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ORIGINAL ARTICLE

# Bats from the understorey of lowland tropical rainforests across Peninsular Malaysia

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## ABSTRACT

To date, 110 bat species are recorded in Peninsular Malaysia. Many of these species depend upon tropical forests, which have rapidly decreased in extent over recent decades. Yet, updated information on species distributions in the region is still lacking. Here, we report bat species records and their distribution based from surveys undertaken at 30 lowland tropical rainforest sites across Peninsular Malaysia. We recorded 56 species from seven families. The three most abundant species across the peninsula were *Rhinolophus affinis*, *Hipposideros bicolor* complex and *Hipposideros cervinus*. Four out of nine singleton species (*Chironax melanocephalus*, *Coelops robinsoni*, *Myotis hermani* and *Hesperoptenus doriae*) are forest specialists that are patchily distributed across the peninsula, while another five are open space/edge species that utilise the forest occasionally. The understorey assemblage comprises frugivorous, insectivorous and nectar-drinking species. Thirteen percent of all captured species are represented by at least one record outside of their previous known distributional range. Furthermore, our study suggests that updated and informative species distribution is essential to further study these bat species since information on their ecology and basic natural history remains poorly known. An improved understanding of species ecology and population status will contribute to more effective conservation efforts. Our survey data provide comprehensive records of understorey forest bats in a biodiversity hotspot.

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# INTRODUCTION

The Malaysian peninsula is the southernmost part of the Asia mainland, located in the centre of the Sunda Shelf (Fig. 1). It forms part of the Sundaland biodiversity hotspot and is a global conservation priority (Cincotta et al. 2000, Myers et al. 2000, Williams 2013). Kuala Lompat from the central region of Peninsular Malaysia hosts the largest concentration of bat richness than any single site surveyed in the Old World tropics to date (Kingston et al. 2003). This impressive bat fauna contributes to the maintenance of healthy and balanced ecosystems and the economy of the country. For example, fruit- and nectar-feeding bats (family Pteropodidae) serve as seed dispersers and pollinators of many economically important plant species, such as the durian, banana and bitter beans, increasing quantity and quality of these crops (Marshall 1983, Fujita & Tuttle 1991, Shilton et al. 1999, Hodgkison et al. 2003, Kingston et al. 2006, Kunz et al. 2011, Aziz et al. 2017, Chaiyarat et al. 2019, Sheherazade et al. 2019). In addition, insectivorous bats are known to serve as effective natural pest control agents in the region (Kingston et al. 2006, Kunz et al. 2011, Wanger et al. 2014).

The long term viability of many forest-dependent bat species in Peninsular Malaysia is uncertain due to substantial habitat loss (Lim et al. 2014, Keenan et al. 2015). Malaysia has lost 1.6% of its natural forest between the year 2010 and 2017 (Hansen et al. 2019) for massive and unsustainable development (Tan-Soo et al. 2016, Global Forest Watch 2019). This resulted in widespread forest degradation and fragmentation, leaving only 15% of land as primary forest (FAO 2019). Studies on bat diversity in Peninsular Malaysia demonstrate how bat community composition varies latitudinally, as well as being affected by habitat area (Struebig et al. 2008, Lim et al. 2014). Richness is higher towards the south, and in forest blocks >300 ha in size. Thus, it is important to maintain large and continuous tracks of natural forest across the southern-most peninsula of Asia Continent.

The dominant insectivorous bat groups in insular Southeast Asia (e.g. Hipposideridae, Rhinolophidae, Murininae, and Kerivoulinae) have evolved over millennia to live within highly-dense humid tropical forests and are thus ill-equipped to adapt to rapid changes in forest structure and cover (Kingston et al. 2003). The anthropogenic consequences on bat diversity were reflected by neighbouring Singapore. The island experienced massive development since the 1960s, which led to the extirpation of one-third of the country's bat fauna (Lane et al. 2006). Nevertheless, subsequent bat surveys in Singapore have reported two microchiropteran species as new records and rediscovered *H. bicolor* on the island (Chan et al. 2009, Leong & Lim 2009), demonstrating the values of regular surveys and monitoring.

Bat research in Peninsular Malaysia began in the mid-19th century (Wallace 1860, Anon 1900) following the arrival of British colonialists. Since then, the number of species observed in the country has increased, and numerous taxonomic revisions were conducted during the twentieth century (e.g. Chasen 1936, 1940, Muul & Liat 1971, Stiller 1976, Mialhe & Landau 1977, Lim & Muul 1978, Gould 1978a, 1978b). Research effort further escalated in 2001 after the establishment of the Malaysian Bat Conservation and Research Unit, a platform and network to bring bat researchers in the country and international bat experts together (Kingston et al. 2012).

Despite intensive bat research over the last two decades, there was no comprehensive inventory on bat diversity across Peninsular Malaysia after Corbet & Hill (1992). We aim to fill this gap by reporting on a four-year intensive forest understorey survey campaign of lowland rainforest sites across the Peninsular Malaysia. We provide descriptions for each bat species reported, in terms of recorded localities and patchiness for species' distribution across Peninsular Malaysia. This information is an important guide for bat conservation and monitoring programs in Malaysia and neighbouring Southeast Asian countries.

# MATERIALS AND METHODS

### Study Site

We performed bat surveys in 30 sites in lowland mixed dipterocarp evergreen tropical rainforest across Peninsular Malaysia (Table 1, Fig. 1). Fieldwork was conducted between January and October from 2007 to 2010. All survey sites were lowland (< 300 m.a.s.l.) intact forest reserves of more than 1000 ha and were recovering from past logging activities undertaken in the previous 30 years. These forest reserves are protected, monitored and enforced by Forestry Department Peninsular Malaysia.

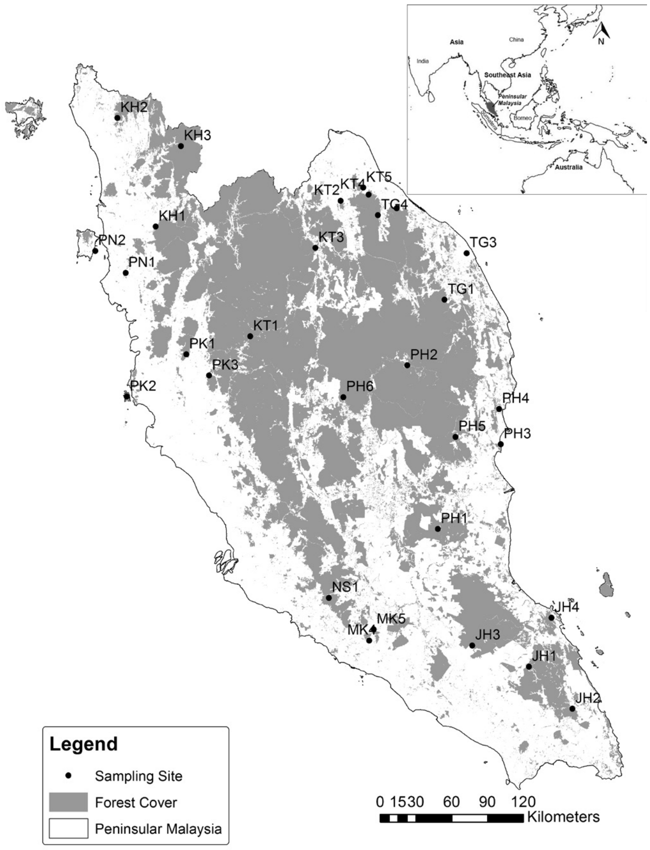


**Fig. 1 -** Map of Peninsular Malaysia showing the 30 lowland tropical rainforest sites visited in this study; Inset: location of Peninsular Malaysia in Southeast Asia and the wider region.

### Bat capture and species identification

Surveys were conducted to primarily target insectivorous bats using harp traps, but netting was also deployed on occasions (Table 1). Depending on access, between two and eight four-bank harp traps were placed across forest trails, old logging skids or small streams. Traps were set at 19:00h and were checked regularly from 20:00h to 22:00h and again at 07:00h the following morning. In some sites where harp trapping was difficult, hand nets and mist nets were used. Hand nets were used when sampling bats from small boulders and caves in the forest sites while two to four four-shelf nets were deployed in forest areas with less understorey vegetation each trapping night, such as along stream banks, or at trapping locations with open mid-storey. We therefore also report some Pteropodid records, which were captured in the mist nets.

To aid in the species identification, standard morphological measurements were taken for each individual such as the length of forearm, tibia, and tail using dial callipers and the body mass using a spring balance. Bats were then identified based on Kingston et al. (2006) and Francis (2008). Wing tissue punches of ca. 3mm in diameter were collected from each capture bat prior to release for future examination and confirmation of identity for a subset of captures. Voucher specimens were only collected if a bat died during the trapping and processing. Voucher specimens were deposited at the Zoology Museum in Universiti Kebangsaan Malaysia and General Biology Lab in Universiti Malaysia Terengganu.

To provide a clearer comparison of community structure across sites we report the proportional abundance of each bat species (percentage of total catch for the target species over total catch of all species) alongside habitat and landscape characteristics of each site (Table 2). For each species we also report the proportion of sites with at least one capture (Total number of visited sites over number of sites with target bat species)– i.e. the naïve occupancy – as a simple indicator of patchiness within each species distribution across Peninsular Malaysia.

# RESULTS

Throughout the four-year survey period, we captured 3169 individuals of 56 bat species from seven families across the peninsula (Table 2, Fig. 2). This included species from the families pteropodidae, emballonuridae, hipposideridae, rhinolophidae, vespertilionidae, megadermatidae and nycteridae (Fig. 2). Recaptured individuals, identified via the wing tissue biopsies taken for each individual, were excluded from the record and analyses. Of a total of 18 species of Pteropodid bats recorded previously for Peninsular Malaysia, we recorded only eight (44%) during the study. We recorded 23 vespertilionid, 12 hipposiderid and 10 rhinolophid species (Fig. 2).

Among the bats captured, the most common and abundant species was *Rhinolophus affinis* (22% of total captured individuals, 87% of sites occupied), followed by *Hipposideros cf. bicolor H. cervinus*, *H. larvatus*, *R. lepidus*, *Cynopterus brachyotis* and *Kerivoula papillosa* (Table 2). Ten singleton species were captured: *Chironax melanocephalus*, *Coelops robinsoni*, *Hesperoptenus doriae*, *Hesperoptenus blanfordi*, *Kerivoula krauensis*, *Myotis muricola*, *M. hermani*, *Scotophilus kuhlii*, *Tylonycteris pachypus* and *T. robustula*.

Seven species were reported outside of their known distribution on the Malay peninsula: *Hipposideros doriae* (approx. 50 km north of distribution range), *Hipposideros dyacorum* (approx. 50 km south), *Hipposideros pomona* (approx. 350 km south), *Hesperoptenus doriae* (approx. 100 km south), *Kerivoula intermedia* (approx. 50 km north), *Myotis ater* (approx. 100 km south), and *Rhinolophus sedulus* (approx. 155 km north). Meanwhile, we also captured five open-space species in our forest inventories (*Miniopterus magnater, Hesperoptenus blanfordi, Scotophilus kuhlii, Tylonycteris pachypus* and *Tylonycteris robusta*).

Among the bat species recorded, nine of the 56 (16%) species are categorised by the IUCN Red List as 'Near threatened', three as 'Vulnerable', and three as 'Data deficient' (Table 2). Out of 30 sites sampled, PH2 (102.68°E, 4.41°N) (Table 1) from the centre of Peninsular Malaysia has the highest number of bat species recorded (n=24 spp.; 43% of total captured species). This was followed by JH2 (n= 23 spp., 41% of total captured species). Other forest with at least 20 bat species were TG1 (21 species recorded), JH3 (20 species recorded) and KT2 (20 species recorded).

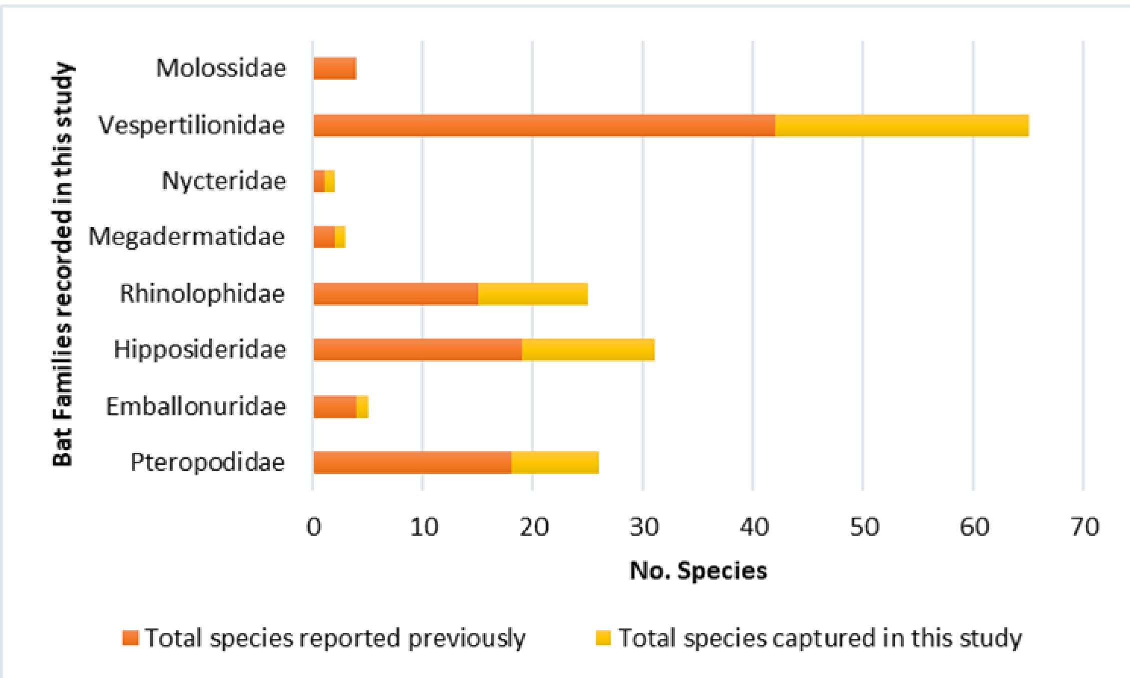


**Fig. 2 -** The number of species recorded during the 4-year survey campaign compared to the known total bat fauna reported for Peninsular Malaysia..

**Table 1 -** Details of the field sites (30) of this study, including the site location, land use of surrounding areas, management regime of each site, and protection status. Trapping methods and total numbers of species captured in this study also listed for each site.

| Site Code | Survey site | Surrounding land use[a] | Major human activity[b] | Protected Status[c] | Trapping methods[d] | Site visited dates | Total numbers of species recorded |
|---|---|---|---|---|---|---|---|
| JH1 | Lenggor<br>103.586°E, 2.186°N | O,F | L | M | HT | 3-5 Mar, 13-20 Apr 2008 | 14 |
| JH2 | Gunung Panti<br>103.914°E, 1.869°N | O,F | R,L | M | HT | 8-17 Sept 2008 | 23 |
| JH3 | Labis Forest Reserve<br>103.159°E, 2.346°N | F,O,V | R | M | HT | 23-27 Jun 2009 | 20 |
| JH4 | Gunung Arong<br>103.756°E, 2.554°N | R,G,V,W | R,M | M | HT | 1-4 Jul 2009 | 13 |
| KH1 | Bukit Hijau<br>100.773°E, 5.501°N | O,R,V | R | M | HT | 26-29 Apr 2008 | 15 |
| KH2 | Wang Hill<br>100.484°E, 6.319°N | V,G | R | M | HT, M | 10-23 Jul 2008 | 15 |
| KH3 | Ulu Muda<br>100.963°E, 6.107°N | F,D,W | R | F | HT, M, H | 25-27 Jul 2008 | 6 |
| KT1 | Lojing Highland<br>101.486°E, 4.674°N | V,F,G | R,A | M | HT | 26-31 May 2008 | 11 |
| KT2 | Temangan Hill<br>102.168°E, 5.695°N | C,G,V | N | F | HT | 25 Aug-2 Sept 2008 | 20 |
| KT3 | Gunung Stong<br>101.977°E, 5.340°N | O,R,F,V | R,L | M | HT, M | 1-9 Jun 2009 | 17 |
| KT4 | Jeram Linang<br>102.378°E, 5.741°N | O,R,G | R,A | F | HT | 11-14 Jun 2009 | 12 |
| KT5 | Jeram Pasu<br>102.338°E, 5.794°N | O,R,G | R,A | F | HT | 14-15 Jun 2009 | 9 |
| MK4 | Senggeh Hill<br>102.383°E, 2.383°N | G,V,O | N | M | HT | 31 Mar-4 Apr 2008 | 11 |
| MK5 | Batang Melaka<br>102.417°E, 2.467°N | G,V,O | N | M | HT, M | 31 Mar-4 Apr 2008 | 6 |
| NS1 | Gunung Angsi<br>102.078°E, 2.705°N | O,R,F,V | N | M | HT | 3-5 Jul 2007 | 16 |
| PH1 | Bukit Ibam<br>102.901°E, 3.223°N | O,C | L,M | M | HT | 2-12 Jun 2008 | 19 |

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|---|---|---|---|---|---|---|---|
| PH2 | Gunung Aais<br>102.681°E, 4.413°N | F | L | M | HT | 15-27 Jun 2008 | 24 |
| PH3 | Beserah<br>103.357°E, 3.861°N | G,W | N,R | M | HT | 16-23 Jul 2009 | 12 |
| PH4 | Balok<br>103.362°E, 4.127°N | C,G,W | L | M | HT | 16-23 Jul 2009 | 5 |
| PH5 | Chalas<br>103.033°E, 3.917°N | O | R | M | H | 16-23 Jul 2009 | 7 |
| PH6 | Forest Kenong<br>102.188°E, 4.216°N | F,O | N,R | F | HT, H | 31 Jul- 3 Aug 2009 | 17 |
| PK1 | Kledang Saiong<br>101.004°E, 4.538°N | O,G | R | F | HT | 18-24 Mar 2008 | 19 |
| PK2 | Pangkor Island<br>100.555°E, 4.220°N | G,F,W | R | F | HT | 4-8 May 2009 | 13 |
| PK3 | Bujang Melaka<br>101.176°E, 4.379°N | G,V | R,L | M | HT | 20-26 May 2009 | 16 |
| PN1 | Bukit Panchor<br>100.546°E, 5.151°N | O,G,V | R | M | HT, H | 11-14 Aug 2008 | 17 |
| PN2 | Pulau Jerejak<br>100.317°E, 5.317°N | F,W | R | F | HT | 12 Aug 2008 | 2 |
| TG1 | Sekayu<br>102.95° E, 04.95° N | O | R | F | M, HT | 18 Aug 2008<br>19 Aug 2009<br>28-30 Jan, 25-27 Feb, 2-3 Apr, 2 May, 2-3 Jun, 2010 | 21 |
| TG2 | Lata Belatan<br>102.589° E, 05.637° N | G,R | R | F | HT, M | 28-31 Aug 2008<br>16-18 Aug 2009 | 12 |
| TG3 | Bukit Besar<br>103.117°E, 05.3°N | G,T | R | F | M | 8-11 Jul, 8-9 Aug, 16-18 Nov, 27-30 Dec 2008 | 3 |
| TG4 | Tembakah<br>102.448° E, 05.587° N | G,R | R | F | M, HT | 23-25 Sept 2010 | 9 |

a. Land-use surrounding the sampling site: A, Acacia plantation; O, oil palm plantation; R, rubber plantation; C, cleared land; F, forest; G, mixed gardens with villages; T, city, V, vegetable and fruit plantation; D, dam; W, water body such as sea and freshwater lake.
b. Main human activity in the sampling site: N, low activity; R, recreational and tourism; L, logging; M, mining; A, Agriculture.
c. Protected status based on the forestry department: F, fully protected from logging or mining, and minor tourism; M, managing for logging, mining, and tourism.
d. Trapping methods used in the site: HT, harp trap; M, mist net; H, hand net.

**Table 2.** Summary of bat species recorded in the study. The captured localities and the total captured individuals of each species are listed. Species in bold are those with new distribution records. Localities outside of the known distribution range were also bold and underlined. Habitat type for each species is summarised based on the capture sites. *Number of captured individuals

| Species | Common name | IUCN status | Total numbers of individuals (percentage of total catch, %) | Proportion of sites occupied | Captured localities (n*) | Habitat at the capture sites |
|---|---|---|---|---|---|---|
| **Pteropodidae** | | | | | | |
| *Balionycteris maculata* | Spotted-winged Fruit Bat | Least concern | 32 (1) | 0.17 | PH1 (3), KH2 (1), PN1 (3), PH2 (1) and TG1 (24) | Understorey of lowland forest included undisturbed and disturbed forest. It can be found at flat or hilly areas. |
| *Chironax melanocephalus* | Black-capped Fruit Bat | Least concern | 1 (0.03) | 0.03 | PN1 (1) | Lowland forest. |
| *Cynopterus brachyotis* | Lesser Short-nosed Fruit Bat | Least concern | 168 (5.3) | 0.27 | MK4 (1), KH1 (1), JH2 (1), JH1 (1), TG1 (60), TG2 (1), TG3 (95) and TG4 (8) | Disturbed and undisturbed lowland forests. |
| *Cynopterus horsfieldii* | Horsfield's Fruit Bat | Least concern | 62 (1.96) | 0.13 | PH6 (1), TG1 (27), TG3 (32) and TG4 (2) | Disturbed and undisturbed hilly forest included limestone area. |
| *Eonycteris spelaea* | Cave Nectar Bat | Least concern | 6 (0.19) | 0.13 | PN1 (2), PK2 (1), TG3 (2) and TG4 (1) | Disturbed and undisturbed hilly forest, outside limestone areas. |
| *Megaerops ecaudatus* | Sunda tailless fruit bat | Least concern | 4 (0.13) | 0.10 | JH1 (1), KH2 (1) and TG1 (2) | Lowland hilly forest. |
| *Macroglossus sobrinus* | Greater Long-tongued Nectar Bat | Least concern | 2 (0.06) | 0.07 | PH2 (1) and TG1 (1) | Inland forest. |
| *Penthetor lucasi* | Lucas's Short-nosed Fruit Bat, Dusky Fruit Bat | Least concern | 2 (0.06) | 0.07 | PN1 (1) and TG1 (1) | Inland forest. |
| **Emballonuridae** | | | | | | |
| *Emballonura monticola* | Lesser Sheath-tailed Bat | Least concern | 7 (0.22) | 0.13 | PN1 (2), KT2 (2), JH2 (2) and JH4 (1) | Inland and coastal hilly forest with boulders. |
| **Hipposideridae** | | | | | | |
| *Hipposideros armiger* | Great Roundleaf Bat | Least concern | 12 (0.38) | 0.20 | PK1 (2), PN1 (3), PK3 (1), PH6 (2), TG1 (1) and TG2 (3) | Hilly inland forest. |

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|---|---|---|---|---|---|---|
| *Hipposideros bicolor* | Bicolored Roundleaf Bat | Least concern | 554 (17.48) | 0.83 | NS1 (17), JH1 (6), PK1 (34), MK4 (16), KH1 (45), PH1 (15), PH2 (25), KH2 (6), PN1 (10), JH2 (68), PK2 (57), PK3 (38), KT1 (2), KT2 (1), KT3 (29), JH3 (36), KT4 (9), KT5 (19), JH4 (1), PH3 (11), PH5 (4), PH6 (22), TG1 (40), TG2 (42) and TG4 (1) | Primary forest of all types. |
| *Hipposideros cervinus* | Fawn Roundleaf Bat | Least concern | 253 (7.98) | 0.47 | NS1 (65), JH1 (14), PK1 (27), MK4 (5), KH1 (10), PH1 (7), PH2 (8), PN1 (3), JH2 (46), PK2 (20), JH3 (22), JH4 (6), PH6 (19) and TG1 (1) | Hilly, dense forest with relative humid conditions. Also forage in forest outside limestone areas. |
| *Hipposideros cineraceus* | Ashy Roundleaf Bat | Least concern | 7 (0.22) | 0.17 | PK2 (1), KT3 (3), JH3 (1), MK5 (1) and PH3 (1) | Disturbed and undisturbed forest. |
| *Hipposideros diadema* | Diadem Roundleaf Bat | Least concern | 57 (1.80) | 0.50 | MK4 (2), KH1 (4), PH1 (1), PH2 (1), KH2 (1), PN1 (2), KT2(19), JH2 (7), KT3 (4), JH3 (3), KT4 (2), PH3 (1), PH6 (3), TG1 (5) and TG2 (2) | Disturbed and undisturbed forests of all types. |
| ***Hipposideros doriae*** | Borneo Roundleaf Bat | Near threatened | 7 (0.22) | 0.17 | JH1 (1), PH2 (2), JH2 (1), JH3 (1) and **KH1 (2)** | Inland forests less disturbed by human activities. |
| ***Hipposideros dyacorum*** | Dayak Roundleaf Bat | Least concern | 62 (1.96) | 0.17 | KT3 (2), **KT4 (12)**, **KT5 (17)**, **PH3 (30)** and **PH6 (1)** | Humid forest with water flow such as large stream, river or waterfalls. |
| *Hipposideros galeritus* | Cantor's Roundleaf Bat | Least concern | 30 (0.95) | 0.33 | PK1 (1), PH2 (6), KT2 (1), JH2 (7), PK2 (2), PK3 (3), JH3 (6), PH3 (1), PH6 (2) and TG2 (1) | Humid forest with boulders or located within limestone areas. |
| *Hipposideros larvatus* | Intermediate Roundleaf Bat | Least concern | 242 (7.64) | 0.63 | NS1 (20), PK1 (35), MK4 (7), KH1 (3), PH2 (25), KH2 (3), PN1 (27), PN2 (14), JH2 (11), PK3 (1), KT3 (36), JH3 (5), KT4 (5), KT5 (13), PH3 (4), PH5 (1), PH6 (20), TG1 (10) and TG2 (2) | Forest with boulders, limestone caves, streams and waterfall. |
| ***Hipposideros pomona*** | Pomona Roundleaf Bat | Least concern | 6 (0.19) | 0.13 | KT4 (1), KT5 (1), PK1 (2) and **MK4 (2)** | Forest with stream or small waterfall. |
| *Hipposideros ridleyi* | Ridley's Roundleaf Bat | Vulnerable A3c | 29 (0.92) | 0.20 | PH1 (11), PH2 (11), KH2 (3), KT2 (2), JH2 (1) and KT3 (1) | Humid and inland forests, preferably undisturbed forest sites. |
| *Coelops robinsoni* | Malaysian Tailless Roundleaf Bat | Vulnerable A4c | 1 (0.03) | 0.03 | TG1 (1) | Forest with boulders. |

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| **Rhinolophidae** | | | | | | |
| *Rhinolophus acuminatus* | Accuminate Horseshoe Bat, Acuminate Horseshoe Bat | Least concern | 7 (0.22) | 0.13 | KH2 (2), KT2 (2), PH2 (2), PH4 (1) | Undisturbed forests. |
| *Rhinolophus affinis* | Intermediate Horseshoe Bat | Least concern | 701 (22.12) | 0.87 | NS1 (46), JH1 (41), PK1 (22), MK4 (6), MK5 (1), KH1 (28), KT1 (5), PH1 (13), PH2 (55), KH2 (16), KH3 (19), PN1 (80), KT2 (3), JH2 (65), PK2 (35), PK3 (25), KT3 (14), JH3 (24), KT4 (43), KT5 (29), PH3 (29), PH5 (22), PH6 (20), TG1 (35), TG2 (15) and TG4 (10) | Found foraging in all types of lowland rainforest. |
| *Rhinolophus chiewkweeae* | Chiew Kwee Tee's Horseshoe Bat | Not listed | 2 (0.06) | 0.03 | PH3 (2) | Primary and secondary forests of inland and coastal area. |
| *Rhinolophus lepidus* | Blyth's Horseshoe Bat | Least concern | 216 (6.82) | 0.63 | NS1 (11), JH1 (4), MK4 (18), MK5 (1), KH1 (54), KH3 (3), PN1 (22), KT2 (1), PK2 (30), PK3 (6), KT3 (1), JH3 (19), KT4 (7), KT5 (9), PH3 (1), PH4 (1), PH5 (18), PH6 (8) and TG1 (2) | Foraging in all types of forest, included urban forest parks. |
| *Rhinolophus luctus* | Great Woolly Horseshoe Bat, Woolly Horseshoe Bat | Least concern | 11 (0.35) | 0.30 | NS1 (1), MK5 (1), PH2 (1), KT2 (1), PK2 (1), PK3 (1), KT4 (2), KT5 (2) and TG2 (1) | Humid forest with streams or waterfall. |
| *Rhinolophus pusillus* | Least Horseshoe Bat | Least concern | 56 (1.77) | 0.30 | KH3 (11), PN1 (6), PK2 (19), PK3 (1), JH3 (10), PH5 (3), PH6 (2), TG1 (2) and TG2 (2) | Inland forests with rock boulders or limestone caves. |
| ***Rhinolophus robinsoni*** | Peninsular Horseshoe Bat, Robinson's Horseshoe Bat | Near threatened | 33 (1.04) | 0.33 | NS1 (13), PK1 (3), **MK4 (3)**, **MK5 (2)**, PH2 (1), PN1 (3), **JH2 (3)**, **JH3 (3)**, KT5 (1) and PH6 (1) | Inland humid forest with waterfall or streams. |
| ***Rhinolophus sedulus*** | Lesser Woolly Horseshoe Bat | Near threatened | 30 (0.95) | 0.27 | JH1 (1), **PK1 (1)**, **KH1 (3)**, PH1 (8), PH2 (6), JH2 (8), JH4 (2) and PH4 (1) | Inland or coastal forest which does not associate with limestone areas. |

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|---|---|---|---|---|---|---|
| *Rhinolophus stheno* | Lesser Brown Horseshoe Bat | Least concern | 51 (1.61) | 0.33 | NS1 (2), KT1 (27), KH1 (1), PH1 (1), PH2 (1), KH3 (8), PK3 (4), KT3 (4), PH6 (2) and TG1 (1) | Forest with rock boulders, limestone caves, also found at forest without big rocks or caves, but relatively higher level of lowland rainforest. |
| *Rhinolophus trifoliatus* | Trefoil Horseshoe Bat | Least concern | 84 (2.65) | 0.47 | NS1 (1), JH1 (4), PK1 (7), KT1 (4), PH1 (14), PH2 (3), KH2 (4), KH3 (2), PN1 (3), KT2 (19), JH2 (13), JH3 (3), KT5 (2) and JH4 (5) | Lowland rainforest of all elevation, both disturbed and undisturbed forests. |
| **Megadermatidae** | | | | | | |
| *Megaderma spasma* | Lesser False-vampire Bat | Least concern | 2 (0.06) | 0.07 | PK2 (1) and PK3 (1) | Forest with rock boulders or within limestone areas. |
| **Nycteridae** | | | | | | |
| *Nycteris tragata* | Malayan Slit-faced Bat | Near threatened | 15 (0.47) | 0.37 | NS1 (1), MK5 (1), KH1 (2), KT2 (1), PK2 (3), PK3 (2), JH3 (1), KT4 (1), JH4 (1), PH4 (1) and TG4 (1) | Forest with lower disturbance, either coastal or inland, can be associate with caves or rock boulders. |
| **Vespertilionidae** | | | | | | |
| *Miniopterus magnater* | Large Bent-winged Bat,<br>Western Bent-winged Bat | Least concern | 1 (0.03) | 0.03 | KT3 (1) | Forage at the canopy gap of waterfall. |
| *Miniopterus medius* | Medium Bent-winged Bat, Intermediate Long-fingered Bat | Least concern | 5 (0.16) | 0.07 | JH3 (1) and PH5 (4) | Open stream in the forest and within limestone forest. |
| *Glischropus tylopus* | Common Thick-thumbed Bat | Least concern | 9 (0.28) | 0.13 | PK1 (3), PH1 (2), PH2 (2) and KT2 (2) | Forest with large bamboo plants. |
| ***Hesperoptenus doriae*** | False Serotine Bat | Data deficient | 1 (0.03) | 0.03 | **JH2 (1)** | Mature and tall forest. |
| *Hesperoptenus blanfordi* | Blanford's Bat,<br>Least False Serotine Bat | Least concern | 1 (0.03) | 0.03 | KT1 (1) | Higher level of lowland rainforest close to the river. |

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| *Kerivoula hardwickii* | Hardwicke's Woolly Bat | Least concern | 88 (2.78) | 0.63 | NS1 (8), JH1 (5), PK1 (5), MK4 (1), KT1 (5), PH1 (13), PH2 (2), KH2 (4), PN1 (10), PN2 (5), KT2 (1), JH2 (11), PK3 (1), KT3 (10), KT4 (2), JH3 (5), JH4 (1), PH3 (2) and TG2 (2) | Almost all types of forest but not forest within limestone areas. |
| ***Kerivoula intermedia*** | Small Woolly Bat | Near threatened | 52 (1.64) | 0.57 | NS1 (5), JH1 (12), PK1 (2), PH1 (2), PH2 (1), KT2 (2), JH2 (1), KT3 (2), JH3 (1), JH4 (6), PH3 (1), PH4 (2), PH6 (8), **KH2 (1)**, TG1 (4), TG2 (2) and TG4 (1) | Almost all types of forest but not forest within limestone areas. |
| *Kerivoula krauensis* | Krau Woolly Bat | Data deficient | 1 (0.03) | 0.03 | TG1 (1) | Forest with boulders and large stream. |
| *Kerivoula minuta* | Least Woolly Bat | Near threatened | 22 (0.69) | 0.23 | KH1 (2), PH1 (3), PH2 (5), JH2 (4), KH2 (2), TG1 (3) and TG4 (3) | Flat or hilly forest outside limestone areas. |
| ***Kerivoula papillosa*** | Papillose Woolly Bat | Least concern | 111 (3.5) | 0.57 | NS1 (3), JH1 (5), PK1 (10), KT1 (8), PH1 (20), PH2 (2), **KH2 (12)**, **KH3 (2)**, PN1 (3), KT2 (6), JH2 (15), PK3 (6), KT3 (3), KT4 (2), JH4 (6), PH6 (5), and TG1 (3) | Almost all types of forests. |
| *Kerivoula pellucida* | Cleared-winged Woolly Bat | Near threatened | 32 (1) | 0.47 | NS1 (3), JH1 (2), KH1 (1), KT1 (1), PH1 (5), PH2 (5), KT2 (2), JH2 (4), PK3 (1), KT3 (1), JH4 (2), PH3 (1), PH6 (3) and PK1 (1) | Almost all types of forest. |
| *Phoniscus atrox* | Groove-toothed Trumpet-eared Bat, Groove-toothed Bat, Gilded Groove-toothed Bat | Near threatened | 11 (0.35) | 0.20 | PK1 (1), PH1 (3), PH2 (2), JH3 (1), JH4 (3) and TG2 (1) | Almost all types of lowland or hilly forest. |
| *Murina aenea* | Bronze Tube-nosed Bat | Vulnerable A2c+3c | 5 (0.16) | 0.17 | KH1, JH1, JH2, PK2, PH1 (One individual from each site) | Matured forest with less disturbance. |
| *Murina cyclotis* | Round-eared Tube-nosed Bat | Least concern | 8 (0.25) | 0.27 | KH2 (1), PK1 (1), KT1 (1), PH1 (1), PK3 (1), JH3 (1), KT4 (1) and PH6 (1) | Matured forest, either hilly or flat, humid or dry. Also captured in the forest nearby limestone caves. |
| *Murina suilla* | Brown Tube-nosed Bat,<br>Lesser Tube-nosed Bat | Least concern | 28 (0.88) | 0.47 | NS1 (1), PK1 (3), MK4 (1), KH1 (1), KT1 (2), PH1 (10), KT2 (1), JH2 (1), PK2 (1), PK3 (1), KT3 (1), JH4 (2), TG1 (2) and TG4 (2) | Almost all forest types. |

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| ***Myotis ater*** | Peters's Myotis, Small Black Myotis | Least concern | 8 (0.25) | 0.13 | PK1 (4), PH2 (1), **JH3 (1)** and **JH4 (1)** | Mature hilly or flat forest, either nearby limestone areas or outside limestone areas; forest with rock boulders nearby coastal area. |
| *Myotis hasseltii* | Lesser Large-footed Myotis, Hasselt's Large-footed Myotis, Lesser Large-footed Bat, Van Hasselt's Bat, The Brown Bat | Least concern | 3 (0.09) | 0.07 | JH2 (2) and JH3 (1) | Forest with streams and boulders but outside limestone areas. |
| *Myotis muricola* | Nepalese Whiskered Myotis, Whiskered Myotis | Least concern | 16 (0.5) | 0.03 | KT2 (16) | Matured and undisturbed forest, with big canopy gap due to old wide logging trails. |
| *Myotis hermani* | Herman's Myotis | Data deficient | 1 (0.03) | 0.03 | KT2 (1) | Matured and undisturbed forest, with big canopy gap due to old wide logging trails. |
| *Myotis ridleyi* | Ridley's Myotis, Ridley's Bat | Near threatened | 5 (0.16) | 0.10 | NS1 (1), JH2 (1), PH5 (3) | Forest with boulders and limestone forest. |
| *Scotophilus kuhlii* | Lesser Asiatic Yellow House Bat, Lesser Asian House Bat, Asiatic Lesser Yellow House Bat | Least concern | 1 (0.03) | 0.03 | KH2 (1) | Tall and matured forest with spacious canopy understorey (Fig. 3). |
| *Tylonycteris pachypus* | Lesser Bamboo Bat, Club-footed Bat, Flat-headed Bat, Lesser Flat-headed Bat | Least concern | 7 (0.22) | 0.03 | KT3 (7) | Forest with large bamboo species and waterfall. |
| *Tylonycteris robustula* | Greater Bamboo Bat, Greater Flat-headed Bat | Least concern | 1 (0.03) | 0.03 | KT3 (1). | Forest with large bamboo species and waterfall. |

# DISCUSSION

With 110 species representing eight families of bats (Lim et al. 2017), Peninsular Malaysia hosts the highest density of Old World bat species (i.e., total number of species reported per total area of land) relative to other geopolitical territories within Southeast Asia. There have been several studies conducted to understand the biology of some of these bats in the past, such as the roosting behaviour of two *Tylonycteris* species (Medway & Marshall 1972) and comparison on the morphological niche and community structure of insectivorous bats from Palaeotropics with those from Neotropics (Heller & Volleth 1995). However, the biology and ecology of most of these species remain understudied (Meyer et al. 2016).

The three most abundant forest species in our survey (*R. affinis*, *H. bicolor* complex, *H. cervinus*) are known to roost primarily in caves (Kingston et al. 2006, Francis 2008) but our data clearly demonstrate they dominate bat communities in nearby forests (Table 2). Although some species such as *R. affinis* and *R. lepidus* are considered to be narrow-space foragers, research in central Peninsular Malaysia demonstrated they can travel between foraging sites (Struebig et al. 2009). The short and broad wings of these species equip them for flying in more cluttered environments (Norberg & Rayner 1987), and so it is likely that they still require some form of forested landscape features such as forest patches or riparian areas, commute to foraging sites.

In contrast, *Miniopterus magnater*, *Hesperoptenus blanfordi*, *Scotophilus kuhlii*, *Tylonycteris pachypus* and *Tylonycteris robusta* were the five singletons categorised as edge or open space species. These insectivorous bat species also have been reported to be common and widely distributed in heavily urbanised areas of the country (Francis 2008, Struebig et al. 2008), but were rarely captured in our forest sites. These species typically fly high and forage above the forest canopy but are sometimes detected in the forest understorey near canopy gaps or when accessing water resources. We captured all the open space singletons at river or waterfall, except *Scotophilus kuhlii* which was captured at the spacious understorey of tall and matured unlogged rainforest with very little undergrowth vegetation (Fig. 3, Table 2). *Scotophilus kuhlii* has been found to occasionally roost and forage in the forest and tree plantations too (Kingston et al. 2006, Francis 2008). In comparison to other forest specialist species reported in this study, the edge/open species we captured already evolved to travel far and survive well in open spaces (Evans 2010), thus face lower risk of extinction from the rapid deforestation cum urbanisation in Peninsular Malaysia.

The forests of Peninsular Malaysia also host bat species that entirely depend on the tropical rainforest in terms of roosting and foraging habitat. Members within the vespertilionid subfamilies Kerivoulinae and Murininae either roost solitary or in small groups, and are not as abundant as the cave roosting bats recorded in the study (Rossiter et al. 2012). This group of species have morphological traits that are adapted to a high-dense tropical forest (Stockwell 2001, Kingston et al. 2003, Hodgkison et al. 2004, Mancina et al. 2012) thus they are sensitive and vulnerable to deforestation and forest degradation (Struebig et al. 2008). Therefore, this group of forest specialists should be prioritised in current bat conservation strategy.

*Rhinolophus chiewkweeae* is a new species first captured from Gunung Ledang, west-coast of Peninsular Malaysia in 2005 (Mizuko & Liat 2005) and later discovered from five localities along the west coast as well as one locality at the north east coast of Peninsular Malaysia by Morni et al. (2016). In our study, we captured one male adult and


**Fig. 3 -** The habitat of where the singleton *Scotophilus kuhlii* was captured: **A**) the high and thick canopy of the forest viewed from the forest gap; **B**) the forest interior illuminated by morning sun. Photos were taken by Ching Fong Lau, Perak State Park Corporation.

one female adult of *Rhinolophus chiewkweeae* from PH3, a forest site within Pahang state of Peninsular Malaysia, making PH3 the second forest site located at the east coast of Peninsular Malaysia reported the existence of *Rhinolophus chiewkweeae*. The historical distribution of bat species may change over time due to habitat change and climate change (Struebig et al. 2015). However, the new distribution records may be be an artefact of inadequate sampling effort or sampling techniques used in the past. Hence, more comprehensive baseline surveys are still necessary in many parts of the Southeast Asian tropics.

# CONCLUSIONS

This study provides distribution records of understorey forest bats across Peninsular Malaysia at the beginning of the second millennium and reveals new localities outside the known distributional range for seven species. Of 56 reported species, nine were categorised as Near threatened by IUCN Redlist in year 2008 (e.g. *Kerivoula minuta*, *Kerivoula pellucida*, *Phoniscus atrox, Hipposideros doriae*, *Hipposideros ridleyi*, *Coelops robinsoni*, *Rhinolophus sedulus*, *Myotis ridleyi, Nycteris tragata*). While abundant and common species are easier to study due to their wide-range distribution, future research should focus more on threatened, data deficient and strict forest specialists which are most at threat from intensive deforestation to assess their conservation status. Such improved knowledge on each bat species needs to be generated to ensure the effectiveness and efficiency of our bat conservation initiatives. Bat communities should be monitored regularly to determine whether there is evidence of distributional shifts in relation to environmental change which will need to be accounted for ongoing conservation efforts.

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