BIOLOGICAL AND ECOLOGICAL CHARACTERISATION OF ROOSTING BATS AND TROGLOFAUNA IN THE DARK CAVE CONSERVATION SITE USING LIDAR TECHNOLOGY

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ABSTRACT

Batu Caves is a habitat island of limestone karst tower surrounded by metropolitan areas located 11 km north of Kuala Lumpur. A total of 20 caves are recognised within the Batu Caves complex and Dark Cave, approximately two kilometres long, is the longest cave system. It supports 151 invertebrates and 22 vertebrates with significant species endemicity. Nine reported caverns were mapped using conventional speleological methods. The cave is known as the most studied tropical cave in Southeast Asia. However, the most detailed biological survey was conducted about 50 years ago, and there has been no up-to-date study on the cave characteristic and detailed biological survey using the latest technology. In this study, the interior of the cave was mapped using three dimensional Light Detection and Ranging (3D LIDAR) laser scanning to produce a 3D model of the caverns. The roosting location of bats were mapped based on LIDAR scans and acoustic data and compared with historical data to detect species trends or any new locations. The location of troglofauna occurrences were marked on the new LIDAR map. The projected 3D point cloud model of the cave was generated after 27 hours of LIDAR data scans that was collected over four site visits which covered 805 m of walking distance. The results produced a more accurate representation of the 3D LIDAR map. The shape and orientation of the underground spaces were similar between the LIDAR map and the latest conventional map. Vertical features (cave height) have provided more precise dimensions of the caverns. The integration of LIDAR-acoustic- visualisation survey methods further confirms only five bat species (Taphozous melanopogon, Hipposideros diadema, H. larvatus, Eonycteris spelaea, and Rousettus leschenaultii) roosting in the Dark Cave. Troglofauna observations found nine species of mammal (including bat), 11 species of invertebrates, five species of birds and 19 species (one genus level) of reptiles were recorded throughout the cave system from 2012 to 2019. Features such as bat roosting locations, speleothem, number of skylights, cave dimensions, man-made structures and seasonal water flowing zones are the map novel features. The spatial information in 3D virtual models can be used repeatedly on post-survey analyses. These outcomes produced a more accurate speleological map of Dark Cave for scientists to conduct long-term monitoring studies and state government together with management authority in managing Dark Cave as an ecotourism, education and conservation site.

ABSTRAK

Batu Caves mempunyai topografi “pulau” berbatu kapur kars yang dikelilingi oleh kawasan metropolitan dan terletak 11 km di utara Kuala Lumpur. Sebanyak 20 gua diiktiraf di dalam kompleks Batu Caves dan Gua Gelap, sepanjang dua kilometer adalah sistem gua terpanjang. Ia menampung lebih 151 spesis invertebrata dan 22 vertebrata, dengan spesis endemik tersendiri. Sembilan gegua telah dipetakan menggunakan kaedah speleologi konvensional. Gua gelap dikenali sebagai gua tropika yang paling banyak dikaji di Asia Tenggara. Bagaimanapun, tinjauan biologi yang terperinci dijalankan kira-kira 50 tahun lalu dan tiada kajian terbaru mengenai ciri gua dan tinjauan biologi terperinci menggunakan teknologi terkini. Dalam kajian ini, bahagian dalam gua telah dipetakan menggunakan Light Detection and Ranging tiga dimensi (LIDAR – 3D) untuk menghasilkan model 3D. Untuk mengesan trend spesis, lokasi bertengger kelawar dipetakan menggunakan alat LIDAR dan data akustik. Lokasi troglofauna ditandakan pada peta LIDAR baru. Model point cloud 3D gua dihasilkan selepas 27 jam imbasan data LIDAR yang dikumpulkan daripada empat kali lawatan tapak dan meliputi jarak berjalan sepanjang 805 m. Keputusannya, peta LIDAR-3D yang lebih tepat dapat dihasilkan. Bentuk dan orientasi gua adalah serupa antara peta LIDAR dan peta konvensional. Ciri-ciri menegak (ketinggian gua) telah memberikan dimensi gua yang lebih tepat. Integrasi kaedah survei LIDAR-akustik- visual mengesahkan hanya lima spesis kelawar (Taphozous melanopogon, Hipposideros diadema, H. larvatus, Eonycteris spelaea, dan Rousettus leschenaultii) berada di Gua Gelap. Pemerhatian troglofauna mendapati sembilan spesis mamalia (termasuk kelawar), 11 spesis invertebrata, lima spesis burung dan 19 spesis reptilia (1 genus) telah direkodkan di seluruh sistem gua dari 2012 hingga 2019. Ciri-ciri seperti lokasi bertengger kelawar, speleothem, bilangan jendela langit, dimensi gua, struktur buatan manusia dan zon aliran air bermusim adalah ciri-ciri baru peta. Maklumat ruang dalam model maya 3D boleh digunakan berulang kali pada analisis pasca tinjauan. Dapatan ini menghasilkan peta speleologi Gua Gelap yang lebih tepat; terutama bagi saintis untuk menjalankan kajian pemantauan jangka panjang dan kerajaan negeri bersama-sama dengan pihak pengurusan menguruskan Gua Gelap sebagai tapak ekopelancongan, pendidikan dan pemuliharaan

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LIST OF ABBREVIATIONS

3D	-	3 Dimension
CE	-	Cave Entrance
CF	-	Constant Frequency
CMG	-	Cave Management Group Sdn Bhd
D	-	Distance
DNA	-	Deoxyribonucleic Acid
DT	-	Duration
DWNP	-	Department Of Wildlife And National Park
EF	-	End Frequency
EN D1	-	Endangered
FM	-	Frequency Modulated
GC	-	Great Chamber
GI	-	Green's Index
H	-	Height
HF	-	High Frequency
IPI	-	Interpulse Interval,
IR	-	Infrared
IUCN	-	International Union For Conservation Of Nature
kHz	-	Kilohertz
KM	-	Kilometer
LF	-	Low Frequency
LI	-	Light Intensity
LIDAR	-	Light Detection And Ranging
MCKC	-	Malaysian Cave And Karst Conservancy
MNS	-	Malaysia Nature Society
RH	-	Relative Humidity
SBCG	-	Selangor Branch Cave Group
SD	-	Standard Deviation
SF	-	Start Frequency
T	-	Temperature

TLS	-	Terrestrial Laser Scanning
USA	-	The United States Of America
USM	-	Universiti Sains Malaysia
UTHM	-	Universiti Tun Hussein Onn Malaysia
UTM	-	Universiti Teknologi Malaysia
W	-	Width
WD	-	Walking Distance
WS	-	Wind Speed
±	-	Plus minus

CHAPTER 1

INTRODUCTION

1.1 Background

Batu Caves is famously known as a religious sacred site for Hindu devotees and also offers a wholesome experience of culture, nature and adventure (Musa et al. 2017). It was named after a nearby stream called Sungai Batu and comprised a very ancient natural and geological history. Prehistoric records indicate Besisi and Sakai aborigines were observed to utilize 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 fertilizer because the soil in Kuala Lumpur was deficient in phosphate (Soepadmo and Hua, 1971).

Dark Cave is the longest cave system in Batu Caves and inhabits diverse troglofauna and geological features and flora. The Dark Cave Conservation Site is a well-known documented site. A diverse cave ecosystem first reportedly surveyed in 1898 by Ridley that reported on the species of cave racer, *Orthriophis taeniurus* (formerly known as *Coluber taeniurus)* rat snake. Located in the outskirt of north Kuala Lumpur urban sprawl, it is an isolated limestone massif that has been reported to support significant endemic species (Moseley, 2009).

The Dark Cave itself is a karst and caves system containing a variety of both terrestrial and aquatic habitats (McClure, 1965; McClure et al. 1967). A total of 151 invertebrate and 22 vertebrate taxa have been recorded from Dark Cave (Moseley et al. 2012). The surveyed length has been reported to be more than 2 kilometres (km) long with species of eutrophic insectivorous and frugivorous bats' guano habitats, mesotrophic cave soil and through to highly oligotrophic sites (active flowstone surfaces and gour pools) (Moseley, 2004). The Dark Cave's biota complex have been relying majorly on the large colonies of roosting bats, that forage outside of the cave each night, which then discharge significant amounts of guano back in the cave. This is the main food source to sustain the troglobites (McClure et al. 1967). The cave racers on the other hand, consume live bats which were caught as they clung to the cave ceiling or walls. The bat carcasses were then decomposed by cave invertebrates such as mites and Collembola (McClure et al. 1967).

Dark Cave has the most comprehensive and unique database collection in Southeast Asia. Still, the fauna inventories are incomplete (Moseley, 2004). However, this massive size of the Dark Cave makes it challenging to implement traditional research techniques. It has a much larger cavern complex compared to the Temple Cave. The height in some caverns can reach up to 45 meters (m) and 30 m wide (McClure et al. 1967). There are lack of studies published on other caves in Batu Caves (Lim et al. 2010).

The recent 3D Light detection and ranging (LIDAR) systems used in terrestrial laser scanning (TLS) have been shown to provide a technological leap that increases the efficiency and the accuracy of speleological surveys and have been used in biodiversity research work (Azmy et al. 2012, Gallay et al. 2015, Shazali et al. 2017). LIDAR systems are contact-free ranging instruments that measure and record geometric information of surface targets using the pulse of laser lights to create 3D representations (Oludare et al. 2016).

LIDAR 3D scanning has been successful in the survey of roosting bats (Azmy et al. 2012, Shazali et al. 2017), swiftlet nests (McFarlane et al. 2015) and even roosting in trees (Blakey et al. 2017). Therefore, it is essential to integrate the new available technologies and methodologies in order to improve the accuracy of the species occurrence and roost characteristic reporting to provide scientists with an accurate, non-invasive, surveying tool that efficiently enables the 3D reconstruction of this cultural and heritage wealth.

In this study, the advanced 3D LIDAR laser scanning method is utilised in combination with conventional biological survey data and archival to produce an updated biological and ecological characterisation of the Dark Cave Conservation Site, further focusing on the roosting bat community.

1.2 Problem Statement

The most detailed biological survey in the Dark Cave was conducted between 1959 to 1961 by McClure's team, which was more than half a century ago (Moseley et al. 2012). Dark Cave was gazetted as a public recreation area in 1930 by the British Colonial Office and was opened to the public in 1973. Infrastructure such as concrete pathways, benches and cave lighting were installed throughout Cavern A, B, D and Great Chamber. This self-guided activity by the visitors has caused a lot of graffiti and rubbish in the cave. In 1984, Malaysian Nature Society (MNS) took over the Dark Cave management and began the cave restoration (Yusoff, 1997). Since then, the Batu Caves surrounding the area have been rapidly developed. Dark Cave is known as the most studied tropical cave in Southeast Asia, but currently there is lacked of updated study on the cave's characteristic and detailed biological survey (Moseley et al. 2012). Thousands of bats are roosting and swarming the cave ceiling. Surveys of bat species in the Dark Cave have relied on conventional survey techniques based on visual observation to produce occurrence and population size data (McClure et al. 1965). However, some of these traditional methods also have limitations for the large clustered and closely roosting bat due to the height of cave ceiling, which is impossible to produce an accurate population size.

In addition, occurrence and species survey of subterranean spaces or caverns used to depend on manually charted maps. Classic cave survey has been always performed through compass and tape techniques, and in very rare cases precise surveying instruments have been used in the survey of large subterranean spaces and caves (Trimmis, 2018). This is also the situation with the caves and karst studies in Malaysia, even for Malaysia's best-studied limestone locality, Batu Caves (Moseley et al. 2012). The first map of the cave was published in 1929 (Heynes-Wood and

Dover, 1929). In recent years, various techniques and technologies have been extensively implemented in cave mapping (Trimmis, 2018). Although technological developments over time have shown improvements on the representation and accuracy, the Dark Cave has yet to be mapped using terrestrial LIDAR scanning. This research would overcome the present limitations, especially in providing accurate location of the bat's roost while providing a more precise representation of the cave map including biology and ecological data of the Dark Cave.

1.3 Research Objectives

The objectives of the research are:

i. To map the interior of the Dark Cave Conservation Site using Light Detection and Ranging (LIDAR) technology
ii. To compile microclimate on selected spots within the cave to produce a complete 3-dimensional speleological map
iii. To map the roosting location of bats based on LIDAR scans and acoustic data, further
iv. To compare current roosting spots with historical data to detect trends or new found locations
v. To mark and characterise the location of troglofauna occurrences on the new LIDAR map

1.4 Significance of Study

This study will highlight the characterisation of roosting bats, which is the largest population inhabit Dark Cave and other troglofauna. The study will produce a more accurate and three dimensional LIDAR based speleological map of the Dark Cave Conservation Site that can be used by biologists for future monitoring purposes. The updated map will be the basis of mapping species occurrences, especially the bats as well as mapping previous occurrences data in archival biodiversity depository. This study also will highlight the importance of ecologists and remote sensing experts to corporate and investigate the LIDAR applications in other areas in field ecology for other major breakthroughs.

1.5 Scope of Research

This study focused on the bats roosting in the Dark Cave Conservation Site at the Batu Caves Limestone Complex. The available data were derived from archival data; the latest manual fauna survey of the cave was by (McClure et al. 1967). The manual map was the basis of comparison with the research using the novel LIDAR data. The occurrences data was based upon the site survey and mined from the bibliometric study of the literature. The species' scope was focused on the chiropteran species (bats) but other species occurrences were highlighted to show species diversity and richness of the conservation site.

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