Temporal changes of bat diversity in the urban habitat island of Batu Caves, Malaysia

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Abstract. Batu Caves is an isolated limestone massif surrounded by urban areas located 11km north of Kuala Lumpur and making it a “habitat island” and sanctuary for wildlife. Urban habitat islands are known as biodiversity hotspots and assist conservation in fragmented city landscapes for animals. The Batu Caves complex offer a unique condition as it houses caves that offer refuge for roosting bats out of the twenty explored caves. The most extensive cave complex is the Dark Cave with more than 2000m of surveyed passages. In this study, we compared the temporal changes of bat species diversity in the habitat island of Batu Caves. Species occurrence data was compiled using a bibliographic search in literature databases and compared with a site survey conducted in 2019 using visual, echolocation and LIDAR methods. Result of the comparison showed that there is a significant decline in bat species occurrences and diversity from previous record of eight species to only four species found roosting in the Dark Cave during our survey in 2019. The showed a decline of the number of roosting bat species especially in the Dark Cave of the habitat island Batu Caves.

1. Introduction
The concept of habitat island was introduced by the application of island biogeography theory to terrestrial patches of green spaces that becomes an “island” that form habitats that supports wildlife in the middle of a city. The habitat island thus becomes a refuge for the wildlife from the urban concrete jungle [1]. The creation of habitat islands are usually the aftermath of urban planning where urban land use planning policies mandate allocation of green spaces. Urban green space or green infrastructure includes the working landscape in cities that functions to improve air quality, serves as flood mitigation system and pollution control [2]. Although the island-biogeography perspective has largely been replaced with metapopulation theory, in which urban green spaces fall within a landscape patch-matrix framework [3], the habitat island concept is applicable to Batu Caves due to the presence of unique roosting spaces for bats. Where the green spaces are characterised by highly fragmented, small, and isolated patches of green space that are often the aftereffect of design of the urban masterplan, the Batu Cave habitat island (BCHI) was inadvertently created by its unique geological formation and the consequent anthropological adaptation slowly surrounding its massif structure, creating a towering habitat island in the Klang Valley.
Batu Caves is famously known as a religious sacred site for Hindu devotees and offers a wholesome experience of culture, nature and adventure [4]. It was named after a nearby stream called Sungai Batu and comprised a very ancient natural and geological history. Prehistoric records indicate Besisi and Temuan aborigines were observed to utilise the ground level of cave entrance for shelter. During the 1860s, the caves were discovered by Chinese farmers who were excavating bat guano to use as fertiliser because the soil in Kuala Lumpur was deficient in phosphate [5]. Realising the importance of the caves, British Colonial Office gazetted parts of Batu Caves as a Public Recreational Area Reserve in 1930. However, the quarry lease was still issued in 1954 and 1961, and only managed to be ceased twenty years later despite this hill being proposed as a national nature monument in the Third Malaysia Plan. In 1989, Malaysia Nature Society (MNS) was appointed by Selangor State Government to be the guardian of Dark Cave. Described as ‘green lung within the congested urban environment’ [6], there are at least, 267 species of invertebrates and 59 species of vertebrates inhabit Batu Caves complex [7,8].

The long history of surveys has shown that the geological structure of the outcrop rising above the Klang Valley attracted many expeditions due to its easy accessibility via river and proximity to the city of Kuala Lumpur. Earliest recorded survey was conducted 1879 [9] in with reports of roosting bats species as early as 1899 [8], representing more than a century of work on cataloguing the species of the area. The present urban developments have created a unique 1.1 km² “habitat island” that serves as a refuge for bats that may fly up to 40km roundtrips to forage for food [10,11].

The objective of this study is to create a temporal map of bat species occurrences throughout its 140 years of history. This will chart the changes over time and present a temporal dynamics available in the literature. The second objective is to update the spatial map of the Dark Cave by surveying the well-trodden underground caverns using the state of the art LIDAR (light detection and ranging scanning) survey. The updated spatial map will highlight roosting location with higher accuracy compared to previous occurrence reports that are descriptive and less precise.

2. Methodology

This study will utilise the combination of three methods: a bibliometric search, a LIDAR survey, site surveys. The data are mapped onto a timeline to identify the changes in bat occurrences until 2019.

2.1. LIDAR survey

The use of LIDAR in biodiversity survey has been successful in identifying roosting bats and swiftlets within the dark confines of caves [12,13]. LIDAR have provided a significant improvement on the accuracy of speleological surveys and improved the accuracy of underground maps [14,15]. To map the interior of the Dark Cave Conservation Site, the LIDAR scanning equipment will be the FARO Focus 3D. To process the point cloud data, the FARO Scene 4.8 is used to combine scans product, feature extraction, data slicing and exporting into other formats. The 3D point clouds created by the laser scanning was compared with previous maps reported in past surveys. The comparison will identify if the roosting location of bats has changed. The cave will be scanned at a 1/4 resolution mode (approximately 244,000points/second) with additional scans at selected locations at full resolution to attempt to identify the roosting species. The scanner has distance accuracy up to ± 2 mm; a range from 0.6 up to 130 meters and it can measure up to 976,000 points/second. The cave was scanned during several sessions from 9:00 a.m. to 4:30 p.m. to allow the roosting bats to settle down after returning to the cave, taking advantage of minimal movement of the roosting bats to improve scanning images. LIDAR’s raw scanning data will be registered using FaroSCENE 5.0 software (http://www.faro.com/) with additional data processing and analysis performed using two open sources software programs; CloudCompare (http://www.danielgm.net/cc/) and the Screened Poisson Surface Reconstruction (http://www.cs.jhu.edu/~misha/Code/PoissonRecon/Version8.0/). The data analysis will be performed separately for overall cave mapping and high resolution for identification of bats. During the survey, the LIDAR scans were restricted to areas that are safe and within line of sight. As the equipment is
expensive, only important spaces are surveyed with small and dangerous spaces avoided to prevent damage to the equipment.

2.2. Bibliometric survey
We employed a scoping review of past studies on the site past species occurrences. Scoping reviews are often employed for bibliometric studies as they can be used to rapidly map the occurrence data that are differentiated in different sources in implicit means e.g. genes, symbiotic species partners like bat flies Nycteribiidae, Streblidae and bat viruses Flaviviridae: Flavivirus. The comprehensive literature search included the use of a combination of predetermined search criteria, as listed in Table 1. The review was performed using electronic databases Google Scholar (https://scholar.google.com/) and Google (https://www.google.com/). Google is the most comprehensive academic search engine with the largest coverage of literature found in academic search engines and bibliographic databases (ASEBDs), which include subscription-based SCOPUS and Web of Science databases [16,17]. The collected publications were collated using Mendeley Desktop software package version 1.19.4 (Mendeley Ltd, London, UK) to prevent duplications. We also searched directly in specialized databases such as the Cab Direct (http://www.cabdirect.org), the legacy database Biodiversity Heritage Library (http://www.biodiversitylibrary.org) and the thesis database https://pqdtopen.proquest.com/ to identify information not available to Google crawlers, a method used previously to create a checklist for DNA barcoding purposes [18].

Table 1. List of keywords used in database and bibliometric search

| Database                        | Keywords used (comma separated)                                      |
|--------------------------------|---------------------------------------------------------------------|
| Literature databases           | Google Scholar, SCOPUS, Lens.org                                    |
| Non-Publication Databases      | GenBank                                                              |
| Specialised database           | Biodiversity Heritage Library (http://www.biodiversitylibrary.org)   |
|                                | Proquest Thesis and Dissertation https://pqdtopen.proquest.com/      |
|                                | “Batu Caves”, Batu Caves, Selangor, bats, Peninsular Malaysia, Chiroptera |
|                                | Batu Caves, Bats species name, Nycteribiidae, Streblidae, Chiroptera, Flaviviridae: Flavivirus. |
|                                | Batu Caves, Selangor, bats, Chiroptera                               |

Resulting papers from the initial search were first assessed for relevance. During the initial screening phase, the papers were assessed based on their titles. Studies showing the implicit indication occurrence of bats in the area were included. For example, the search protocol returned datasets and papers related to studies on parasites extracted from the fur of bat species taken from the Batu Caves area were included. These implicit evidences are indicators that the bat species were present at that particular time. The date of the study was used in the timeline rather than the date of publication as studies may be published significantly later than the actual completion of the study due to lengthy editorial processes.

2.3. Site survey
The site survey is the Dark Cave Conservation Site (Entrance: 3.2379°N, 101.6837°E) Batu Caves, Malaysia. It is situated in Selangor state, Peninsular Malaysia (Figure 1). Dark Cave is one of 20 limestone caves in the Batu Caves hill complex and the longest cave system in which is comprised of

3
2km surveyed passage [19] and located about 350 m above the base level and the thickness of its limestone cover is approximately 400 m [20], creating a habitat “island” surrounded by a “sea” of urban sprawl.

![Figure 1. Aerial view of Batu Cave habitat “island” surrounded by housing estates that form the suburban “sea” north of Kuala Lumpur, Malaysia. (Image from Google Maps) ](image)

The site survey collected bat calls using Pettersson’s M500 USB Ultrasound Microphone (https://batsound.com/product/m500-usb-ultrasound-microphone/) that attached to a tablet with Windows 10 Operating System. This ultrasound microphone was able to detect sounds up to 250kHz. Detected calls were monitored and recorded into the tablet via BatSound® Touch Lite program (https://batsound.com/product/batsound-touch-lite/).

The bat calls were collected concurrently with LIDAR data collection by one-way walking transect conducted on the main trail of Dark Cave with ultrasound microphone held in hand. The order of the bat calls survey by walking continuously on the main trail began from the main entrance at Cavern A and ended at Cavern C. The similar walking-transect with hand-held ultrasound microphone bat call survey then conducted separately for other caverns beside the main trail of Dark Cave e.g. Cavern D, Great Chamber, Cavern E and Cavern F.

Collected calls were analysed using BatSound® version 4.0 to identify echolocating bat species based on each species’ unique call patterns. Call characteristics that have been quantified to identify roosting bat species were call types, maximum frequency, number of harmonics, dominant harmonics, call intervals, length of each call pulse, and minimum call frequency.

2.4. Species Occurrences Dataset

Dataset from 2011 to 2018 was obtained from Cave Management Group, a management company that responsible to manage Dark Cave from March 2011 to January 2019. Observation on fallen bat were made during cave inspection morning routine, tour programs and Liphistius batuensis nest monitoring. Measurement of the bat forearm, ear, tail, tibia and weight were recorded. The morphological species identification on the fallen bat individuals was performed following the key features highlighted in [21,22].
3. Results and discussion

3.1. Mapping the occurrence timeline
The results of the three methods; a bibliometric search, a LIDAR survey and site surveys are combined to produce a plot of species versus time (years) starting from 1899 to 2019 (Appendix A1). The results showed that although the Batu Caves has a long history as a study site since 1899 and with dataset of occurrences from Cave Management Group from 2011 to 2018, the reported species are mostly from the family Pteropodidae with the nectar feeding bat *E. spelaea* being the most frequently reported. The bats from family Hipposideridae, Rhinolophidae and Vespertilionidae are only reported during the surveys in the 1960s [8]. Limited reports were found for Vespertilionidae, *Myotis muricola* in 1916 [23] and *M. federatus* in 1981 [24] and 2013 [25]. A variety of indirectly reported occurrences was found to be reported by molecular studies [11,26], work on bat flies Nycteribiidae and Streblidae [27] and bat viruses Flaviviridae: *Flavivirus*. [28]. The results showed that the nectar feeding bat *E. spelaea* was the most frequently reported compared to other species. This is possibly due to the abundance of the species in the Batu Cave complex makes it an easier subject to study. The near absence of *Vespertilio*nae could be due to their ability to roosting in manmade structure and not dependent of natural spaces like those available in the Batu Cave complex.

3.2. Acoustic and Visual Species identification
A total of four species were identified in the echolocation and on-site survey by eyes conducted in parallel with LIDAR Scan performed continuously from the entrance of Dark Cave till the end of Cavern C. These species are *Eonycteris spelaea*, *Rossettus leschenaultii* from Pteropodidae or plant-diet bat family (Figure 2), *Hipposideros diadema* from Hipposideridae family, and *Taphozous melanopogon* from Emballonuridae family (Table 2). *Eonycteris spelaea* and *Rossettus leschenaultii* were identified based on the fallen individuals on the cave ground, whereas *Hipposideros diadema* and *Taphozous melanopogon* were identified base on echolocation and fallen individuals. A total of 228 fallen individuals were recorded and 70 specimens were measured from 2012 to 2019 (Table 3, Table 4). The most common species observed are *Eonycteris spelaea* and *Hipposideros diadema*.

*Taphozous melanopogon* which is an open space species was detected right at the entrance of the Dark Cave. *Hipposideros diadema* which evolved to fly at dense and complicated habitat in the dark occupied the darkest part of the Dark Cave e.g. tunnel connecting Cavern A and the Great Chamber and the remote Cavern C. Although *Eonycteris spelaea* and *Rossettus leschenaultii* were found to have the basic ability in echolocating in the dark [29,30], these two species were detected to roost at Cavern A and around the Great Chamber with sky light sources.

| Table 2. Bat species detected within the Dark Cave base on one or more of the survey methods, as well as the detected locality in the Cave |
|---------------------------------|---------------------------------|---------------------------------|
| **Detected bat species** | **Methods of detection** | **Locality of detection** |
| Pteropodidae | | |
| *Eonycteris spelaea* | Visualisation of fallen individuals | Cavern A, Great Chamber |
| *Rossettus leschenaultii* | Visualisation of fallen individuals | Great Chamber |
| Hipposideridae | | |
| *Hipposideros diadema* | Ultrasound detector, fallen individuals | Cavern B, Cavern C |
| Emballonuridae | | |
| *Taphozous melanopogon* | Ultrasound detector | Entrance of Dark Cave |
Figure 2. Two Pteropodidae bats found fell at ground level of Great Chamber and cave entrance. A) A fallen pup of Rossetus leschenaulti, B) A fallen female Eonycteris spelaea with her newborn pup. C) An adult Hipposideridae bat, Hipposideros diadema was found hanging at lower ground of Cavern B and (D) A fallen Emballonuridae bat, Taphozous melanopogon was found at cave entrance. Photos contributed by Cave Management Group Sdn Bhd.
### Table 3. Bat species recorded within the Dark Cave based on fallen individuals from 2012 to 2019

| Classification (Scientific name) | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Grand Total |
|---------------------------------|------|------|------|------|------|------|------|------|-------------|
| *Eonycteris spelaea*             | 1    | 18   | 15   | 24   | 31   | 16   | 1    | 1    | 107         |
| *Hipposideros diadema*          | 10   | 15   | 2    | 33   | 24   | 11   |      |     | 95          |
| *Hipposideros galeritus*        |      |      |      |      | 1    |      |      |      | 1           |
| *Rousettus leschenaultii*       | 1    | 1    | 13   | 2    | 1    | 1    |      |      | 19          |
| *Taphozous melanopagon*         | 2    | 1    | 2    |      | 1    |      |      |      | 6           |
| Grand Total                     | 14   | 34   | 17   | 60   | 68   | 30   | 3    | 2    | 228         |

### Table 4. Individual recorded within the Dark Cave based on fallen individuals with measurement from 2012 to 2019. Some smaller individuals were still pup or juvenile when fell.

| Year | Cavern | Classification (Scientific name) | Forearm (mm) | Ear (mm) | Tail (mm) | Tibia (mm) | Weight (g) |
|------|--------|---------------------------------|--------------|----------|-----------|------------|------------|
| 2012 | B      | *Hipposideros diadema*          | 87           | 26       | 49        | 35         | N/A        |
|      | A      | *Hipposideros diadema*          | 66           | 30       | 40        | 29.1       | N/A        |
|      | Entrance | *Eonycteris spelaea*               | 46.7        | N/A      | N/A       | 21.6       | N/A        |
|      | A      | *Hipposideros diadema*          | 85.5         | 22.3     | 44        | 54.5       | N/A        |
|      | A      | *Hipposideros diadema*          | 80.05        | 22.8     | 40.9      | 43.9       | N/A        |
|      | A      | *Eonycteris spelaea*             | 42.2         | 10.2     | 6.4       | 23.7       | N/A        |
|      | A      | *Hipposideros diadema*          | 71.8         | 23.3     | 36.8      | 42.4       | N/A        |
|      | B      | *Hipposideros diadema*          | 84.7         | 18.8     | 50.8      | 41.5       | N/A        |
|      | A      | *Eonycteris spelaea*             | 49.6         | 10.1     | 14.1      | 20.9       | N/A        |
|      | Great Chamber | *Eonycteris spelaea*               | 47.1        | 15.3     | 0.64      | 29.1       | N/A        |
|      | Great Chamber | *Eonycteris spelaea*               | 42.4        | 13.2     | 0.84      | 34.3       | N/A        |
| 2013 | Great Chamber | *Eonycteris spelaea*               | 55.2        | 12       | 0.95      | 41.4       | N/A        |
|      | Great Chamber | *Hipposideros diadema*          | 80.5         | 21.9     | 31.3      | 38.9       | N/A        |
|      | Great Chamber | *Eonycteris spelaea*             | 73.2         | 15       | 9.5       | 29.1       | N/A        |
|      | A      | *Eonycteris spelaea*             | 25.9         | 9.7      | 7.4       | 12.9       | N/A        |
|      | A      | *Eonycteris spelaea*             | 57.4         | 14.5     | 11.5      | 24.5       | N/A        |
|      | A      | *Hipposideros diadema*          | 79.5         | 21.3     | 37        | 32.8       | N/A        |
|      | Great Chamber | *Eonycteris spelaea*               | 83.3        | 18.5     | 6.5       | 38.1       | N/A        |
|      | B      | *Hipposideros diadema*          | 87.7         | 17       | 35.4      | 43.1       | N/A        |
|      | A      | *Eonycteris spelaea*             | 69.1         | 13.4     | 12       | 29.9       | N/A        |
|      | Great Chamber | *Eonycteris spelaea*               | 28.4        | 7.8      | 4.6       | 13.9       | N/A        |
|      | A      | *Hipposideros diadema*          | 82.9         | 15.6     | 32.3      | 27.1       | N/A        |
| 2014 | A      | *Eonycteris spelaea*             | 64.2         | 10.9     | 4         | 29.2       | N/A        |
| Year | Location      | Species                  | 2015 | 2016 | 2017 |
|------|---------------|--------------------------|------|------|------|
|      |               | Eonycteris spelaea       | 80.9 | 63.2 | 32.4 |
| C    |               | Eonycteris spelaea       | 32.4 | 35.3 | 18.9 |
| C    | Great Chamber | Eonycteris spelaea       | 63.2 | 35.3 | N/A  |
| Great Chamber | Eonycteris spelaea | 63.2 | 35.3 | 18.9 |
| Entrance | Hipposideros diadema | 24   | 24   | 18.9 |
| A    | Eonycteris spelaea | 34   | 34   | 34   |
| Great Chamber | Eonycteris spelaea | 44.2 | 44.2 | 34   |
| Great Chamber | Eonycteris spelaea | 18.9 | 18.9 | 34   |
| B    | Eonycteris spelaea | 48.5 | 48.5 | 30   |
| A    | Eonycteris spelaea | 30   | 30   | 30   |
| A    | Eonycteris spelaea | 29   | 29   | 29   |
| Great Chamber | Eonycteris spelaea | 30   | 30   | 29   |
| A    | Rousettus leschenaultii | 82.8 | 24.5 | 30   |
| Entrance | Eonycteris spelaea | 24.5 | 24.5 | 30   |
| A    | Eonycteris spelaea | 64.7 | 64.7 | 30   |
| Entrance | Eonycteris spelaea | 62.5 | 62.5 | 30   |
| A    | Eonycteris spelaea | 37.5 | 37.5 | 30   |
| A    | Eonycteris spelaea | 25.7 | 25.7 | 30   |
| Entrance | Taphozous melanopagon | 30   | 30   | 30   |
| Entrance | Eonycteris spelaea | 27   | 27   | 27   |
| Great Chamber | Hipposideros diadema | 26.1 | 26.1 | 27   |
| B    | Hipposideros diadema | 43.3 | 43.3 | 27   |
| A    | Hipposideros diadema | 25.4 | 25.4 | 27   |
| A    | Hipposideros diadema | 38.4 | 38.4 | 27   |
| A    | Eonycteris spelaea | 18.5 | 18.5 | 27   |
| A    | Eonycteris spelaea | 37   | 37   | 27   |
| Entrance | Eonycteris spelaea | 34.6 | 34.6 | 27   |
| A    | Eonycteris spelaea | 35.3 | 35.3 | 27   |
| A    | Hipposideros diadema | 51   | 51   | 27   |
| A    | Eonycteris spelaea | 44   | 44   | 27   |
| A    | Eonycteris spelaea | 44   | 44   | 44   |
| Entrance | Eonycteris spelaea | 38   | 38   | 44   |
| Great Chamber | Eonycteris spelaea | 38   | 38   | 44   |
| A    | Rousettus leschenaultii | 56.7 | 56.7 | 44   |
| A    | Hipposideros diadema | 55.8 | 55.8 | 44   |
| A    | Eonycteris spelaea | 53   | 53   | 44   |
| A    | Eonycteris spelaea | 64.7 | 64.7 | 44   |
| Great Chamber | Rousettus leschenaultii | 79.4 | 79.4 | 44   |
| A    | Hipposideros diadema | 51.4 | 51.4 | 44   |
| AB   | Eonycteris spelaea | 42.6 | 42.6 | 44   |

**Notes:**
- **2015:** Data for the year 2015.
- **2016:** Data for the year 2016.
- **2017:** Data for the year 2017.
- **N/A:** Not available.
3.3. 3D LIDAR map of the Dark Cave and roosting locations

The survey of the cave was completed in two sessions and transferred to a 2D map and compared with the 1967 McClure map [31]. (Figure 3).

**Figure 3.** The map of the Dark Cave, the only recorded map among the 20 caverns found the Batu Cave complex. The LIDAR map (left) and the hand-drawn from McClure [31] (right) with the roosting species denoted by coloured zones in the LIDAR map.

The use of LIDAR scanning allowed the direct identification of location of roosting bats as the individual bats can be distinguished from the cave wall [12]. The different reflectance values between the bats and the surrounding cave are generated because the bats possess darker colour and characteristics of the bat's fur that allows it to absorb the laser pulses more compared to solid surface of the cave. These difference in the values are used to classify the point cloud and to distinguish the roosting bats.

Combination of LIDAR Scan, acoustic and visualisation survey methods concurrently have verified the roosting zones of the detected species, which *Taphozous melanopogon* roosting at the entrance of the Dark Cave, *Hipposideros diadema* roosting at the total darkness part of the Dark Cave (e.g. Cavern...
B, and Cavern C), *Eonycteris spelaea* roosting at Skylight areas of Cavern A and Great Chamber, and *Rousettus leschenaultii* occupying the Great Chamber and skylight areas of Cavern C (Figure 3).

It must be noted that the LIDAR scan would not be able differentiate between different species in a mixed roosting colony of more than one species. Past LIDAR scanning was only able to detect *H. larvatus* because it is relatively large size and the physical characteristics [32]. In order to identify and distinguish specific species which are small size without unique external features using LIDAR scan, this approach needs to combine with visual and acoustic methods.

Appendix A1 indicated historically rich diversity of bat community in this isolated natural habitat of Batu Cave limestone karst. Out of 23 species recorded, eight species were recorded roosting in the Dark Cave. However, only four species detected base on our one-time LIDAR-visual-acoustic integrated survey approach and fallen bat records between 2012-2019, which is relatively low diversity in comparison to what had reported previously. Given the huge size and complicated structure of Dark Cave, there may still be small groups of other bat species roosting in the Dark Cave but fail to be detected by our survey design. One of the reasons maybe our study is just a one-time survey without applying conventional bat trapping methods such as mist nets or harp traps which trapping efficiency have been proven. Challenge that make us exclude harp traps and ground level mist nets is because the cave ceiling and openings of Dark Cave were too high up and very complicated at most areas. Besides, smaller rooting sites at complicated crevices or holes beyond reach by eye sights, ultrasound mic and LIDAR Scan maybe missed. Therefore, thorough survey from different approaches are needed to conclusively determine the role of Dark Cave and other caves of Batu Caves as a refuge for bats of north Kuala Lumpur.

### 4. Conclusion

The conservative survey results showed that the Dark Cave, which is the most studied and the largest cave within Batu Caves complex only retained four species identified in 2019, despite a total of eight bat species were reported depended on this cave based on literature collection of over a century. Although *E. spelaea* was mostly reported and other species were reported less, the apparent bias to report *E. spelaea* was probably due to its abundance and their roosting locations near the entrance that makes it relatively easier to sample. The severe decline in retention of bat species reported for Dark Cave, alarmed us the loss of its role as a refuge for bats against the ever expanding urban sprawl of Klang Valley for the past 100 years. A detailed survey is required to conclusively identify all other species as well as re-explore other caverns around the Batu Cave habitat island. Concerted effort must start on officially recognising the whole Batu Cave complex as a protected area to avoid the disappearance of this unique yet remain nature heritage of Kuala Lumpur.

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### Appendix A

The results of the three methods; a bibliometric search, a LIDAR survey and site surveys are combined to produce a plot of species versus time (years) starting from 1899 to 2019.
| No | 1 | 2 | 3 | 4 | 5 | 6 |
|----|---|---|---|---|---|---|
| Family | Emballonuridae | Emballonuridae | Emballonuridae | Emballonuridae | Emballonuridae | Emballonuridae |
| Taxon | Emballonuridae | Pteropodidae | Pteropodidae | Pteropodidae | Pteropodidae | Pteropodidae |
| Common English name |  |  |  |  |  |  |
| Black Bearded Tomb Bat | Cave Nectar Bat, Lesser Dawn Bat | Daisy fruit Bat | Dayak fruit Bat | Leschenault's Rousette Bat | Geoffroy Rousette Bat | Geoffroy Rousette Bat |
| Taphozous melanopogon * (Temminck 1841) | Eonycteris spelaea* (Dobson 1871) | Pteropus hypomelas* (Dobson 1871) | Pteropus hypomelas* (Dobson 1871) | Rousettus leschenaultii* (Desmarest 1820) | Rousettus aegyptiacus* (Geoffrey 1810) | Rousettus aegyptiacus* (Geoffrey 1810) |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Decade | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 | 2011-2019 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 |
| Decade        | Family | Genus                     | Species | Common English name                  | Taxon                          | English name |
|--------------|--------|---------------------------|---------|--------------------------------------|-------------------------------|--------------|
| 1961-1970    |        | Cynopterus                | C. brachyotis | Lesser short-nosed fruit bat         | Cheiroptera                  | Cynopterus   |
| 1971-1980    |        | Cheiromeles               | C. torquatus  | Greater Naked Bat                   | Molossidae                   | C. torquatus |
| 1981-1990    |        | Megaderma                | M. spasma   | Lesser False Vampire Bat             | Megadermatidae               | M. spasma    |
| 1991-2000    |        | Hipposideros              | H. armiger  | Great Roundleaf Bat                  | Hipposideridae               | H. armiger   |
| 2001-2010    |        | Hipposideros              | H. bicolor  | Bicoloured Roundleaf Bat             | Hipposideridae               | H. bicolor   |
|              |        | Hipposideros              | H. diadema  | Diadem Roundleaf Bat                 | Hipposideridae               | H. diadema   |
|              |        | Hipposideros              | H. galeritus| Cantor Roundleaf Bat                 | Hipposideridae               | H. galeritus |

| No | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|----|---|---|---|----|----|----|----|
|    |   |   |   |    |    |    |    |
| No | Family | Taxon | Common English name | Decade | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 | 2011-2019 |
|----|--------|-------|---------------------|--------|-----------|-----------|-----------|-----------|-----------|-----------|
| 14 | Rhinolophidae | Rhinolophus affinis* (Horsfield 1823) | Intermediate Horseshoe Bat | 1991 to 1995 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | Rhinolophidae | Rhinolophus luctus (Temminck 1835) | Woolly Horseshoe Bat | 1961 to 1975 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 16 | Rhinolophidae | Rhinolophus pusillus (Temminck 1834) | Least Horseshoe Bat | 1971 to 1985 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 | Rhinolophidae | Rhinolophus trigolatus (Temminck 1833) | Trefoil Horseshoe Bat | 1981 to 1995 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 18 | Rhinolophidae | Rhinolophus stheno | Lesser Brown Horseshoe Bat | 1991 to 2005 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 | Rhinolophidae | Rhinolophus latus (Blyth 1844) | Glossy Horseshoe Bat | 1961 to 1975 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 20 | Vespertilionidae | Myotis ridleyi (Thomas 1989) | Ridley's Myotis | 1971 to 1985 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 21 | Vespertilionidae | Myotis muricola | Asian Whiskered Myotis | 1981 to 1995 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 22 | Vespertilionidae | Myotis federatus | Malay Whiskered Myotis | 1991 to 2005 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | Vespertilionidae | Myotis sp** | | 1971 to 1985 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
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Identified and reported in this work

Species recorded in Dark Cave based on past studies

* Species recorded in Dark Cave but requires further confirmation

**Appendix A1.** The bibliometric timeline for the Family and species of bats occurrences from 1899 to 2019 for the entire Batu Caves limestone karst. The brown boxes denotes the largest compilation by Moseley [8], the numbered green boxes represent the most frequently reported species *E. spelaea*, the differently coloured boxes represent different species and the red boxes are species reported in this work.

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