Malaysian Cave and Karst Conservancy Batu Caves Scientific Expedition 2019

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Abstract : Batu Caves, an isolated limestone karst hill covering 1.1 km^2 and 329 m tall, lies about 11 km from Malaysia's capital city, Kuala Lumpur. It is surrounded by urbanisation and encroachment presses ever-closer to its base. It is famous for the Sri Subrarmaniam Swamy Temple Cave that attracts thousands of devotees and tourists. The forested buffer zone has been eliminated making the hill vulnerable to accidental fires and invasion by alien species. Although the last quarry closed in 1982 due to public pressure, the hill has yet to be given secure legal protection. However, the Expedition demonstrated that it still harbours significant biodiversity: 366 species of vascular plants, of which one is a new species, five are endemic to Batu Caves, 22 are threatened and five are probably extinct; 56 bryophytes with two liverworts that are new records for Peninsular Malaysia; 15 species of bats roost in the caves and include 6 new records; a family of dusky leaf monkeys still survive; 51 bird species were recorded including three limestone specialists; 25 reptiles including the bent-toed gecko endemic to Batu Caves; seven species of amphibians; 38 native species of snail of which eight are endemic to Batu Caves; 52 butterflies; as well as five new caves that were discovered and mapped and fossil sites recorded. Batu Caves is important as the site where orang-utan fossil teeth were first discovered in Peninsular Malaysia.

Keywords: biodiversity, conservation, endangered species, geomorphology, limestone

INTRODUCTION

The Batu Caves massif, *Gua Batu* in Malay, is an iconic tower karst limestone hill that dominates the landscape. With its white vertical cliffs, it can be seen from miles around. It lies in the state of Selangor (3º 14′ N 101º 41′ E), about 11 km northeast of Kuala Lumpur city District under the jurisdiction of the Selayang District Council. It is the southernmost large tower karst hill in continental Asia (Figure 1).

Batu Caves is not only an outstanding nature monument, it is also of paramount scientific importance for its cave ecosystem and unique animal and plant biodiversity that includes many rare and/or endemic organisms. Nationally, it is classified as an Environmentally Sensitive Area Rank 1 (National Physical Plan, 26 April 2005). Batu Caves is best known among the general public for their Temple Cave that houses the Sri Subramaniam Swamy Temple, where up to a million devotees and visitors converge annually for Thaipusam festival and is a tourist attraction throughout the year. Parts of the 2-km long Dark Caves have been open to tourists.

The impetus for organising the Expedition arose from increasing concern on the escalating encroachment – both in extent and speed – on Batu Caves, exemplified by the Great Burn in February 2016, when a large area burned for three days and was even featured on national television. Encroachment continues daily. The buffer zone of forest has been almost eliminated by urbanisation with only a narrow remnant left in a few areas, alien and secondary forest species of both plants and animals have invaded, and all ground-level caves have been occupied, raising the question of whether any biodiversity remains and whether the caves have suffered irreversible damage.

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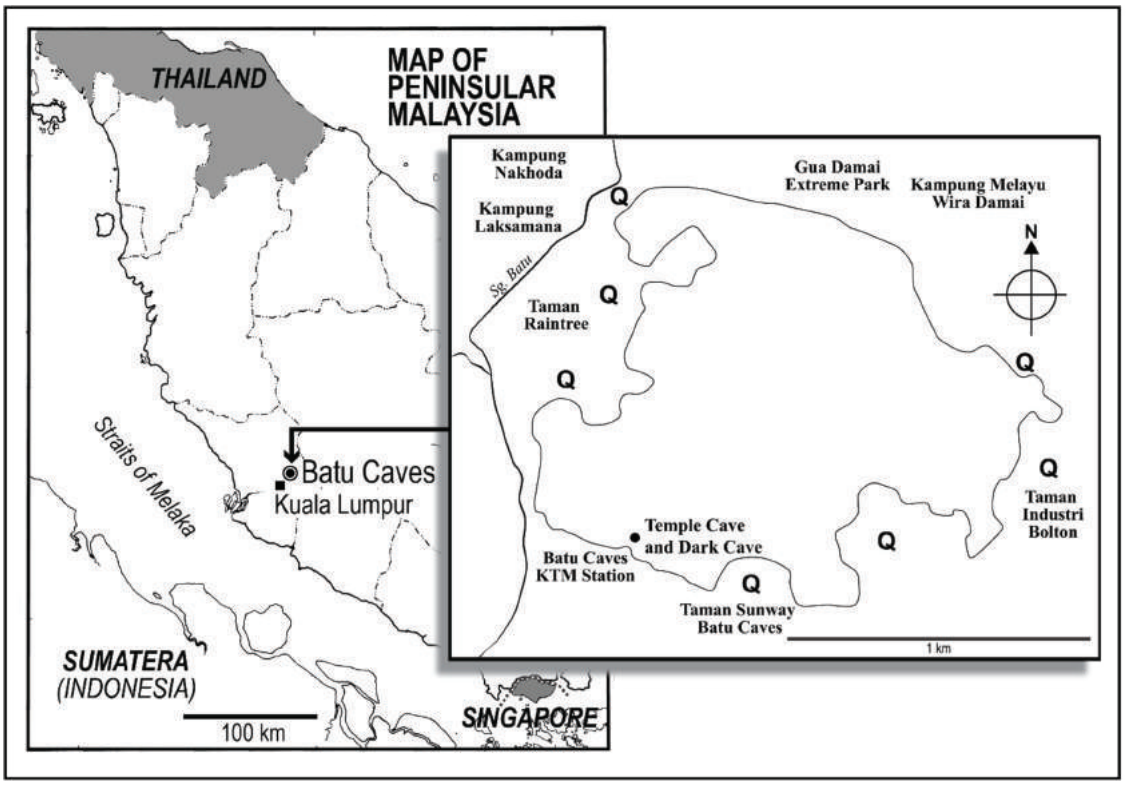

Figure 1. Map of Batu Caves (Q: Old Quarry Area).

The Expedition was initiated and organised by the Malaysian Cave and Karst Conservancy (MCKC), a specialist NGO concerned with promoting conservation, scientific research and exploration of caves and karst. The NGO also advocates for proper management of cave and karst resources, especially for responsible tourism of cave and karst areas, and advancing awareness of the scientific, educational, aesthetic, historical and cultural values of caves and karsts.

History of threats and protection

In 1930, the British Colonial Office gazetted Batu Caves as an area reserved for Public Recreation through the provisions of the Land Code of 1926. Part of the cave was excised for a quarry in 1954, and again in 1959 where a second quarry was established. The irreversible damage from these quarries aroused great concern. In 1961, a group of scientists and the Malayan Nature Society (MNS) protested but their concerns were ignored. This led to setting up the Batu Caves Protection Association (BCPA) in 1964 to bring greater public pressure to protect Batu Caves. In 1970, the government declared Batu Caves a tourist attraction, but a third quarry was opened by the Public Works Department. In July 1971, the BCPA (in conjunction with the Malayan Nature Society and the Sri Maha Mariamman Temple) strengthened their joint appeal for an end to quarrying. A small, scholarly 30-page Guide to Batu Caves was then issued, edited by Soepadmo and Ho (1971) that covered history, geology, animal life, plants, culture and religion to raise awareness of the importance of Batu Caves. In 1971, the Selangor State Tourist Corporation laid concrete paths into the Dark Cave and installed lighting to illuminate 'features of interest'.

In 1976, the Third Malaysia Plan recognised Batu Caves as unique national heritage and proposed it as a Nature Monument. In April 1980, Dr Ng Sook Ming from University Malaya, who carried out regular monitoring, reported rock falls in the Dark Caves associated with blasting by the nearby quarry. The local press raised the alarm that the roof of the adjacent

Temple Cave might collapse. The Dark Cave was closed to visitors, but quarrying continued until increasing public outcry finally ceased the blasting in December 1980. The Malayan Naturalist (1980) provided summaries of scientific works carried out on Batu Caves and chronicled the attempts to protect Batu Caves. In 1997, the first guidebook for the Dark Caves, *The Natural and Other Histories of Batu Caves* by Shaharin Yussof, was produced by MNS. MNS soon took over supervision of the Dark Caves from the State government for education and tourism and from 2011-2019, it was managed by the Cave Management Group.

Aims of Batu Caves Scientific Expedition (BCSE)

The aims of BCSE were three-fold. Firstly, to assess whether known features of the Batu Caves still persisted, and to close the knowledge gaps for groups of plants and animals that had not been inventoried previously. For example, organisms that inhabit outside the caves like mammals, birds, snakes, lizards, frogs and toads, and snails, as well as bryophyte plants.

Secondly, the Malaysian Cave and Karst Conservancy (MCKC) felt that it was equally important to raise awareness on the importance of the geology and biodiversity of Batu Caves among the public, stakeholders, schools and people who lived in the immediate vicinity.

Thirdly, the ultimate aim of BCSE was not only to provide baseline data, but also to advocate for the secure and permanent protection and the management of Batu Caves.

Previous scientific studies

In 1897-1898, the first scientific visit to Batu Caves was carried out by Ridley (1898), Director of the Botanic Gardens, Singapore, who collected plants and explored the caves collecting animals and archaeological remains. Dover and Heynes-Wood, who were then working in the Institute of Medical Research (IMR), Kuala Lumpur, produced the first detailed faunal inventory from the Dark Caves (Dover 1929). Between May 1959-January 1961, McClure and his team from IMR carried out regular monitoring of the ecology of the Dark Caves (McClure 1961; McClure *et al.* 1967). Later studies in the Dark Caves included those by Bullock (1965), who updated the inventory to the Dark Caves, and in the 1970s, Start and Marshall (1976) studied the food sources of nectarivorous bats from pollen in their guano in Batu Caves, and established the importance of link between bats and durians. In 1980s, the MNS Selangor Branch Caving Group explored and mapped many of the caves. Unfortunately, these maps were never published. After a hiatus of almost twenty years, two inventories were published: one for fauna of the Dark Caves (Moseley *et al.* 2012) and the other for vascular plants (Kiew 2014). These inventories drew attention to Batu Caves as a type locality for many plant and animal species, and at least 31 species of vascular plants (Kiew *et al.* 2023), which emphasises the great scientific importance of Batu Caves as a living museum and where scientists of future generations can return to obtain living material from the type population to verify identifications and carry out more sophisticated studies as technologies advance.

Batu Caves is a Mecca for scientists and specialists who continue to make new discoveries. Since the two inventories were published, new records have been reported regularly: a new species of bent-toed gecko *Cyrtodactylis metropolis* (Grismer *et al.* 2014), a snail *Alycaeus selangorensis* (Foon and Liew 2017), a tree *Polyalthia guabatuensis* (Turner *et al.* 2018); and molecular analysis confirmed the identity of the flatworm *Dugesia batuensis* (Khang *et al.* 2017) and collembolan *Pseudoparonella doveri* (Deharveng *et al.* 2018) as Batu Caves endemics. Discovery of Pleistocene fossil teeth of orangutan from the cistern and swamp caves at Batu Caves were the first record for Peninsular Malaysia (Yasamin *et al.* 2012, 2013) and in 2019, Ishlahuda *et al.* reported finding fossil teeth of six species of extinct and extant rat species indicative of lowland forest environments in the Pleistocene.

BATU CAVES SCIENTIFIC EXPEDITION: 2019-2020

The expedition scientific committee (Zubaid Akbar bin Mukhar Ahmad (Chairman) with Nur Atiqah bte Abd. Rahman (Executive Secretary), Nurul Hidayah binti Abdullah (Treasurer) and committee members Ruth Kiew, Don Haider bin Kamarudin, and Lim Teck Wyn shouldered the organisation of the expedition to fulfil the various aims of the Expedition as follows:

(a) To close the knowledge gaps and to assess the current status by assembling a scientific team to survey the biodiversity of as many groups of plants and animals as possible and to explore and examine geological features and processes;

(b) To provide a permanent record and dissemination of information through holding a symposium with the subsequent publication of scientific studies in this symposium volume;

(c) To generate awareness and publicity for conservation of Batu Caves by setting up a website, posting regular bulletins on facebook, by the production of a guidebook, Batu Caves Malaysia's Majestic Limestone Icon, and conducting awareness programmes;

(d) To ensure the safety of participants due to difficulty of access and the dangerous terrain, collaborating with the Wira Extreme Park to provide experienced guides.

Generous grants from Tan Jiew Hoe and the Cave Management Group enabled the BCSE to begin activities in October 2018. Critically, it enabled MCKC to employ an Executive Secretary to co-ordinate the activities, facilitate scientific work, liaise with government departments and other actors, set up the website, initiate the Friends of Batu Caves group, produce and disseminate monthly newsletters, set up and conduct the awareness programme, act as assistant editor for the guidebook as well as contributing text and photographs and organise the scientific symposium. In 2019, the Selangor State Government, Qaira Hijab Holdings Sdn. Bhd., Asia Pacific Environmental Consultants Sdn. Bhd. and local village associations sponsored the awareness programme and other symposium activities. Tan Jiew Hoe sponsored the production of the guidebook. The Selayang District Council, the Selangor Chief Minister's office and the Gombak Library co-organised and funded the symposium.

The Expedition also received strong support from MNS Selangor Branch, who shared their auditorium for meetings and many of their members were active in scientific studies, photography and the awareness programmes; the Cave Management Group provided office space and logistic support that enabled the Expedition to get off the ground and provided funds for the initial reconnaissance of suitable trails for scientists on Batu Caves; EcoKnights allowed us to be based at their office; Treat Every Environment Special (TrEES) gave inputs for the awareness programs; Selayang District Council gave strong support and interest throughout the Expedition and Damai Extreme Park and their guides provided logistical assistance to the participants.

The BCSE attracted a wide range of dedicated experts and specialists who care about the future and well-being of Batu Caves and gave their time and used their funds. Sixty-four individuals from ten institutions participated in the expedition. Biologists carried out surveys to provide up-to-date information and comprehensive inventories. For many fauna groups, this was the first time that species that live on the karst, rather than in the caves, were surveyed. Geologists explored the karst morphology to understand its formation, and record cave features and sites of fossil remains. Their results were presented at a one-day symposium held on 26 September 2020, that included 13 presentations and 20 posters with 79 attendees and a further 4000 people viewing online. The scientific results of the BCSE are to be published in a special symposium volume of The Malayan Nature Journal.

Meanwhile, a preliminary survey was conducted on 116 respondents in the Batu Caves area to determine their awareness levels. About a third of respondents (35.8%) stated that Batu Caves is well known for the Thaipusam festival, followed by extreme sports and recreation (33%), high biodiversity (19.6%) whilst 11.7% of respondents thought Batu Caves had no interesting attractions. Most of the respondents (88.8%) agreed that Batu Caves Limestone Hill is important enough to be conserved while 11.2% disagreed. About 28% of respondents agreed that the Batu Caves Limestone Hill be conserved specifically for economic importance in the tourism industry, unique flora and fauna (27.7%), important paleontological site (23.8%), place of worship (19.9%), and only 6.1% of respondents agreed with all four purposes (Nuratiqah and Yong 2023).

Astonishingly, although Batu Caves is a premier tourist destination in Kuala Lumpur, there is no guidebook available at the Temple or in shops around the temple compound. The 1997 guidebook (Yussof 1997) focused mostly on caves, especially the Dark Caves but is long out of print. There was a clear need for a comprehensive guidebook that covered all aspects of the history, culture, geology, biodiversity and conservation. Tan Jiew Hoe sponsored the production of the new guidebook *Batu Caves: Malaysia's Majestic Limestone Icon* based on up-to-date information from the Batu Caves Scientific Expedition and photographs generated from the BCSE (Kiew *et al.* 2020). The Selayang District Council printed 700 copies for libraries in their district. The guidebook was launched at the BCSE Symposium by Haji Shamsul Shahril Badliza bin Mohd Noor, Yang DiPertua of the Selayang District Council.

RESULTS OF THE BATU CAVES SCIENTIFIC EXPEDITION

Batu Caves is confirmed in its position as a premier scientific site for geology, biodiversity and cave biology. In spite of persistent encroachment, it still retains much of its biodiversity besides continuing to be a source of new discoveries. It is imperative to preserve it for future generations of scientists and naturalists to investigate.

Plants

- The updated inventory (Kiew *et al.* 2023) demonstrated that Batu Caves is the most species-rich karst in Peninsular Malaysia with at least 366 species of vascular plants, more than any other limestone karst in Peninsular Malaysia, and representing 24% of Peninsular Malaysia's limestone hill flora, of which five hyper-endemic species are known only from Batu Caves.
- A new aroid species was discovered during the BCSE, *Schismatoglottis guabatuensis* (Wong and Boyce 2020) that is endemic to Batu Caves.
- Rafidah (2023) recorded 28 threatened species of flowering plants of which six are Critically Endangered, 13 are Endangered, three are Vulnerable, while one is Data Deficient. As for Malaysian populations, five species are probably Extinct in the Wild. The flora continues to face multiple threats of almost complete elimination of the buffer zone, encroachment, fire, invasion of alien species and change in climate as temperatures rise due to the vast concretisation of the surroundings.
- In response to the Great Burn in 2016, the survey by Rambe *et al.* (2023) is the first detailed study of recovery of the vegetation after burning. The importance of this study lies in its implications that fire is a major threat to limestone hill vegetation throughout Malaysia. Their study showed that the first species to re-colonise were secondary, weed or cultivated species dispersed by birds or wind.

- Yong and Cheah (2023) provided the first inventory of bryophytes for Batu Caves listing 16 liverwort and 40 moss species representing more half the moss species that are known to grow on Peninsular Malaysian limestone. Notable discoveries were two new liverwort records for Peninsular Malaysia and an extremely rare moss, *Erpodium biseriatum*, previously recorded from Peninsular Malaysia but without a specimen to back this claim. It was therefore exciting to find two small populations of this rare species.
- The study by Tam *et al.* (2023) illustrated the value of Batu Caves as a living museum, where living populations of unique and rare species are available for future study as more sophisticated methods of analysis become available. Using molecular techniques, they were able to show that the distinctive variegation of *Begonia phoeniogramma* was selectively neutral and the striking silver-grey leaf spots do not play an adaptive role as has been postulated in the literature.

Animals

- The status of the iconic serow, *Capricornis sumatraensis*, the largest mammal on limestone terrain, is still in doubt. Camera trapping by the PERHILITAN serow team (Siti Noraini *et al.* 2023) did not reveal serow, but only snapped civets, long-tailed macaques, and domestic dogs. However, Miard *et al.* (2023) heard serow in two places on separate occasions during nocturnal surveys: one occasion being preceded by the barking of dogs.
- The first study of mammals outside the caves by Miard *et al.* (2023) recorded eight mammals (common tree shrew, three squirrel species, a long-tailed giant rat, common palm civet, dusky leaf monkey and long-tailed macaques) from diurnal and nocturnal surveys. The dusky leaf monkey was also observed by Chong and Rosli (2023).
- Previous inventories of bats in the Dark Caves included several unverified records. Using modern methods of trapping (e.g. using harp nets), and by sonar recording, Nuratiqah *et al.* 2023) established that 12 species roost in Batu Caves, of which six are new records for Batu Caves. They were able to confirm, supported by molecular studies a living population of the extremely rare *Rousettus leschanaulti*, previously known only from a skull found in the Dark Caves. Batu Caves is its only known locality in Peninsular Malaysia.
- Chong and Rosli (2023) conducted the first inventory of birds. Together with five nocturnal birds observed by Miard *et al.* (2023), 51 birds are now documented from Batu Caves. Bird diversity is rated low to medium, but the three karst specialists: Peregrine Falcon, Blue Whistling Thrush and Blue Rock Thrush, are present (Chong and Rosli 2023) while Crag Martin was not recorded.
- Although the cave racer (Yussof 1997) and amphibians (Kiew 1979) have previously been studied inside the Dark Cave, no inventory existed for the herpatofauna of Batu Caves as a whole until BCSE. Teo *et al.* (2023) recorded a total of 25 species of reptiles (18 snakes, two lizards, one skink, three geckos and one turtle) and seven species of amphibians (six frog species and one species of toad). Twenty species are new records for Batu Caves. The Malayan box turtle, was also sighted by Miard *et al.* (2023). In addition to the type population of the Batu Caves, the endemic bent-toed gecko *Cyrtodactylus metropolis*, three other populations were discovered during BCSE.
- Snails are one of the most biodiverse groups on karst limestone. In a preliminary study, Foon and Marzuki (2023) recognised 38 native species, of which eight are known only from Batu Caves, while three are restricted to Selangor limestone. Seven alien species were also recorded.
- Choong (2023) provided the first report of dragonflies and damselflies from the environs of Batu Caves with an inventory of five damselfly and 20 dragonfly species, of which one dragonfly *Ceriagrion auranticum* is a new record for Selangor.

- The first inventory on butterflies on Batu Caves by Rosli (2023) listed 52 species with a further nine yet to be identified to species level. The list included some unexpected species such as the montane species or the rare Yellow Grass darter. It is of concern that the abundance of alien Julia butterfly *Dryas iuliain* were detected in some areas of Batu Caves, and its impact on native butterfly diversity.
- Lim T.W. (2023) investigated the impact of the alien house cockroach *Periplaneta americana* on native cave cockroach *Pycnoscelus striatus* in the Dark Caves, and demonstrated that in fact they live in different niches. Such *in situ* studies are important in formulating conservation, and management strategies to manage the impact of alien species.

Geology and Paleontology

- Muhammad, R.F. *et al.* (2023) provided a preliminary description of the landform history and dynamics (morphology) of the high, middle and low level caves.
- Five new caves were discovered, named and pinpointed, adding an update to the previous total of 25 caves in the Batu Caves complex. Using climbing equipment in places, routes to two of the summits were pioneered and mapped (Lim *et al.* 2023).
- Juliana *et al.* (2023) using a new method – 3D Light detection and ranging (LIDAR) system, enabled them to map the caves in three dimensions and produce an updated speleological map of the caverns along with biological and ecological characterisation of the Dark Cave. The LIDAR outcomes include the precise location of bat populations and demonstrate how they partition the cave ceiling. This study is the first to apply LIDAR technology to Malaysian caves.
- T.T. Lim (2020) demonstrated that Batu Caves still has value in providing a glimpse into past changes in the fauna (detailed by Ishlahuda *et al.* 2019 and Yasamin *et al.* 2012, 2013), but the opportunities for study have been hugely compromised by the removal of original cave floors and by the peripheral location of known fossil sites impacted by surrounding development.

MANAGEMENT ISSUES

Batu Caves is still without a well-defined boundary. Encroachment in many places has reached to the foot of vertical cliffs, in other places residential areas creep ever closer, and cultivation extends up valleys. All the ground level caves are occupied. Karst limestone is fractured and prone to rock falls without warning. For these reasons, as a rule of thumb, a safety zone with a width of 2.0 to 2.5 times the height of the karst is recommended, i.e., for Batu Caves the safety buffer zone should be 650-1000 m wide.

Loss of buffer zone of the forest not only has a catastrophic effect on the biodiversity of Batu Caves, but also increased the risk of accidental fires spreading to the hill itself and opens the massif to invasion by alien and secondary species.

The buffer zone is now almost eliminated, surviving in only a few places as a narrow strip of trees. This was a significant element of the limestone hill flora. It was in this forest that the now-extinct species grew (Kiew *et al.* 2023). Loss of the buffer zone also has a knock-on effect in the reduced diversity of mammals, birds (Chong and Rosli 2023), and butterflies (Chong and Rosli 2023) that are now represented by open country or secondary habitat species. This might also account for the loss of nine species of snakes that were recorded by Moseley *et al.* (2012), but not sighted during the BCSE (Teo *et al.* 2023).

Whether limestone hill biodiversity will ever recover after fire is not known. In 2019, Rambe *et al.* (2023) investigated plant succession following the Great Burn in 2016 and recorded more than 200 species, the majority being secondary and aliens species. Rosli (2023) recorded there was also a noticeable absence of butterflies from the burned area.

The number of alien species is increasing and the BCSE reported many instances, like the tree *Piper aduncum* or fern *Adiantum tenerum* (Kiew *et al.* 2023), feral dogs (Siti Noraini *et al.* 2023); seven species of snails (Foon and Marzuki 2023), *Acraea terpsicore* and *Dryas iulia* butterflies (Rosli 2023), and the common cockroach *Periplaneta americana*. Their biology needs to be studied so that management strategies can be devised to prevent them from having adverse effects on native species. The need for understanding their biology was illustrated by Lim (2023), who showed that the common cockroach population does not impact native species and can be controlled by removing the rubbish deposits where it lives. The observation by Miard *et al.* (2023) that they heard serow after hearing dogs barking may be an indication that the canines are harassing wildlife.

Long over-due is the implementation of guidelines for the utilisation and management of caves and for their development as tourist caves or for cultural purposes (Kiew *et al.* 2020). Caves are particularly vulnerable because damage or removal of cave features are permanent and irreplaceable. Particular concern is for fossil deposits that are continuing to yield new and unexpected discoveries.

BEYOND THE EXPEDITION

This symposium volume brings together the results by the many participants in a wide range of fields and clearly demonstrates how much of the biodiversity and geological features of Batu Caves still remain and how invaluable it is as an icon of Malaysia's scientific heritage. While a year-long expedition provided the opportunity for multiple visits, it has also uncovered the need, in some cases for long-term, for more intensive and/or detailed scientific research. The expedition has revealed that there are still more discoveries awaiting to be made. Perhaps the greatest difficulty of karst limestone research is the rugged and often formidable terrain that hides hidden gullies and caves, and inaccessible peaks. The exploration by Lim *et al.* (2023) not only revealed new caves, but by pioneering routes to the summits, they have opened up new areas yet to be explored. Siti Noraini (2023) has suggested that camera trapping would produce better results if the cameras were positioned higher up on the hill to avoid the regular human disturbances near the base. Perhaps this will solve the riddle of whether the serow can still survive as suggested by the tantalising calls of serow heard during the nocturnal mammal surveys (Miard *et al.* 2023). Batu Caves is too small to sustain a healthy population of serow. With increasing urbanisation and major roads as barriers, it becomes increasingly difficult for them to safely get to Batu Caves from the Klang Gates Ridge and Gombak forests.

Some groups such as birds, will certainly repay further sampling. Chong and Rosli (2023) drew attention to the low number of migrant birds in their inventory and suggested further sampling during the bird migration season. Rosli (2023) noted that his butterfly checklist was incomplete as he encountered 'new' species on every visit and that the list would be extended if sampling periods included dawn and dusk.

Other groups require more detailed studies that take time. For example, to verify the identity the 20 species of snails recorded in earlier studies requires consultation of international snail collections (Foon and Marzuki 2023). The identity of the 'extinct' *Pseuderanthemum lilacinum*, a Batu Caves endemic was solved by examining the original collections at Kew (Kiew and Rafidah 2023) which showed that this 'species' was no different from the more widespread *P. teijsmannii*, illustrating that *P. lilacinum* was neither extinct nor endemic to Batu Caves! Other studies such as the study of plant succession after burning (Rambe *et al.* 2023) would benefit from long-term monitoring, before we can answer the question of whether the limestone hill flora can recover its original composition.

Half of the 42 species of epiphytic orchids recorded in earlier studies were not found during the present survey (Kiew *et al.* 2023). The major reason could be due to higher temperatures and change in the climate of Batu Caves, which now sits in an urban heat bubble generated by the surrounding expanse of concrete. Dry wind in a period of hot weather was also identified as a factor behind the extensive burn in 2016. This draws attention to the need for long-term measurements of basic environmental parameters like rainfall, temperature and humidity at Batu Caves so these changes can be monitored.

Populations of threatened and hyper-endemic plant species also require long-term monitoring to assess their viability (Rafidah 2023). We need to know their mode of pollination, dispersal or establishment requirements before conservation strategies for their survival can be devised. Batu Caves is now a small habitat island where changes in one species will have a knock-on effect on others. For example, *Epithema parvibracteatum* needs to be pollinated to produce viable seeds. If the populations of pollinating agent are reduced or die out, then the *Epithema* population will eventually perish. The same applies to the isolated dusky leaf monkey population on Batu Caves (Chong and Rosli 2023) if their food source is reduced by frequent fires or is displaced by invasive aliens species like *Piper aduncum*.

Only long-term monitoring will show the effect of urbanisation and loss of forested areas on the bat populations in Batu Caves, a topic that has immediate importance because of the crucial role bats play as the main pollinators of durian. Greater focus on the Dark Cave ecosystem is also needed to explain the reasons for the recent drastic crash in the population of cave racer *Elaphe taeniura ridleyi*, which is now hardly ever seen (Teo *et al.* 2023).

Several groups were not covered by the BCSE because there are no Malaysian experts, nor local reference collections for many of the obscure and poorly known invertebrates that inhabit the dark cave ecosystem. For example, there was no monitoring to assess the current status of the endemic springtail, millipedes or well spider (Zonstein and Marusik 2014), and even the iconic trapdoor spider *Liphistius batuensis*, which is globally recognised as a Critically Endangered species. Its population was reported to have suffered a severe historic decline between 1930s and 1961. There was concern that opening the Dark Cave to visitors and installation of lights would cause a population decline in trapdoor spiders. With the removal of lights and control of visitor numbers, Lim and Yussof (2009) suggested its population had stabilised in 1960 levels. However, its current status has not been reported.

To fully understand the taxonomy, especially of invertebrate groups, there needs to be a free collaboration between scientists. At present, this is hampered by a lack of understanding by the authorities of how science works, for example in the exchange of scientific specimens. Besides, Malaysia is hindered by the lack of a national natural history museum where collections of these 'obscure' groups of animals can be housed in state-of-the-art conditions (Ng 2008). The early collections of Ridley and Dover were sent to the Natural History Museum in London and the Bishop Museum in Hawaii, respectively, because of the lack for a local science museum. These collections are still available for study in the aforementioned museums.

The value of Batu Caves as a living museum should not be overlooked. Being so close to and accessible to many local universities and research institutes offers a great opportunity to study organisms *in situ* and access materials for more advanced studies, particularly with the advent of molecular techniques. One example was that of Khang *et al.* (2017), who were able to demonstrate that the Batu Caves flatworm is endemic to Batu Caves through molecular analysis. Similarly, Tam *et al*. (2023) used molecular methods to answer the question of whether the white-spots on the variegated leaves of *Begonia phoeniogramma* have a selective advantage. (They don't). Studies, such as these, illustrate the need to protect Batu Caves in perpetuity to preserve its precious biodiversity for the future.

The ecosystem and population of organisms in Batu Caves are dynamic. The concern, therefore, is that changing trends are causing disturbance, loss or depauperisation of the flora and fauna. The BCSE has revealed an increasing number of alien organisms – butterflies, snails, dogs and plants (see above) for the first time. Long-term studies are needed to quantify their populations and impact on local species, and management action should be taken to lessen or eliminate their impact on the native fauna and flora, if necessary.

Hope for the future

It has been more than 55 year since the Batu Caves Protection Association was established to persuade the government to stop quarrying projects and to protect Batu Caves, and more than 40 years since the last quarry closed in 1980. To date, Batu Caves remains as an area reserved for Public Recreation since its set up in 1930. In 1976, Batu Caves was proposed as a Nature Monument in the Third Malaysia Plan, but up to present moment, the Selangor State Government has not taken any action to securely protect this iconic karst hill. Today, Batu Caves remains vulnerable to increasing encroachment, threat of fire, and the occupation of all ground-level caves. Protecting Batu Caves in perpetuity is complex as its implementation must take into consideration the multiple stakeholders and their diverse interests. Among legislations that place conservation on an ecosystem approach, Sarah *et al.* (2023) opined that establishing Batu Caves as a Nature Monument needs serious consideration. Nature Monuments fall within the same category as national and state parks, nature reserves, and wildlife sanctuaries as they all involve an ecosystems approach to conservation measures. Establishing a Nature Monument can leverage on the provisions of the National Land Code 1965 and for the management of the Batu Caves Nature Monument, a specific authority similar to the Selangor State Water Authority should be established to manage the Nature Monument directly by the State Government.

CONCLUSION

While the positive outcomes of BCSE were the discovery of new records and even a new species, and the general conclusion that much of the biodiversity and geodiversity still remains on and in Batu Caves, the negative side includes increasing and accelerating encroachment all around Batu Caves, and the lack of legal protection and enforcement. How long can the biodiversity of Batu Caves sustain this relentless encroachment? Signs are the situation is reaching a tipping point. The buffer zone is almost eliminated, the number of alien species becoming established is increasing, populations are crashing like that of the cave racer or the epiphytic orchids. The best way forward for the conservation and sustainable use of Batu Caves is to embrace an approach that considers the interests and harnesses the strengths of all parties who have a stake in Batu Caves. Establishment of Batu Caves as a Nature Monument under a Selangor state authority managed directly by the state government is proposed as a practical step.

The Batu Caves limestone massif remains a treasure trove of both biological and non-biological diversity overlooking an ever-expanding urban landscape. Indeed, Batu Caves is unique in Asia in its long history of well-documented scientific studies. With its proximity to universities and research institutes, Batu Caves is an ideal location to set up a science and education centre. It would serve as a centre to attract both local and international research and enable long-term studies to be carried out. It is a living classroom to demonstrate how the karst came into being and how caves and cave features form. It unlocks the history of the past when orangutan still lived near Batu Caves, and how a whole world of darkness is fuelled by bat guano.

It is hoped that with increased awareness and appreciation of Batu Caves and its many wonders, support will grow in strength and number for the long-term legal protection and effective management of this majestic limestone monument

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