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Species Diversity of Bats in the Rich Limestone Complex Area of Merapoh in Lipis National Geopark, Malaysia

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Abstract

Merapoh, Pahang is an area rich with limestone karst located within Lipis National Geopark and home to the Sungai Relau gate of Taman Negara Pahang, a totally protected rainforest in Malaysia. Much of the research conducted here is mainly inside the national park, with few published faunal records for the Merapoh caves. Hence, this study compiled the data on the bat species diversity of eight Merapoh caves (March 2020 to March 2022) using mist nets and harp traps. Our results indicate that Chiroptera diversity at Merapoh caves is rich, with a total of 32 species recorded from 865 individuals and four new locality records for the state of Pahang namely *Rousettus leschenaultii, Lyroderma lyra*, *Rhinolophus coelophyllus* and *Hipposideros pomona*.. Gua Gunting has the highest diversity of bats (19 species) and also recorded the highest capture rate (640.63%, n=205 individuals).) Significant Merapoh caves that has primary colony bat roosts include Gua Jinjang Pelamin (*Eonycteris spelaea* & *Rousettus leschenaultii*), Gua Tahi Bintang (*Hipposideros larvatus*) and Gua Pasir Besar (*Miniopterus medius*). *Rhinolophus convexus,* previously recorded only in upper montane rainforests was also recorded in Merapoh caves indicating that this species can also be found in lower elevation than previously thought. Based on the findings of the current study and additional records from two previous studies have increased the Merapoh bat diversity checklist to 38 species. On the whole, the rich bat diversity in Merapoh is reflective of its immense limestone karst landscape highlights the reason Lipis National Geopark is recently gazetted. Future bat research should continue here and other karst in Lipis Geopark to not only better conserve biological diversity and geological structures but also raise awareness to the locals to appreciate their national heritage in aspiration to obtain the UNESCO Global Geopark status by 2025.

Keywords

Merapoh, Lipis National Geopark caves, limestone karst, bat diversity

Introduction

Lipis National Geopark in the state of Pahang is a newly gazetted Geopark in Malaysia (November 2023) with an area of 5198 km^2 showcasing 28 national geological heritage, six biologically diverse areas and 18 cultural heritage sites (Lau and Lau 2023). The Merapoh area within Lipis Geopark is surrounded by several forest reserves and borders Taman Negara Pahang, the largest national park in Peninsular Malaysia. The main geological feature in Merapoh is the large number of limestone hills from the Gua Musang formation, which were formed around the Permian-Triassic period millions of years ago (Jeyanny et al. 2019). The abundance of limestone hills in Merapoh and forested regions have blessed the area rich in biodiversity, particularly karst flora and fauna.

Bats belonging to the order Chiroptera, are the only mammals with the capability of sustained flight. The order Chiroptera is a diverse order encompassing more than 1300 species globally that can be traditionally divided into Megachiroptera and Microchiroptera (Srinivasulu et al. 2010, Lim and Wilson 2019). However, recent studies suggested that these suborders could be substituted with new suborders named Yinpterochiroptera and Yangochiroptera (Lei and Dong 2016). Bats are particularly diverse in the tropics, accounting for around 40% of the mammal species in Southeast Asia (Lim and Wilson 2019). There are about 143 bat species in Malaysia, 113 of these species like the rare *Hypsugo macrotis* can be found in Peninsular Malaysia (Lim et al. 2016, Lim et al. 2017, Juliana Senawi and Norhayati Ahmad 2021).

The limestone karst landscape, where caves are prominent, provides permanent roosting sites for bats and foraging resources in the forest above and surrounding the limestone hill (Struebig et al. 2008, Furey et al. 2010). Furthermore, limestone karst landscapes are biodiversity hotspots that support a rich diversity of flora and fauna with a high endemism rate which covers about 10% of the total land area in Southeast Asia, highlighting the biological importance of this landscape (Tolentino et al. 2020, Liew et al. 2021). Threats facing the karst landscape include limestone quarrying and habitat degradation, as limestone hills have no direct legal protection status unless the landscape is in a protected area such as Gua Niah in Niah National Park, Gua Gomantong in Gomantong forest reserve and also Gua Gajah inside Taman Negara Pahang Sungai Relau (Day 2011, Tolentino et al. 2020). While not every limestone karst can feasibly be included within protected areas, geoparks are the next best thing as the status provides a form of legal protection to karst areas by empowering local communities working with government agencies to holistically managed their geological resources intertwined with biological diversity and cultural heritage for sustainable economic output. This bottom up approach will hopefully instils sense of pride among locals to conserve their natural heritages, along

with the opportunity to be recognised internationally through UNESCO Global Geopark designation (Lipis Geopark 2023, UNESCO 2015).

Though the many geological and fossil research published in Lipis district contribute greatly to the Geopark gazettement, there has been little faunal studies here. Merapoh, in particular, have many studies that mainly conducted research inside Taman Negara Sungai Relau in contrast to the limestone hills and forested areas outside said national park (Nizam et al. 2006, Kawanishi and E. Sunquist 2008, Jeyanny et al. 2019). Despite the numerous research potential of karst landscape, there are only a few bat diversity studies in Merapoh, despite the strong association of bats and caves. Thus, it is imperative this gap of knowledge is addressed as Merapoh serve as a transitional area between protected rainforest habitat and human modified habitat in the larger scope of Lipis Geopark. Finally, this study aims to find and compile the bat species composition of Merapoh caves.

Study site description

As its name suggests, Lipis National Geopark encompasses the entire Lipis district with geological formations (Bentong-Raub suture zone & Gua Bama Permian-Triassic boundary), limestone karst landscapes (Merapoh & Kenong) since the Ordovician period, plus reside to a large portion of Taman Negara Pahang, one of the world's oldest rainforests (Lau and Lau 2023). In northern Lipis, there lies Merapoh, a small town that is located next to the Pahang-Kelantan border about 30 km from Gua Musang in Kelantan and 80.7 km from Kuala Lipis in Pahang. This town is home to the lesser-known Sungai Relau gate of Taman Negara Pahang and is surrounded by a large number of limestone hills forming the Merapoh cave system which consists of 85 explored caves believed to be 130 million years old, along with many more unexplored caves waiting to be discovered. Fieldwork sampling of bats was carried out at eight caves in Merapoh, which are as follows: Gua Air Mata Dayang, Gua Persit, Gua Gunting, Gua Jinjang Pelamin, Gua Kalong, Gua Katak, Gua Pasir Besar and Gua Tahi Bintang.

Gua Katak, Gua Persit, Gua Tahi Bintang is located in an area that has a considerable amount of local agriculture activities such as oil palm plantations, mixed fruit orchards and rubber plantation. Gua Air Mata Dayang is literally behind a villager's house and his durian orchard while Gua Kalong is surrounded by small forest patches that have been gradually opened up for agricultural purposes.

Three caves (Gua Gunting, Gua Jinjang Pelamin & Gua Pasir Besar) have substantial forest areas in their vicinity. Gua Gunting, for instance, is located in a sizeable forest patch that is connected to the Persit Forest Reserve. Gua Jinjang Pelamin have scattered forest patches that also links to Sungai Relau, which borders Taman Negara Pahang Sungai Relau, a protected rainforest area. Lastly, Gua Pasir Besar is sandwiched between two forest reserves, Tanum Forest Reserve and Sungai Yu Forest Reserve which connected to the Taman Negara region. Fig. 1 shows the map of all eight sampled caves in Merapoh, Pahang.

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Materials and Methods

The sampling period is around two years, from March 2020 to March 2022 for eight caves. All eight caves have varying total bat sampling nights as samplings were conducted opportunistically, but each cave does have a minimum of four trapping nights. Table 1 lists all the GPS readings, sampling dates and number of trapping nights of all caves.

About two mist nets and two harp traps were used for every cave to capture bats at two locations: 1) inside the cave or near the cave entrance and 2) at the forest trail where bats are likely to forage. All traps were opened at 1830 hours and closed at 2300 hours. All standard body measurements, weight, gender and maturity state of each captured bat were recorded and used for species identification referring to the identification keys from Kingston et al. (2009) and Francis (2019). These were deposited at Faculty of Earth Science, Universiti Malaysia Kelantan.

Statistical analysis

The Merapoh bat species checklist is compiled from the bat sampling results of the eight caves. Comparisons between the sampled caves were made for the following aspects: diversity and abundance of bat species, dominant bat species in each cave and bat species distribution the between caves. A rarefaction curve was constructed for standardisation as the bat sampling efforts (number of sampling nights) for each cave are different. The rarefaction curve was conducted using PAST software. Lastly, a comparison with previous bat diversity studies done in Merapoh caves were prepared to generate the full bat species composition in Merapoh, with their conservation status obtained from the global IUCN Red List (IUCN 2023) and the Red List of Mammals for Peninsular Malaysia Version 2.0 (PERHILITAN 2017).

Results

During the sampling period (March 2020-March 2022), a total of 865 individuals consisting of 32 bat species from seven families were captured at eight caves in Merapoh. For the fruit bat species complex, *Cynopterus brachyotis*, the two forms (‘Forest’ & ‘Sunda’) were highlighted due to the captures of different body sizes and the occurrence of different habitat types that can be utilised by *C. brachyotis* ‘Forest’ and *C. brachyotis* ‘Sunda’ (Abdullah and Jayaraj 2006). The species identification of these two forms relied on body sizes and calculations from a predictive model proposed by Jayaraj et al. (2012).

The most abundant bat species caught is *Hipposideros kunzi* (n=170), followed by *Hipposideros larvatus* (n=142) and *Eonycteris spelaea* (n=100). By comparison, *Rhinolophus coelophyllus*, *Rhinolophus convexus*, *Hipposideros lylei* and *Hipposideros pomona* were recorded as singleton captures. Gua Gunting has the highest number of bat

captures (n=205), while Gua Persit is the cave with the lowest bat capture numbers (n=15). Table 2 shows the diversity and abundance of bat species in all the sampled caves.

Among the 32 bat species recorded, *Rhinolophus pusillus* (n=57) and *Hipposideros kunzi* (n=142) were found in seven out of eight caves sampled, while *Cynopterus horsfieldii* (n=14) and *Rhinolophus stheno* (n=76) were found in six caves. Furthermore, *Rhinolophus affinis* (n=76), *Hipposideros cineraceus* (n=27) and *Hipposideros larvatus* (n=142) were recorded in 5 different caves. As for the rarest bat species among the eight caves, about 9 species (*Rhinolophus coelophyllus, R. convexus, Hipposideros diadema, H. lylei, H. pomona, Kerivoula pellucida, Murina suilla, Miniopterus magnater* & *Myotis ater*) were found at their respective cave area only.

Gua Gunting is the most diverse cave in Merapoh, with a total of 19 bat species recorded, while Gua Persit is the least diverse at 5 species. As the bat sampling conducted in Merapoh for this study is opportunistic, we do not have the same number of sampling nights for each cave. By extrapolating a rarefaction curve (Fig. 2) with a standardised number of individual captures (n=15), Gua Katak is surprisingly the cave with the highest expected number of species, with seven compared to Gua Gunting, with only five expected bat species. Similarly, Gua Persit is not the cave with the lowest expected number of species but Gua Kalong with three expected bat species.

Based on Table 3, about 38 species of bats are recorded in Merapoh, one of which is *Hipposideros pomona*, listed as Endangered (IUCN 2023) and Data Deficient for Peninsular Malaysia while *R. convexus* is listed as Data Deficient for both conservation statuses. Other bat species that are listed as Data Deficient in the Red List of Mammals in Peninsular Malaysia, but Least Concern in IUCN 2023 are *Macroglossus minimus, Emballonura monticola, Lyroderma lyra, Rhinolophus coelophyllus, Hipposideros dyacorum, H. lylei, Hesperoptenus blanfordi* and *Myotis ater. Eonycteris spelaea* is listed as Near Threatened, while *Hipposideros kunzi* is listed as Vulnerable for Peninsular Malaysia. For Near Threatened status in the global IUCN 2023, the species listed include *Rousettus leschenaultii, Nycteris tragata* and *Kerivoula pellucida,* but both *N. tragata* and *K. pellucida* are only Least Concern, in the Red List of Mammals in Peninsular Malaysia.

Furthermore, this bat species checklist updates four new locality records for Pahang: *Rousettus leschenaultii, Rhinolophus coelophyllus, Lyroderma lyra* and *Hipposideros pomona.* One intriguing capture for this study is *Rhinolophus convexus*, which has only been found in the upper montane rainforest even though the limestone hills in Merapoh do not reach the previously observed elevation. As this species is Data Deficient, genetic studies will be needed to determine whether their elevation limit can expand towards limestone hill forests or a different species completely (Francis 2019).

Species accounts

Family Pteropodidae

***Rousettus leschenaultii* Desmarest, 1820 (Leschenault's Rousette)**

This species is a new locality record for the state of Pahang. A total of 21 individuals were captured in Merapoh in which 19 were from Gua Jinjang Pelamin and two were from Gua Tahi Bintang. This species is one of the few fruit bat species that roost inside caves, can be found roosting with *Eonycteris spelaea* in Gua Jinjang Pelamin for this study and Batu Caves, Selangor (Francis 2019, Nuratiqah et al. 2023). *R. leschenaultii* can use a rudimentary echolocation call by tongue clicking (Raghuram et al. 2007). Their diet are mainly fruits but will opportunistically exploit nectar and pollen when floral resources are plentiful (Stewart and Dudash 2016). Fig. 3 shows an individual of this species caught during sampling.

Family Megadermatidae

Lyroderma lyra E. Geoffroy, 1810 (Greater False Vampire Bat)

This species is a new locality record for the state of Pahang. Three individuals were captured in Merapoh with two were at Gua Kalong and one was at Gua Tahi Bintang. *L. lyra* has been recorded in Peninsular Malaysia within two states; Perak and Selangor (Lim et al. 2017). This bat species has been found roosting in in small numbers in caves, abandoned buildings and tunnels (Francis 2019). This species is a seasonal predominantly gleaning carnivore bat that preys on vertebrates when insect prey resources are scarce; vertebrate prey includes lizards, small mammals and birds (Gual-Suárez and Medellín 2021). The smaller relative, *Megaderma spasma* differs from *Lyroderma lyra* by having a shorter posterior noseleaf, a heart-shaped intermediate noseleaf and its diet consist mainly of large insects with a lesser frequency of hunting small vertebrates (Francis 2019, Gual-Suárez and Medellín 2021). Fig. 4 shows a Greater False Vampire Bat sampled during this study.

Family Rhinolophidae

Rhinolophus convexus Csorba, 1997 (Convex Horseshoe Bat)

One individual was captured at Gua Gunting (elevation: 191 m). *Rhinolophus convexus* is a species that has very little information and is listed as Data Deficient (DD) in the IUCN Red List of Threatened Species. *R. convexus* has been recorded in Cameron Highlands, Pahang in Peninsular Malaysia (Csorba 1997). A study in 2020 has also since recorded the existence of *R. convexus* in the state of Terengganu (Nurulhuda et al. 2020). The specimens recorded were obtained in Sungai Buweh, Kenyir area (elevation: 204 m) which is close to our Gua Gunting elevation in Merapoh but this elevation aspect of *R. convexus* was not highlighted by the previous researcher (Nurulhuda et al. 2020). The current distribution of this species is very limited with specimens only known from Peninsular Malaysia and possibly Laos, though further taxonomic work is needed to verify whether the Laos specimens indeed represent *R. convexus* (Csorba et al. 2016).

This species was first described in Cameron Highland, Pahang, and have been found in upper montane rainforest (elevation: 1600m) in Peninsular Malaysia (Csorba 1997, Csorba et al. 2016). The specimen captured in Merapoh indicates a new elevation record for *R.*

convexus with a possibility that this bat species can travel down the montane forest region. Since very few specimens have ever been captured, the habitat, ecology, population, and distribution information for this bat species is still uncertain. A photograph of a *R. convexus* is shown inFig. 5.

Rhinolophus coelophyllus Peters, 1867 (Croslet Horseshoe Bat)

One individual was captured at Gua Gunting, with this bat species being a new locality record for Pahang. *Rhinolophus coelophyllus* has been recorded in Peninsular Malaysia within three states; Kedah, Perlis, and Selangor (Lim et al. 2017). This species can be confused with a similar-looking species, *R. shameli* which have a broader noseleaf, generally lower echolocation call frequency and are not found in Peninsular Malaysia (Francis 2019, Furey et al. 2020). *R. coelophyllus* roosts in limestone caves and have been found foraging in various forests including lowland forest to hilly forests (Francis 2019). An individual of this species can be seen in Fig. 6.

Family Hipposideridae

Hipposideros pomona K. Andersen, 1918 (Large Eared Roundleaf Bat)

One individual of *Hipposideros pomona* was caught at Gua Gunting with this species is a new locality record for the state of Pahang. *H. pomona* has been recorded in Peninsular Malaysia within four states; Perlis, Perak, Kelantan and Melaka (Lim et al. 2017). As its name suggested, *Hipposideros pomona* have very large, rounded ears among the small Hipposiderid bats. This bat species mainly roosts inside caves and can be found foraging in disturbed areas aside from forests (Francis 2019).

H. pomona have unresolved taxonomy status due to the lack of DNA barcodes from Peninsular Malaysia and genetic analyses have yet to fully set the boundaries, particularly the uncertainties with a complex of species including *H. gentilis* and *H. pomona* which have three subspecies from China (Douangboubpha et al. 2010, Lim et al. 2017). The specimen captured in Merapoh will hopefully contribute for future taxonomic research for this species complex. Fig. 7 shows a photograph of an individual of this species.

Discussion

Firstly, it is not at all surprising that bat species diversity in Merapoh area is high as the number of limestone hills containing many cave structures allows bats to utilise this area as roosts. Bats are often associated with caves and limestone karst ecosystems in general, where bats functions as primary contributor to the organic resources and nutrient flow inside the caves for other cave fauna such as small invertebrates (spiders, earwigs & centipedes), cave fish, frogs and microbes (Clements et al. 2006, Sakoui et al. 2020). Other limestone karst ecosystems also harbour many bat species such as Taman Negara Gunung Mulu, Malaysia with that is known to harbour 41 species of bats. This cave is also home to a million of *Chaerephon plicatus* occupying a single cave. The. T

Sangkulirang limestone karst formations in Kalimantan, Indonesia has 36 bat species while the Kim Hy Nature Reserve in Vietnam is known to harbour 36 bat species (Suyanto and Struebig 2007, Furey et al. 2010, Isham Azhar et al. 2013, Tolentino et al. 2020).

Our findings in Merapoh indicate that several caves are deemed significant in bat diversity conservation. Starting with Gua Jinjang Pelamin, the cave houses the primary colony of *Eonycteris spelaea* and a refuge for *Rousettus leschenaultii* (n=19) in which both bat species are important pollinators of durian, providing their pollination services to the less-intensively managed durian orchards in the surrounding area (Aminuddin Baqi et al. 2022). Other caves include Gua Tahi Bintang, which has a a large colony of *Hipposideros larvatus* and Gua Pasir Besar, home to a large community of *Miniopterus medius* and possibly other *Miniopterus sp.* Although it was possible that these species can occupy other sampled caves, the habitat quality and cave structure complexity, to a certain extent, may influence the distribution and population of such species of bats. Habitat quality degradation reduces the abundance and diversity of food resources (fruits & insects) as some bat species prefer certain food resources, like how fruit bats (*Cynopterus brachyotis* & *E. spelaea*) forage more in low crop density plantations and insectivorous bats on less intensive farms with minimal agrochemical use (Wickramasinghe et al. 2003, Azhar et al. 2015, Syafiq et al. 2016, Wagner et al. 2021).

Cave structure complexity does play a role in bat species selecting roosting sites inside caves as a large cave can support a larger number of bat populations, and a complex cave with many chambers can affect air circulation inside the cave, which indirectly influences the microclimate of a potential roosting site (Cigna 2004, Glover and Altringham 2008). In spite of these cave features, cave selection by bats is also significantly influenced by the habitat quality surrounding the cave. Many cave areas experience high anthropogenic activities which usually involves habitat destruction (Struebig et al. 2009, Phelps et al. 2016). The caves in Merapoh are fairly fragmented, with agricultural areas and secondary forest patches in between. Gua Persit is an extreme example of the isolation of limestone karst outcrops and caves in Merapoh, where the cave is surrounded by oil palm plantations and a major highway nearby. According to the villagers here, Gua Persit used to be a guano-collecting hotspot for the village, but nowadays, there are few guano sediments. The isolation of Gua Persit increases the foraging distance for bats, particularly which causes a long term reduction in population size, similar to the conclusion brought up in another karst landscape by Struebig et al. (2009). Limestone karst outcrops are technically land ‘islands’ in which the degree of isolation is amplified by habitat fragmentation (Clements et al. 2006). While insectivorous bats roosting inside caves are less impacted by limestone karst fragmented landscape, overall bat diversity may erode, particularly forest foragers, negatively affected by ‘island’ isolation and degradation (Hazard et al. 2023). The overall diversity and abundance of bats may also decrease and experience changes in composition due to biotic relaxation. Gua Air Mata Dayang, Gua Tahi Bintang, Gua Katak, and Gua Kalong have a lesser degree of isolation as these caves still have forest patches and are surrounded by mixed fruit orchards or rubber plantations, which do support a satisfactory level of insect abundance. Gua Gunting and Gua Pasir Besar areare positioned at a more favourable location despite habitat fragmentation, as these caves not

only have forest patches but are also near a forest reserve border and are connected to Taman Negara, respectively.

When comparing this study bat diversity results with two other past studies in Merapoh as shown in Table 3 (Ratnam et al. 1989, Muhammad Aminuddin Baqi et al. 2020), the Merapoh bat diversity count increased to 38 bat species. Most of these bat species are recorded outside of Taman Negara Pahang Sungai Relau, except for Ratnam et al. (1989) whose team did some bat sampling inside Taman Negara and a banana plantation near a Merapoh limestone hill. The high bat diversity count shows that limestone karsts are biodiversity arks, and Merapoh should also be acknowledged as one of Peninsular Malaysia's priority regions for bat conservation (Clements et al. 2006, Suyanto and Struebig 2007). The recent gazettement of Lipis Geopark area as a prime limestone geopark is a step in the right direction for bat conservation in Pahang.

The significance of Merapoh Caves and at a larger scale the Lipis Geopark cannot be understated for bat conservation, with many cave-roosting bat species and 8 fruit bat species can be found in this district. The current bat diversity shown in this study is an understatement of bat diversity in the area as there are still many limestone hills and caves in Merapoh that have yet to be sampled. This sampled study was only able to survey bats in eight Merapoh caves out of the 85 known caves here. Further bat samplings and roost surveys should be conducted at other limestone hills (caves & rock shelters) in Lipis Geopark overall as these areas particularly Merapoh, may reveal more bat species records, collectively enhancing the bat conservation efforts in the country.

Conclusions

Undoubtedly, the rich limestone karst landscape in Merapoh harbours a high number of bat species, with 865 individuals from 32 species recorded from eight Merapoh caves, totalling up to 38 species when combined from previous studies. Two caves are considered highly important: Gua Jinjang Pelamin which harbours the largest colony of *Eonycteris spelaea* found in Merapoh and Gua Gunting, the cave with most diverse bat species. (19 species in total). Aside from the four new locality records for Pahang, this Merapoh bat species checklist contains several bat species that are of Least Concern for the global IUCN Red List, but their status in the country is Data Deficient. Such information is crucial in adding up to the whole body of bat diversity knowledge in Malaysia. The capture of *Rhinolophus convexus* at a lower elevation in Merapoh reflects the high potential of bat species diversity in this area, even more so with the inclusion of the Taman Negara Sungai Relau.

The significance of Merapoh within Lipis National Geopark as a bat conservation area is comparable to Krau Wildlife Reserve, Pahang. Merapoh provides both permanent roosting structures (caves) and reliable foraging grounds for bats as the area is surrounded by Taman Negara and the various forest reserves, conducive for the long-term continuation of bat populations in Gua Jinjang Pelamin for *E. spelaea* and Gua Pasir Besar for *Miniopterus medius* amidst anthropogenic disturbances. Future bat research should be continued in Merapoh as there are still many limestone hills in Merapoh that have yet to be explored.

Assessment of human disturbance in the caves and habitat enrichment near limestone hills should also be evaluated to create an integrated bat conservation management plan. Elements of bat diversity can also be integrated into the Merapoh ecotourism activity to educate the public on the importance of bats in the ecology of the tropical rainforest ecosystem. Lastly, this Merapoh bat species checklist can contribute to the country's bat conservation efforts and hopefully serve as a catalyst for others to conduct bat research here in Merapoh and Lipis Geopark overall.

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Conflicts of interest

The authors have declared that no competing interests exist.

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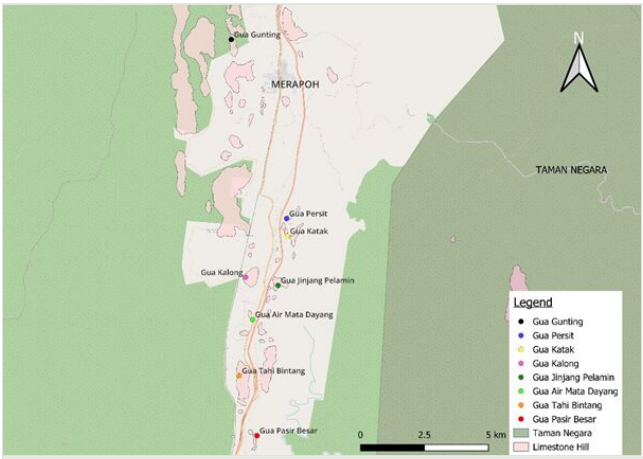

Figure 1.

Limestone hills map layer based on Liew et al. (2021).

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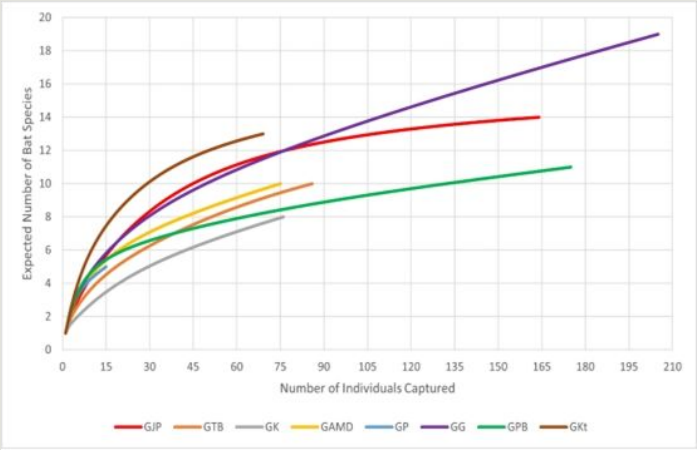

Figure 2.

Rarefaction curve showing the number of bat species in eight caves in Merapoh. Abbreviations: **GJP:** Gua Jinjang Pelamin, **GTB:** Gua Tahi Bintang, **GK:** Gua Kalong, **GAMD:** Gua Air Mata Dayang, **GP:** Gua Persit, **GG:** Gua Gunting, **GPB:** Gua Pasir Besar, **GKt:** Gua Katak.

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Figure 3.

A Leschenault's Rousette individual sampled in this study.

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Figure 4.

A Greater False Vampire Bat individual.

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Figure 5.

A Convex Horseshoe Bat individual captured during sampling.

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Figure 6.

A Croslet Horseshoe Bat individual captured in this study.

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Figure 7.

A Large Eared Roundleaf Bat individual.

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Table 1.

GPS locations, number of trapping nights and trapping night dates at eight Merapoh caves.

No.	Caves	GPS location	Trapping nights	Date of sampling
1	Gua Air Mata Dayang	4°36'37.39" N, 101°59'37.0968" E	4	9/4/2021- 21/8/2021
2	Gua Persit	4°38'45.72" N, 102°00'23.38" E	4	23/7/2020-24/12/2020
3	Gua Gunting	4°42'31.94"N 101°59'11.88"E	8	7/9/2021-10/3/2022
4	Gua Jinjang Pelamin	4°37'16.03" N,102° 0'10.81" E	6	13/8/2020-16/10/2021
5	Gua Kalong	4°37'38.23"N, 101°59'36.15" E	4	3/3/2021-6/3/2021
6	Gua Katak	04°38'27.27" N, 102° 0'21.34"E	4	5/3/2022-11/3/2022
7	Gua Pasir Besar	4°34'9.90" N, 101°59'42.92" E	4	14/2/2021-17/2/2021
8	Gua Tahi Bintang	4°35'26.94" N, 101°59'19.59"E	5	5/3/2020-8/4/2021

Table 2.

The bat species composition at the eight caves in Merapoh, Pahang.

No	Species	GJP	GTB	GK	GAMD	GP	GG	GPB	GKt
	Pteropodidae								
1	*Cynopterus brachyotis* (Müller, 1838)	0	9	0	0	0	1	0	3
2	*Cynopterus* cf. *brachyotis* Forest	7	0	0	1	0	0	0	0
3	*Cynopterus horsfieldii* Gray, 1843	2	0	1	2	3	1	0	5
4	*Cynopterus sphinx* (Vahl, 1797)	0	0	0	0	0	2	0	2
5	*Eonycteris spelaea* (Dobson, 1871)	94	0	0	0	6	0	0	0
6	*Rousettus leschenaultii* (Desmarest, 1820)	19	2	0	0	0	0	0	0
	Emballonuridae								
7	*Emballonura monticola* Temminck, 1838	0	0	1	0	0	14	0	0
	Megadermatidae								
8	*Lyroderma lyra* (É. Geoffroy Saint-Hilaire, 1810)	0	1	2	0	0	0	0	0
	Rhinolophidae								
9	*Rhinolophus affinis* Horsfield, 1823.	5	2	0	0	0	4	33	4
10	*Rhinolophus coelophyllus* Peters, 1867	0	0	0	0	0	1	0	0
11	*Rhinolophus convexus* Csorba, 1997	0	0	0	0	0	1	0	0
12	*Rhinolophus pusillus* Temminck, 1834	9	3	6	1	0	4	15	2
13	*Rhinolophus refulgens* Andersen, 1906	4	0	0	0	0	8	0	0
14	*Rhinolophus stheno* K. Andersen, 1905	1	12	4	0	0	1	55	3
	Hipposideridae								
15	*Hipposideros armiger* (Hodgson, 1835)	0	0	1	8	0	12	0	11
16	*Hipposideros bicolor* (Temminck, 1834)	0	1	0	0	1	1	1	0
17	*Hipposideros cervinus* (Gould, 1854)	3	0	0	0	0	0	3	0
18	*Hipposideros cineraceus* Blyth, 1853	0	0	1	4	4	15	0	1
19	*Hipposideros diadema* (É. Geoffroy Saint-Hilaire, 1813)	5	0	0	0	0	0	0	0
20	*Hipposideros dyacorum* Thomas, 1902	6	0	0	7	0	68	0	14
21	*Hipposideros galeritus* Cantor, 1846	0	0	0	0	0	0	1	1
22	*Hipposideros kunzi* Murray, Khan, Kingston, Akbar & Campbell, 2018	2	1	60	18	0	68	4	17
23	*Hipposideros larvatus* (Horsfield, 1823)	6	54	0	32	0	0	20	5
24	*Hipposideros lylei* Thomas, 1913	0	0	0	0	1	0	0	0

25	*Hipposideros pomona* K. Andersen, 1918	0	0	0	0	0	1	0	0
	Vespertilionidae								
26	*Hesperoptenus blanfordi* (Dobson, 1877)	0	0	0	0	0	1	1	0
27	*Kerivoula pellucida* (Waterhouse, 1845)	1	0	0	0	0	0	0	0
28	*Kerivoula hardwickii* (Horsfield, 1824)	0	0	0	0	0	1	0	1
29	*Murina suilla* (Temminck, 1840)	0	0	0	0	0	1	0	0
30	*Myotis ater* (Peters, 1866)	0	0	0	1	0	0	0	0
	Miniopteridae								
31	*Miniopterus magnater* Sanborn, 1931	0	0	0	0	0	0	1	0
32	*Miniopterus medius* Thomas & Wroughton, 1909	0	1	0	1	0	0	41	0
	Total individuals (N)	164	86	76	75	15	205	175	69
	Total number of species	**14**	**10**	**8**	**10**	**5**	**19**	**11**	**13**

Keys; GJP: Gua Jinjang Pelamin, **GTB**: Gua Tahi Bintang, **GK**: Gua Kalong, **GAMD**: Gua Air Mata Dayang, **GP**: Gua Persit (also known as Gua Baja), **GG**: Gua Gunting, **GPB**: Gua Pasir Besar, **GKt**: Gua Katak.

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Table 3.

Comparison of all bat diversity studies with their conservation status in Merapoh (IUCN 2023, PERHILITAN 2017).

No	Species	Ratnam et al. 1989	Bekong	This Study	IUCN Red List 2023	Red List Peninsular Malaysia 2017
	Pteropodidae					
1	*Balionycteris seimundi* Kloss, 1921	+	+	-	LC	LC
2	*Cynopterus brachyotis* (Müller, 1838)	+	+	+	LC	LC
3	*Cynopterus* cf. *brachyotis* Forest	-	-	+	LC (grouped with *C. brachyotis*)	LC
4	*Cynopterus horsfieldii* Gray, 1843	+	-	+	LC	LC
5	*Cynopterus sphinx* (Vahl, 1797)	-	+	+	LC	LC
6	*Eonycteris spelaea* (Dobson, 1871)	-	-	+	LC	NT
7	*Macroglossus minimus* (É. Geoffroy Saint-Hilaire, 1810)	-	+	-	LC	DD
8	*Rousettus leschenaultii* (Desmarest, 1820)*	-	-	+	NT	DD
	Emballonuridae					
9	*Emballonura monticola* Temminck, 1838	-	-	+	LC	DD
	Nycteridae					
10	*Nycteris tragata (K. Andersen, 1912)*	-	+	-	NT	LC
	Megadermatidae					
11	*Lyroderma lyra* (É. Geoffroy Saint-Hilaire, 1810)*	-	-	+	LC	DD
12	*Megaderma spasma* (Linnaeus, 1758)	+	-	-		
	Rhinolophidae					
13	*Rhinolophus affinis* Horsfield, 1823	+	+	+	LC	LC
14	*Rhinolophus coelophyllus* Peters, 1867*	-	-	+	LC	DD
15	*Rhinolophus convexus* Csorba, 1997	-	-	+	DD	DD
16	*Rhinolophus luctus* Temminck, 1834	-	+	-	LC	LC
17	*Rhinolophus pusillus* Temminck, 1834	-	+	+	LC	DD
18	*Rhinolophus refulgens* Andersen, 1906	-	-	+	LC (as *R. lepidus*)	DD
19	*Rhinolophus stheno* K. Andersen, 1905	-	-	+	LC	LC
	Hipposideridae					
20	*Hipposideros armiger* (Hodgson, 1835)	-	-	+	LC	LC
21	*Hipposideros bicolor* (Temminck, 1834)	-	+	+	LC	LC
22	*Hipposideros cervinus* (Gould, 1854)	-	-	+	LC	LC

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23	*Hipposideros cineraceus* Blyth, 1853	-	+	+	LC	LC
24	*Hipposideros diadema* (É. Geoffroy Saint-Hilaire, 1813)	+	-	+	LC	LC
25	*Hipposideros dyacorum* Thomas, 1902	-	-	+	LC	DD
26	*Hipposideros galeritus* Cantor, 1846	-	-	+	LC	LC
27	*Hipposideros kunzi* Murray, Khan, Kingston, Akbar & Campbell, 2018	-	-	+	LC (as *H. atrox*)	VU
28	*Hipposideros larvatus* (Horsfield, 1823)	-	+	+	LC	LC
29	*Hipposideros lylei* Thomas, 1913	-	-	+	LC	DD
30	*Hipposideros pomona* K. Andersen, 1918*	-	-	+	EN	DD
	Vespertilionidae					
31	*Hesperoptenus blanfordi* (Dobson, 1877)	-	-	+	LC	DD
32	*Kerivoula pellucida* (Waterhouse, 1845)	-	+	+	NT	LC
33	*Kerivoula hardwickii* (Horsfield, 1824)	-	-	+	LC	LC
34	*Murina suilla* (Temminck, 1840)	-	+	+	LC	LC
35	*Myotis ater* (Peters, 1866)	-	-	+	LC	DD
36	*Myotis horsfieldii* (Temminck, 1840)	+	-	-		
	Miniopteridae					
37	*Miniopterus magnater* Sanborn, 1931	-	-	+	LC	Not assessed
38	*Miniopterus medius* Thomas & Wroughton, 1909	-	-	+	LC	DD
	Total number of species	**7**	**13**	**34**		

Keys; + : Present, - : Absent, * : New locality record in Pahang