), weight (WT), and sex were recorded for each captured individual. Bats were photographed using CANON EOS Rebel T5 for reference.

Echolocation

Echolocation calls were recorded either using Petterson M500 USB Ultrasound Microphone, EM3+ Bat Detector or Echo Meter Touch 2 Pro Android (Wildlife Acoustic Inc, USA). Bats were released after echolocation calls were recorded. Echolocation calls were used to assist species identification of insectivorous bats. Only clearly defined calls with good quality were analysed. Call recordings were in WAV files and analyzed by using Kaleidoscope Pro Software V4.5.5 (Wildlife Acoustic, Inc. Massachussets, USA). Five call parameters were taken into accounts: Peak frequency (Fppeak), Start frequency (Fstart), End frequency (Fend), Pulse duration (PD), and Interpulse interval (IPI). Echolocation calls from family Hipposideridae, Rhinolophidae, and *Myotis* sp. from the family Vespertilionidae were recorded in a flight tent, while release calls were recorded for *Tylonycteris pachypus*, *Glischropus tylopus,* and *Emballonura alecto*.

Data Analysis

Species richness was calculated using the combined number of bat species caught from both sampling period. The relative abundance was calculated by the total number of individuals per species over the total number of individuals sampled. Further comparison was done between species recorded from Mount Silabur with species found from localities with similar vegetation and landscape in western Sarawak, namely Wind Cave Nature Reserve (hereafter "WCNR") reported by Hall *et al.* (2001), Jub *et al.* (2003), Karim *et al.* (2004), Mohd Azlan *et al.* (2005); Pathe *et al.* (2005), Mohd-Ridwan *et al*. (2011), Rosli *et al.* (2014), and Morni *et al.* (2018), and; Fairy Cave Nature Reserve (hereafter "FCNR") reported by Mohd Azlan *et al.* (2005) and Rajasegaran *et al*. (2018) (Table 1). Rarefaction curve was constructed using PAST 3.22 software and species richness was plotted as a function of the accumulated number of individuals (Gotelli & Colwell, 2001) with 95% confidence intervals.

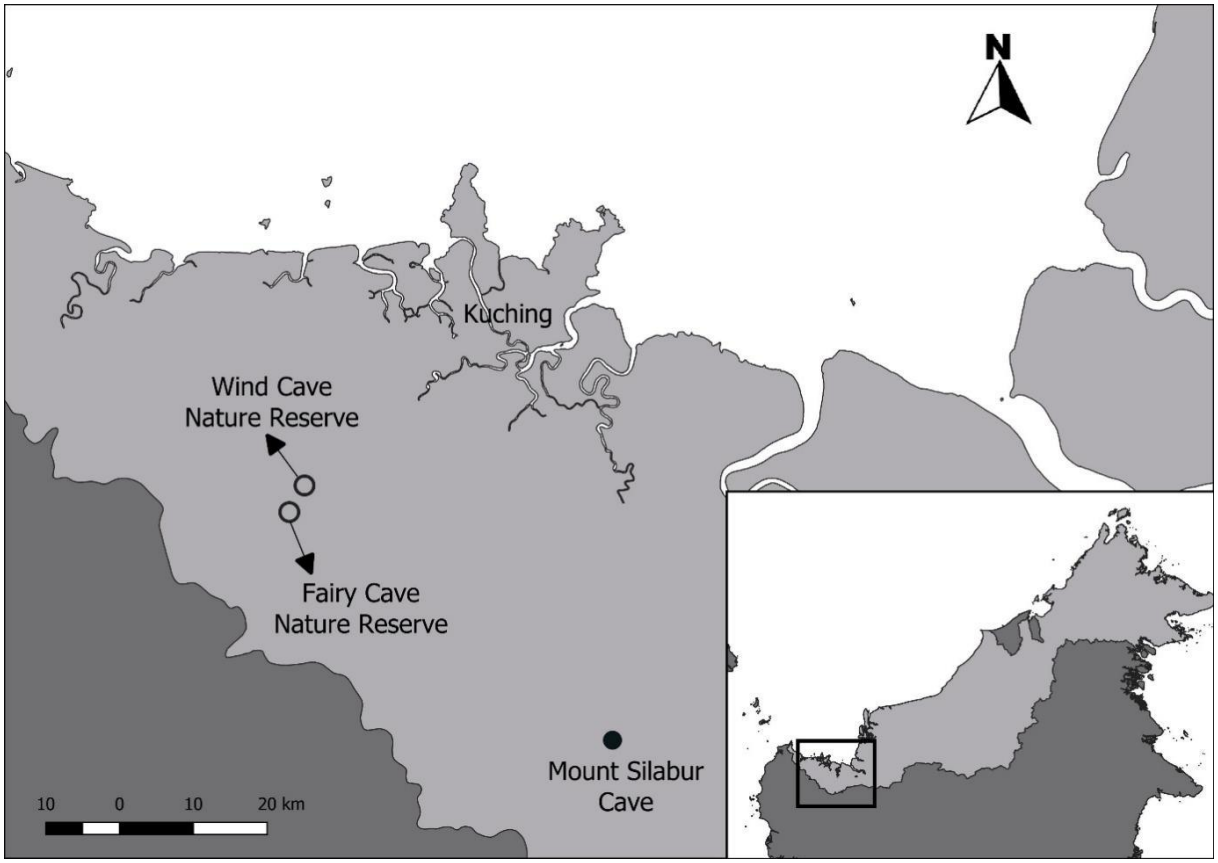

Figure 1. Maps showing the location of Mount Silabur Cave, marked with a black dot, and two nature reserves (Wind Cave Nature Reserve and Fairy Cave Nature Reserve) to compare with on the Western part of Sarawak (Maps were prepared using QGIS version 3.4.2.)

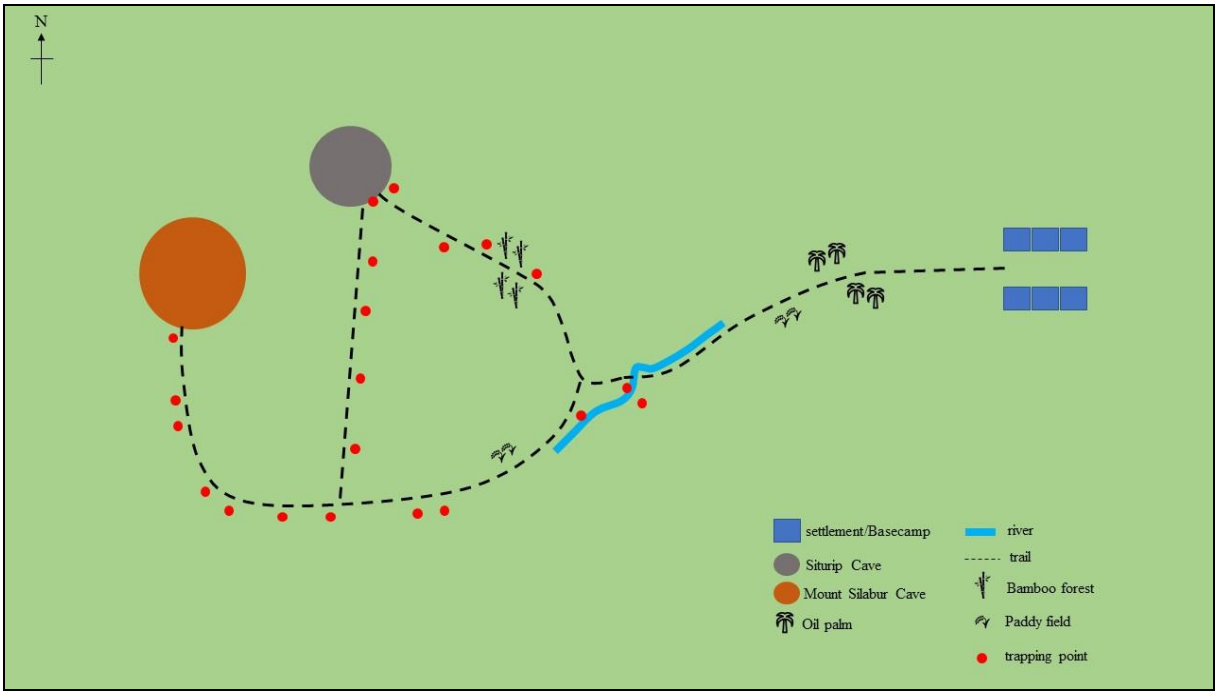

Figure 2. Illustration of sampling transect and trails within Mount Silabur vicinity

Figure 3. Mist nets deployed at Siturip Cave entrance

Table 1. List of bat species recorded in Mount Silabur Cave forest (MSC), Wind Cave Nature Reserve (WCNR) and Fairy Cave Nature Reserve (FCNR). Species captured from Mount Silabur Cave forest marked with '*'

Species	Common name	Number of Individuals				IUCN STATUS (2022)	Population trend	Wildlife Protection Ordinance
		MSC (Both surveys)		WCNR	FCNR			
Family Hipposideridae		1st survey	2nd survey					
*Hipposideros ater**	Dusky Roundleaf Bat	3	1	+	+	LC	Unknown	P
*Hipposideros bicolor**	Bicolored Roundleaf Bat	3	0	+	+	LC	Stable	P
*Hipposideros cervinus**	Fawn Roundleaf Bat	13	8	+	+	LC	Unknown	P
Hipposideros cineraceus	Ashy Roundleaf Bat	0	0	+		LC	Unknown	P
*Hipposideros coxi**	Cox's Roundleaf Bat	1	0	+	+	EN	Decreasing	P
*Hipposideros diadema**	Diadem Roundleaf Bat	1	2	+	+	LC	Unknown	P
*Hipposideros dyacorum**	Dayak Roundleaf Bat	0	2	+	+	LC	Unknown	P
*Hipposideros galeritus**	Cantor's Roundleaf Bat	6	26	+	+	LC	Unknown	P
*Hipposideros larvatus**	Intermediate Roundleaf Bat	4	2	+	+	LC	Unknown	P
Hipposideros ridleyi	Ridley's Roundleaf Bat	0	0	+		VU	Decreasing	P
Family Rhinolophidae								
*Rhinolophus affinis**	Intermediate Horseshoe Bat	6	13	+		LC	Stable	P
Rhinolophus cf. *proconsulis*	Arcuate Horseshoe Bat	0	0	+		DD	Stable	P
*Rhinolophus borneensis**	Bornean Horseshoe Bat	3	4	+	+	LC	Unknown	P
*Rhinolophus luctus**	Great Woolly Horseshoe Bat	2	1	+	+	LC	Unknown	P
Rhinolophus sedulus	Lesser Woolly Horseshoe Bat	0	0	+	+	NT	Decreasing	P
*Rhinolophus philippinensis**	Large-eared Horseshoe Bat	0	1			LC	Unknown	P

Table 1. Continued

Family Emballonuridae								
*Emballonura alecto**	Greater Sheath-tailed Bat	5	8	+		LC	Decreasing	P
*Emballonura monticola**	Lesser Sheath-tailed Bat	2	0		+	LC	Decreasing	P
Family Vespertilionidae								
*Glischropus tylopus**	Thick-thumbed Pipistrelle	2	0	+		LC	Unknown	P
*Kerivoula hardwickii**	Hardwicke's Woolly Bat	1	0			LC	Stable	P
*Kerivoula intermedia**	Small Woolly Bat	3	0	+	+	NT	Decreasing	P
*Kerivoula papillosa**	Papillose Woolly Bat	6	0			LC	Unknown	P
Kerivoula pellucida	Clear-winged Woolly Bat	0	0	+	+	NT	Decreasing	P
*Murina suilla**	Brown Tube-nosed Bat	1	0			LC	Unknown	P
Myotis ater	Black Myotis	0	0	+		LC	Unknown	P
*Myotis borneoensis**	Bornean Whiskered Myotis	1	0	+		DD	Unknown	P
Myotis hasseltii	Lesser large-footed Myotis	0	0	+	+	LC	Unknown	P
*Myotis horsfieldii**	Horsfield's Myotis	1	3	+		LC	Stable	P
Myotis muricola	Whiskered Myotis	0	0	+	+	LC	Stable	P
Myotis ridleyi	Ridley's Myotis	0	0	+	+	NT	Decreasing	P
*Tylonycteris pachypus**	Lesser Bamboo Bat	2	2	+		LC	Unknown	P
Tylonycteris robustula	Greater Bamboo Bat	0	0	+		LC	Unknown	P
Family Nycteridae								
*Nycteris tragata**	Malayan Slit-faced Bat	1	0	+		NT	Decreasing	P
Family Megadermatidae								
Megaderma spasma	Lesser False Vampire	0	0	+		LC	Unknown	P
Family Pteropodidae								
*Cynopterus brachyotis**	Short-nosed Fruit Bat	2	1	+		LC	Unknown	P
Cynopterus horsfieldii	Horsfield's Fruit Bat	0	0	+	+	LC	Unknown	P
*Balionycteris maculata**	Spotted-winged Fruit Bat	10	15	+	+	LC	Unknown	P
*Eonycteris spelaea**	Cave Nectar Bat	0	8	+	+	LC	Unknown	P
Macroglossus minimus	Long-tongued Nectar Bat	0	0	+	+	LC	Stable	P
*Penthetor lucasi**	Dusky Fruit Bat	8	3	+	+	LC	Decreasing	P
Rousettus amplexicaudatus	Geoffroy's Rousette	0	0	+	+	LC	Unknown	P
Family Mollosidae								
Cheiromeles torquatus	Greater Naked Bat	0	0	+		LC	Unknown	TP
Total of species		**27**		**37**	**23**			
Total of family		**6**		**8**	**4**			

Notes: + = presence, MSC= Mount Silabur Cave forest, WCNR= Wind Cave Nature Reserve, FCNR= Fairy Cave Nature Reserve, DD= Data Deficiency, EN= Endangered, LC= Least Concern, NT= Near Threatened, P=Protected, TP= Totally Protected

RESULTS

Species List and Abundance

Sampling efforts for a total of 12 trapping nights resulted in 27 species representing six families. A total of 24 species from the first survey and 17 species from the second survey were recorded (Table 1). The results documented 27.27% of the total 99 species of bats known from Borneo (Phillipps & Phillipps, 2018). For the first survey, three species were fruit-eating bats from the family Pteropodidae, namely *Penthetor lucasi*, *Cynopterus brachyotis,* and *Balionycteris maculata.* Meanwhile, the second survey recorded an additional species of pteropodid, *Eonycteris spelaea*. The other 23 species were insectivorous bats (85.19% of total species captured) that represent five families (Hipposideridae, Rhinolophidae, Emballonuridae, Vespertilionidae, and Nycteridae). Family Vespertilionidae has the greatest number of species captured (8 species). *Hipposideros cervinus* was the most abundant species during the first survey (N= 13), while *H. galeritus* was the most abundant species captured during the second survey (N= 26). Six species were captured as singleton: *H. coxi*, *Kerivoula hardwickii*, *Myotis borneoensis*, *Murina suilla*, *Nycteris tragata and Rhinolophus. philippinensis*. The accumulation curves for each sampling have yet to reach asymptote (Figure 4).

Comparison of Species Diversity

Results from this survey was compared with results from WCNR, and FCNR (Table 1). Bats survey in Mount Silabur represents more than half (71.05%) of the total number of bat species recorded from WCNR and FCNR. Four species recorded in Mount Silabur were not reported for both WCNR and FCNR, namely, *K. papillosa, K. hardwickii, M. suilla* and *R. philippinensis.*

A total of 15 species known from either WCNR or FCNR were not recorded from Mount Silabur Cave forest: *Cheiromeles torquatus*, *C. horsfieldii*, *H. cineraceus*, *H. ridleyi*, *K. pellucida*, *Macroglossus minimus*, *Megaderma spasma*, *M. ater*, *M. ridleyi*, *M. hasseltii*, *M. muricola*, *R.* cf. *proconsulis*, *R. sedulus*, *Rousettus amplexicaudatus* and *Tylonycteris robustula*. Rarefaction curve (Figure 5) showed that Mount Silabur have higher species richness compared to a single study from WCNR by Mohd-Ridwan *et al.* (2011) and FCNR by Mohd-Azlan *et al.* (2005).

Species Highlights and New Distributional Records

Hipposideros coxi is listed as endangered (EN) with decreasing population trend in the IUCN Red List (2022). This study has included Siturip Cave as an additional locality for this species in Sarawak. Additionally, *K. intermedia* and *N. tragata* listed as Near Threatened (NT) while *M. borneoensis* is listed as Data Deficiency (DD) by IUCN Red list (2022). *Rhinolophus philippinensis* which is rarely captured bat species from Western Sarawak was also recorded from Mount Silabur. These records were described as follows:

***Hipposideros coxi* (Shelford,1901)**
Figure 6(a)
Materials examined. SARAWAK: 1 adult ♂; Serian, Kampung Lobang Batu, Siturip Cave; 10th January 2019; MZU/M/7457; Caught using harp trap inside Mount Siturip Cave.
Identification. Forearm 55.15 mm**.** This species is easily recognised as it has different noseleaf structure that is larger as compared to *H. cervinus* and *H. galeritus*. The noseleaf completely covered the nostril. The internarial septum is ridged swollen, median noseleaf is raised, and posterior noseleaf is large and expanded upwards.

***Kerivoula intermedia* (Hill and Francis, 1984)**
Figure 6(b)
Materials examined. SARAWAK: 1 adult ♂; Serian, Kampung Lobang Batu; 5 January 2019; MZU/M/7048; Caught using harp trap set across a forest trail.
Identification. Forearm between 32.11 mm. Ears are small. Upperparts is orange-brown with dark bases and the underparts is paler. Compared to *K. minuta*, the forearm is overlapping but body size is larger**.** *Kerivoula pellucida* has pale fur with whitish bases and longer ears. Meanwhile, *K. hardwickii* also has longer ears, larger in size, and greyer fur with dark bases.

***Myotis borneoensis* (Hill & Francis, 1984)**
Figure 6(c)
Materials examined. SARAWAK: 1 adult ♀; Serian, Kampung Lobang Batu; 5 January 2019; MZU/M/7455; Caught using harp trap set across a forest trail.
Identification. Forearm 41.87 mm. Upperparts is rather long or dense fur with blackish brown bases and dark brown tips. Ears are long and narrow, with long tragus that reaches half of the ear and bend slightly forward. It is almost similar with *M. ater*, but has slightly shorter forearm and smaller body, tooth and skull.

***Nycteris tragata* (K. Andersen, 1912)**
Figure 6(d)
Materials examined. SARAWAK: 2 adults ♂; Serian, Kampung Lobang Batu; 7 January 2019, 11 January 2019; MZU/M/7491, MZU/M/7480; Caught using mist net set across a forest trail.
Identification. Both with forearms 48 mm. The fur colour is uniformly dark brown or reddish. Its noseleaf has parallel skin flaps on both sides a depressed groove that extends from the nose to between the eyes. It has long, rounder ears and not joined at base while its tail is long with a 'Y' shaped tip.

***Rhinolophus philippinensis* (Waterhouse, 1843)**
Figure 6(e)
Materials examined. SARAWAK: 1 sub-adult ♀; Serian, Kampung Lobang Batu; 30 October 2019; SC19-052; Caught using mist net set close to Siturip Cave entrance.
Identification. Forearm is between 48 mm. It has very large ears. Posterior noseleaf is long and triangular; long and protruding sella that expanded at base between nostrils. The fur is dark grey-brown but this specimen has orange-brown fur. This species is easily identified among other Rhinolophidae and *R. luctus* is the closest except that it lacks a cup-like base and less protruding sella.

Echolocation Calls

Table 2 shows that calls of identified species that were taken for references. Echolocation call recordings from 12 out of 23 insectivorous bats were analyzed by measuring the range of five parameters. The calculated mean and standard deviation for these parameters are shown in Table 2.

Family Hipposideridae uses Constant Frequency (CF) call type and Frequency Modulated (FM) call type in their call structure (Figure 7(a)). Only four species were recorded from this family, with Fppeak frequency ranging from 65.26 kHz (*H. diadema*) to 126.60 kHz (*H. cervinus*). Unfortunately, the call of *H. coxi* was not taken. Family Rhinolophidae also uses a similar combination of FM-CF-FM call type and has longer call durations than Hipposideridae (Figure 7(b)). Member of family Emballonuridae uses Quasy Constant Frequency (QCF) with energy focused on narrow bandwidth. Vespertilionidae produces FM-type calls and calls from three species were successfully recorded calls (Figure 7(c)). Vespertilionid bats have shorter call duration compared to family Hipposideridae and Rhinolophidae.

DISCUSSION

Diversity of Bats in Mount Silabur Cave Forest

This study presented the first bat checklist for Mount Silabur. A total of 27 bat species were recorded for the private land. The accumulation curve indicated that more species can be added with further sampling in this area. In comparison with surveys from protected areas of Bau Limestone Areas reported by Mohd-Azlan *et al.* (2005) and Mohd-Ridwan *et al.* (2011) also reveals that Mount Silabur does supports high number of bat species despite of the exposure to environmental disturbance such as agricultural activities. The differences in the observed species diversity recorded may be due to several factors such as sampling method, total effort, suitability of habitat, habitat of the chosen study site and weather condition (Mohd-Azlan *et al.*, 2005; Mohd-Ridwan *et al.*, 2011). The settings of nets, with usage of harp traps does affects the total capture rate (Mohd-Azlan *et al.*, 2005). In these surveys, trappings were focused more on the adjacent forests surrounding the caves. Future sampling should focus more on the cave entrance, trails, streams, under small bridges, under trees in open fields, and at water holes and feeding sites

to document additional cave species and individuals (Tuttle, 1974).

Species richness and composition are highly associated with the different habitats and vegetation types present at a locality (Khan *et al.*, 2007). The ecological niche of cave-dependent bats is interrelated with the surroundings, including forest adjacent to the caves (Kumaran *et al.*, 2011). The heterogenous landscape provide more roosting and foraging opportunities (Ethier & Fahrig, 2011), such as of Mount Silabur that may also explain the high number of bat species recorded from both surveys. During the surveys, bat trappings covered different areas with different vegetations that include logged forest, karst forest, hill forest, and plantations (bamboo, durian, banana, oil palm, and paddy). The high capture rate of cave-dwelling bats indicates the presence of suitable roosting sites such as small caves, boulders, and rock crevices (e.g., *Penthetor lucasi*, *H. cervinus*, *H. galeritus*, *H. coxi*, *Emballonura alecto*, *E. monticola*, and *Eonycteris spelaea*; Mohd-Azlan *et al.*, 2005).

Threats to Bats of Mount Silabur

In Borneo, bat population are subjected to multiple threats especially hunting (Struebig *et al.*, 2003). Bats are hunted primarily for consumption and traditional medicinal practices, contributing to the decline in bat population (Kingston, 2010). Edible swiftlet bird's nest harvesting is among the important source of income for the locals at Mount Silabur. Moreover, this activity give rise to opportunistic bat hunting while the locals are safeguarding the edible swiftlet bird's nest at night in the cave. We were informed that bats were collected with mist-nets in the cave for consumption. Bamboo bats are among the targeted species as they can be easily found in bamboo culms (*Tylonycteris* sp. and *Glischropus tylopus*; Struebig, 2010).

Other than edible-nest swiftlet harvesting and bat hunting, unsustainable guano extraction and the increasing ecotourism activities may also threaten cave bats at Mount Silabur (e.g., Mohd Ridwan *et al.*, 2010). Similarly, unregulated caving activities can disrupt cave ecosystem integrity (Pulido-Bosch *et al.*, 1997), which has been of the source of threats to cave-dependent bat species (Stone & Howarth, 2007).

Implementing Conservation Management

In Southeast Asia, karst landscape is an important habitat for bats, however threatened by anthropogenic activities (Kingston, 2003). As for the privately owned land embedded within karst landscape such as Mount Silabur, the landscape matrix and magnitude of disturbances are possible factors influencing bat diversity in the area.

The lack of biodiversity surveys in such neglected habitats has put a serious impediment to the conservation of the private land, which potentially may harbour endemic and/or rare species. Hence, biological knowledge is needed to prioritise habitat conservation and to develop a model for sustainable land use practices and resource management, such as timber and bushmeat (Sodhi *et al.*, 2004). For instance, the local community need to be informed about ecosystem services provided by bats such as the role of pteropodids in forest regeneration. Also, the role of insectivorous bats as pest control, which can reduce the prevalence of mosquito borne diseases and the use of pesticides for agriculture (Phommexay *et al.*, 2011). Most importantly, increasing awareness on biodiversity conservation have seen improvement in managing overexploitation of bushmeat through bat hunting (Craig *et al.*, 1994a, 1994b; Brooke & Wiles, 2008; Mildenstein *et al.*, 2016).

Based on the data from early 2000, it is estimated about 2.6 million animals were hunted and about 24,000 tons of wildlife meat consumed on annual basis in Sarawak (Bennett *et al.*, 2000; Bennett, 2002; Sodhi *et al.*, 2004). Mount Silabur is becoming a tourist attraction site for ecotourism recently. The local community developed protocols for visitors including limiting number of daily visitors to the caves in Mount Silabur and make available local guide services to ensure visitors' safety. However, the existing guidelines can be improved with the aid of safety instruments, enhancing public environmental awareness on nature and wildlife conservation, and promoting protection of the

area. Hopefully, the cooperation between local government, agencies and communities would be an important element to develop and implement proper conservation framework and strategies in preserving the heterogenous landscape of Mount Silabur and its biodiversity.

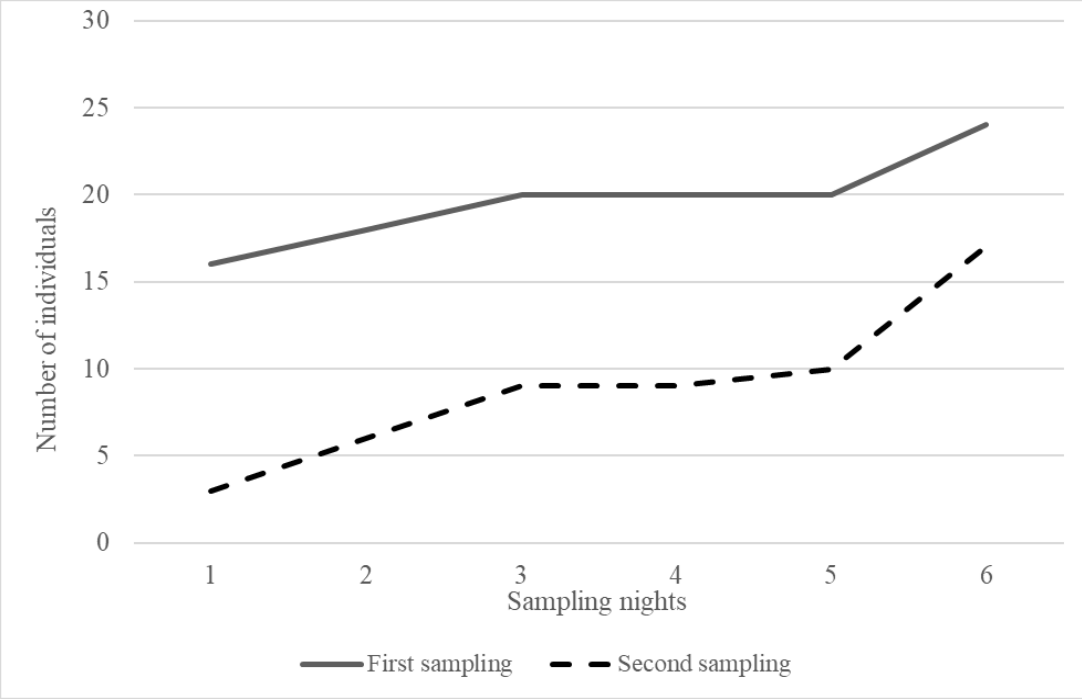

Figure 4. Species accumulation curve indicating the cumulative number of species encountered on first survey (January 2019) and second survey (November 2019)

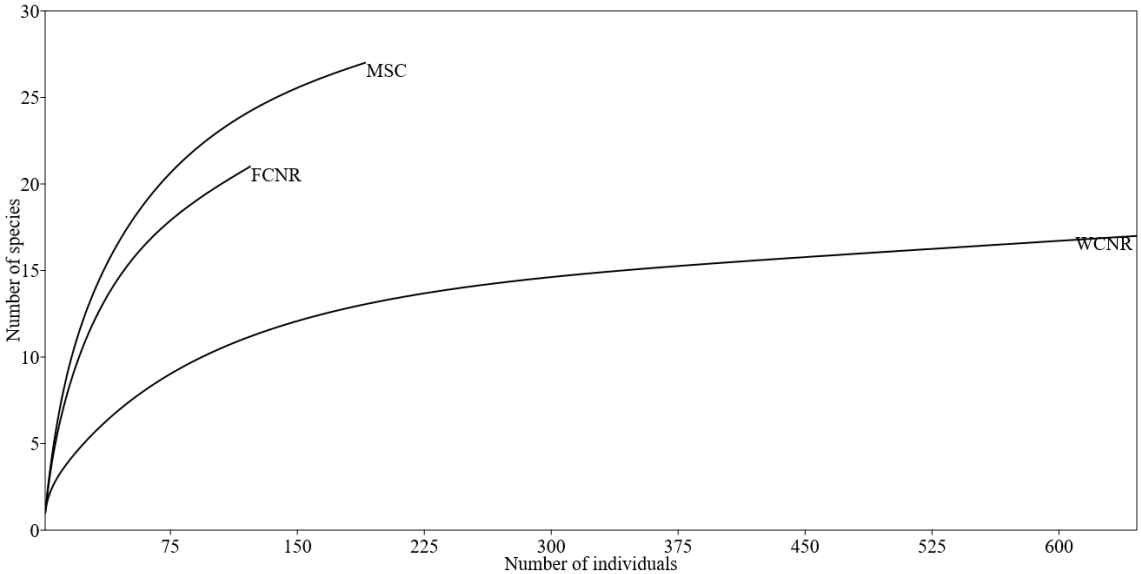

Figure 5. Rarefaction curves with number of species and individuals of Mount Silabur Cave forest (MSC), Wind Cave Nature Reserve (WCNR) and Fairy Cave Nature Reserve (FCNR)

Figure 6. Live images of highlighted species from Mount Silabur. (a) *Hipposideros coxi* (Shelford,1901); (b) *Kerivoula intermedia* (Hill & Francis, 1984); (c) *Myotis borneoensis* (Hill & Francis, 1984); (d) *Nycteris tragata* (Andersen, 1912); and (e) *Rhinolophus philippinensis* (Waterhouse, 1843). (Photos by Emy Ritta Jinggong)

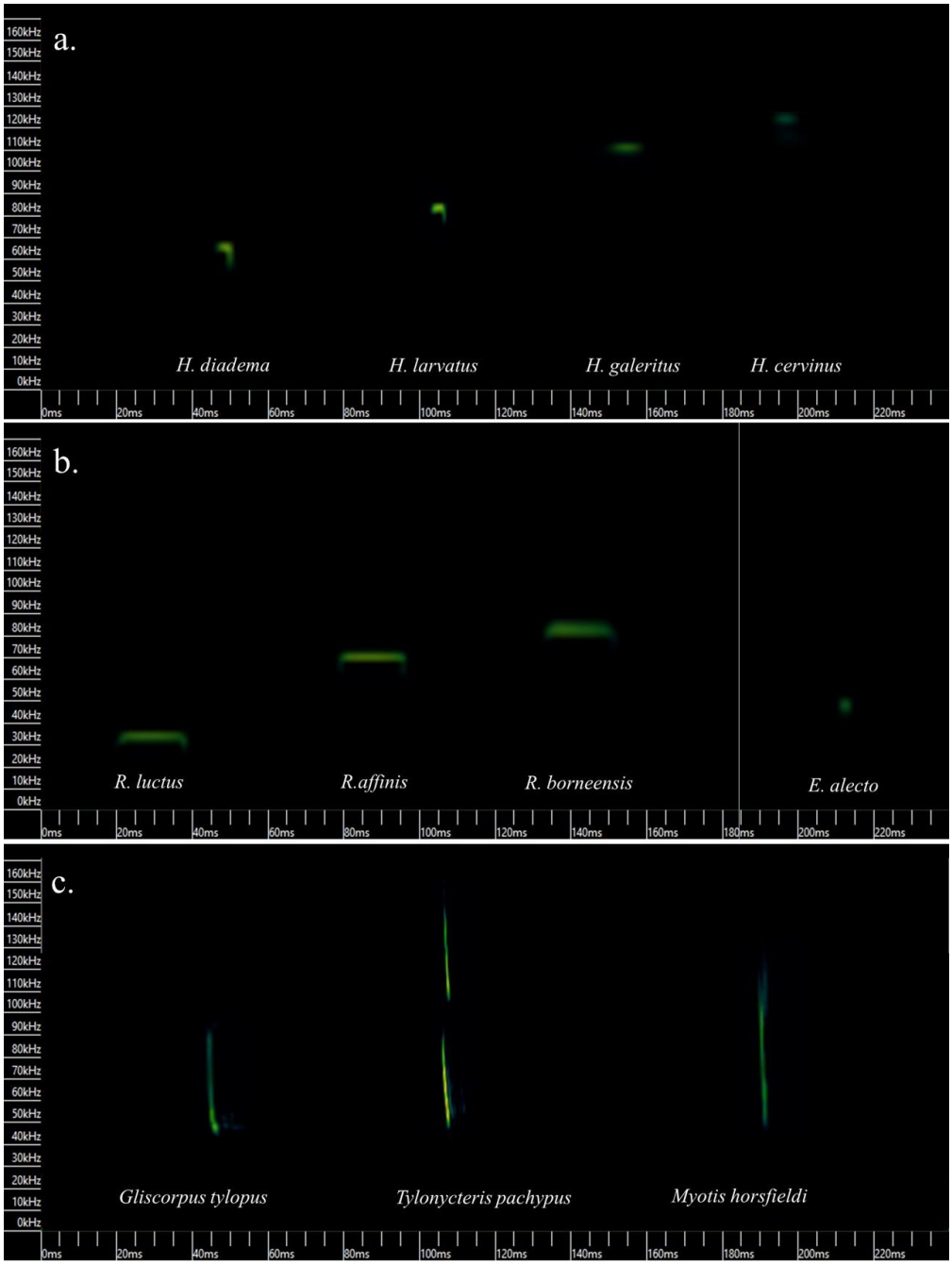

Figure 7. Spectrogram showing echolocation calls recorded from bats captured at Mount Silabur (a) Spectrograms for four species from the family Hipposideridae; (b) Spectrograms for three species from the family Rhinolophidae and *Emballonura alecto* from the family Emballonuridae; and (c**)** Spectrograms for three species from the family Vespertilionidae (Images were extracted from the Kaleidoscope Pro Software V4.5.5)

Table 2. Five parameters of call measurements including mean, standard deviation and range of bat species recorded from Mount Silabur. n = number of individuals

Species	n	Fppeak (kHz)	Fstart (kHz)	Fend (kHz)	Duration (ms)	IPI (ms)
Family Hipposideridae						
Hipposideros cervinus	7	124.85±1.84	107.77±3.23	126.46±1.01	5.28±0.54	25.29±5.67
		123.01-126.69	104.54-111.00	125.45-127.47	4.74-5.82	19.62-30.96
Hipposideros diadema	2	67.52±2.26	57.70±6.44	68.01±2.74	10.64±0.81	38.07±5.30
		65.26-69.78	51.26-64.14	65.27-70.75	9.83-11.45	32.77-43.37
Hipposideros galeritus	19	110.13±1.51	93.01±3.71	111.96±1.78	5.84±0.87	25.70±6.68
		108.62-111.64	89.30-96.72	110.18-112.74	4.97-6.71	19.02-32.38
Hipposideros larvatus	1	88.41	86.70	89.42	7.62	27.02
Family Rhinolophidae						
Rhinolophus affinis	19	69.74±0.36	68.27±0.47	71.12±0.52	37.64±5.82	110.95±27.51
		69.38-70.10	67.80-68.74	70.60-71.64	31.82-43.46	83.44-138.46
Rhinolophus borneensis	1	82.25±1.14	80.58±1.30	83.97±1.22	55.72±22.67	120.49±44.92
		81.11-83.39	79.28-81.88	82.75-85.19	33.05-78.39	72.57-165.41
Rhinolophus luctus	1	39.14	37.67	41.31	55.28	194.94
Family Vespertilionidae						
Glischropus tylopus	1	49.164	81.64	47.37	5.53	93.47
Myotis horsfieldii	3	70.32±17.58	43.81±6.26	100.61±11.67	3.49±0.15	25.53±5.72
		52.74-87.90	37.55-50.07	88.94-112.28	3.34-3.64	19.81-31.25
Tylonycteris pachypus	2	63.38±4.07	54.75±0.98	97.03±4.90	4.06±0.52	134.35±58.55
		59.31-67.45	53.77-55.73	92.13-101.93	3.54-4.58	75.80-192.90
Family Emballonuridae						
Emballonura alecto	1	45.24	40.15	50.54	2.75	32.44

Significant Species Distribution Record

The record of the Bornean endemic *H. coxi* highlighted the potential of Mount Silabur in supporting endemic and rare bat species. The finding serves as a new locality record for this elusive species, which was previously known only from five localities in Sarawak: Gunung Mulu National Park (Shazali *et al.*, 2018), Tanjung Datu NP (Khan *et al.*, 2015), Bako NP (Naharuddin *et al.*, 2015), Mount Penrissen (Kumaran *et al.*, 2006), and Bau Limestone Area (Khan *et al.*, 2008). *Hipposideros coxi* is assessed as 'Endangered' species on the IUCN Red List with a decreasing population trend due to its low area of occupancy (less than 500 km^2) (IUCN, 2022). The presence of endemic and endangered species in this karst system could pave a way for the implementation of conservation and management plans for the cave and the surrounding forest. Similarly, the capture of *R. philippinensis* provided a new distribution record for the species in western Sarawak. Previously, this species has been recorded only from Bako National Park and Mount Penrissen in western Sarawak (Hall *et al.*, 2002). Another significant finding in Mount Silabur is the record of *M. borneoensis.* This species is listed as a 'Data Deficient' on the IUCN Red List. This species is only known from Bukit Sarang, Bintulu in Sarawak (Wilson *et al.*, 2006). Genetic analysis was done to determine the taxonomic status of *R.* cf. *proconsulis* also to reconfirm species identification carried out during the survey. However, our results indicated that it was a misidentification and the individual examined was *R. affinis*.

CONCLUSION

This study has provided the first checklist of bats for Mount Silabur. The area seems an important habitat for both cave- and forest-dependent bats. This is supported by the findings of the high number of species (N=27) that was captured from the 12 sampling nights, which have resulted in higher bat species richness compared to FCNR in Bau Limestone Areas. This indicated the potential of private lands in providing suitable roosting resources for bats despite the presence of human activities at Mount Silabur. To develop a conservation framework for Mount Silabur, it is crucial to raise awareness and inform the local community of the biodiversity existing within their land. It is also pivotal to highlight the importance of safeguarding the karst system as well as the biodiversity within the landscape. Collaboration with local institutions may be the key in providing much-needed information about biodiversity in the area. Given the short sampling

period, it is possible that more bat species can be discovered in the area and long-term studies may provide insights on the population dynamics of the bat community in Mount Silabur. The discovery of *H. coxi*, *M. borneoensis*, *R. philippinensis*, and a few other rare and threatened species have highlighted the potential of Mount Silabur and the surrounding vegetations as another important area to support viable bat community in western Sarawak. Hence, it is essential to have a legal authority to protect and conserve this land, and to develop comprehensive conservation management plan to protect the bat population, as well as other inhabitants in Mount Silabur.

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