A preliminary survey of the invertebrate fauna of the Gunung Mulu World Heritage karst area, Sarawak, Malaysia

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Abstract

The Gunung Mulu World Heritage Area (Mulu) is situated in the north eastern corner of Sarawak, Malaysia on the Island of Borneo, adjacent to the South China Sea. The area was prescribed as a national park in 1974 and is the largest national park in Sarawak covering an area of 528 km^2 . The area contains significant karstic limestone, with some of the world's largest caves by volume known from the area including Deer Cave and the Clearwater System.

In 2012 a team of Australian speleologists undertook a preliminary survey of the invertebrate biodiversity of eight caves within Mulu. The caves were a mix of tourist, adventure and wild caves within the park. Invertebrates were recorded from a mixture of different microhabitats found within the caves and reference specimens from each cave were collected and preserved for future study.

The aims of the study were to document the biodiversity of the caves; provide a photo inventory of species recorded; compare the invertebrate diversity and abundance between different cave zones and microhabitats; compare the invertebrate diversity and abundance between caves used for different tourism purposes.

The survey recorded over 19,000 specimens using a combination of collection and observation of species that presently represents 100 different morpho-species, from 28 orders and 9 classes. The number of morpho-species is expected to increase with additional sampling and further identification of the specimens already collected. Forty different species have been photo-inventoried thus far.

Preliminary analysis of data has shown no discernible differences in invertebrate diversity or abundance between tourist caves and wild caves. Observed differences in invertebrate populations are related to microhabitat variability and availability within sampled caves, with greater invertebrate abundance related to bird and bat guano deposits. This study represents the first stage of invertebrate research at Mulu, and future efforts will focus on increasing the photo inventory to provide a useful resource to the Mulu Park and Sarawak Forestry staff to identify cave invertebrates in the field. Ultimately increasing the local knowledge of cave invertebrate fauna will provide the best protection for these important ecosystems.

Introduction

The Gunung Mulu World Heritage Area (Mulu) is situated in the north eastern corner of Sarawak , Malaysia on the Island of Borneo, adjacent to the South China Sea (Figure 1). The area was prescribed as a national park in 1974 and is the largest national park in Sarawak covering an area of 528 km^2. Mulu contains the second highest peak in Borneo, Gunung Mulu, a sandstone mountain situated to the east of the Melinau Limestone that contains the extensive caves that are the subject of the current study.

Gunung Mulu World Heritage Area (GMWHA) contains significant karst and associated subterranean fauna. Although substantial research was undertaken on the bio-speleological values, this was more than 30 years ago and much has changed in regard to our knowledge of such fauna especially within tropical settings.

Dr G E Wilford was the first individual to visit the Mulu caves with the objective to explore the caves in the early 1960s. Wilford worked with the Geological Survey of the Borneo region and completed surveys of Deer cave, parts of Wind cave and Terikan cave. He indicated in his book of the caves of Sabah and Sarawak that large and spectacular caves are most likely to be discovered in the Melinau area.

Prior to the 15 month scientific expedition by the Royal Geographical Society in 1977 - 78, the Mulu caves had first been reported in 1858, however, little work had been done on the biospeleological values of the area.

Aims and Objectives of Preliminary Survey

The current preliminary survey aims to provide a basis for future biological surveys in Mulu by building upon the only other substantial biospeleological survey undertaken in the area by Chapman (1982). The current preliminary survey aims to provide an initial overview of the invertebrate fauna in the cave systems near the Park Headquarters and predominately in those used as tourist caves and adventure caves.

The primary survey aims were to:

1. Preliminary overview of the biodiversity and initial insights into the cave ecosystems as a baseline and starting-point for future ecosystem studies of the cave systems.
2. Provide a photo inventory of species recorded.
3. Compare the invertebrate diversity and abundance between different cave zones and microhabitats.
4. Compare the invertebrate diversity and abundance between caves used for different tourism purposes.
5. Provide management strategies to facilitate fauna survival and mitigate threats.
6. Provide recommendations for future works to compliment the findings of the current study.
7. Preparation of recommendations for further cave biodiversity studies, potentially focusing on sustainable cave management and adequate tourism development

The caves chosen were a mixture of tourist caves, adventure use caves and wild caves and included a range of habitats and use levels. The caves examined are shown in Table 1.

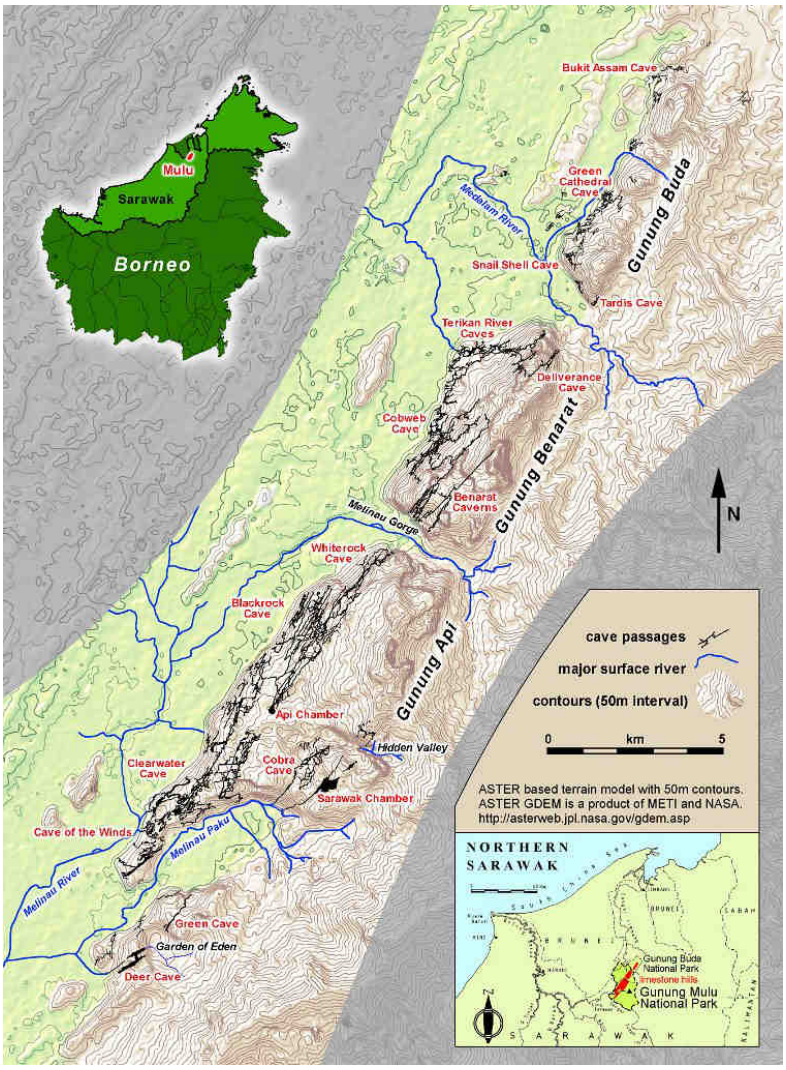

Figure 1 Map of all Mulu Cave systems (after www.mulucaves.org)

Cave Name	Primary Use	Limestone Section	Visitation
Deer Cave	Tourism	Deer/Green Section	High
Deer Water Cave	Wild	Deer/Green Section	Low
Green Cave	Wild	Deer/Green Section	Low
Stonehorse Cave	Adventure	Deer/Green Section	Low
Fruit Bat Cave	Adventure	Kenyalang/Fruit Bat	Low
Kenyalang Cave	Adventure	Kenyalang/Fruit Bat	Low
Lagang Cave	Tourism/Adventure	Gunung Api	Moderate
Racer Cave	Adventure	Gunung Api	Moderate
Clearwater Cave	Tourism/Adventure	Gunung Api	Moderate

Table 1 Cave usage and location within Mulu

Survey Timing and Participants

The survey was undertaken between the 29th April – 12th May 2012. The survey was undertaken by a specialist cave biologist, Dr Timothy Moulds (Australia), and assisted by a team of Australian speleologists who have experience in cave interpretation, guiding and speleology. An additional field visit was undertaken by Dr Timothy Moulds and a smaller speleological team from the Western Australian Speleological Group (WASG) in December 2012 (12th – 17th December) to revisit some of the primary caves examined previously. The Australian biospeleological team were Dr Timothy Moulds, Jay Anderson, Ross Anderson, Patrick Nykiel, Rob Susac, Barbara Zakrzewska, Dr Stephen Swabey, Toni Lowe, Sharon Thwaites, Ian Thwaites, Jane Pulford, Tony Veness, Dr Bert De Waale, Gregoriy Tsaplin, Christine Best, Andrew Thomas, and Sandi Cheema.

Mulu park administration provided assistance to the project through the provision of accommodation, staff for field work and guiding, and numerous other forms.

Further field assistance was provided by Mulu Park staff including, Bian Rumei, Syria Lenjau, Jeffry Simun, Brian Clark, Sue Clark, Jeremy Clark and Sarawak Forestry Staff led by Anne Malissa King.

Introduction to Subterranean Biology

Caves form a very stable and generally homogenous environment in which to conduct various ecological and evolutionary experiments, such as on competition between species, resource partitioning, and the processes of speciation (Poulson and White, (1969)). The total absence of light severely alters or completely removes many circadian cycles affecting ecosystem function (Lamprecht and Weber, (1992), Langecker, (2000)). Temperatures are usually constant, varying only slightly between seasons. Humidity is commonly high, providing an ideal habitat for many invertebrate species susceptible to desiccation. The lack of photosynthetic plants changes the trophic structure of cave ecosystems, with energy sources usually being transported from the surface (Poulson and Lavoie, (2000), Poulson, (2005)). Caves are defined as human-sized subterranean voids, although cave adapted animals are known to occur in the smaller spaces between large voids called micro- and meso caverns (Howarth, (2003)).

Caves are divided into several distinct biological zones to aid interpretation (Figure 2). These correspond to the amount of available light and varying environmental conditions (Humphreys, (2000)). The *Entrance Zone* is the area directly around the cave entrance; it is generally well lit, often supports photosynthetic plants, and undergoes daily temperature and humidity fluctuations. The *Twilight Zone* is just beyond the entrance zone and is often dominated by lichen and algae that require low light conditions. The temperature and humidity are still variable but fluctuations are dampened compared with epigean variation.

Deeper into a cave, light is reduced to zero and the *Dark Zone* is entered, which is subdivided into three zones, the transition, deep cave and stale air zones. The *Transition Zone* is perpetually dark, but still fluctuates in temperature and humidity determined by epigean conditions. The *Deep Cave Zone* is almost constant in temperature and humidity conditions.

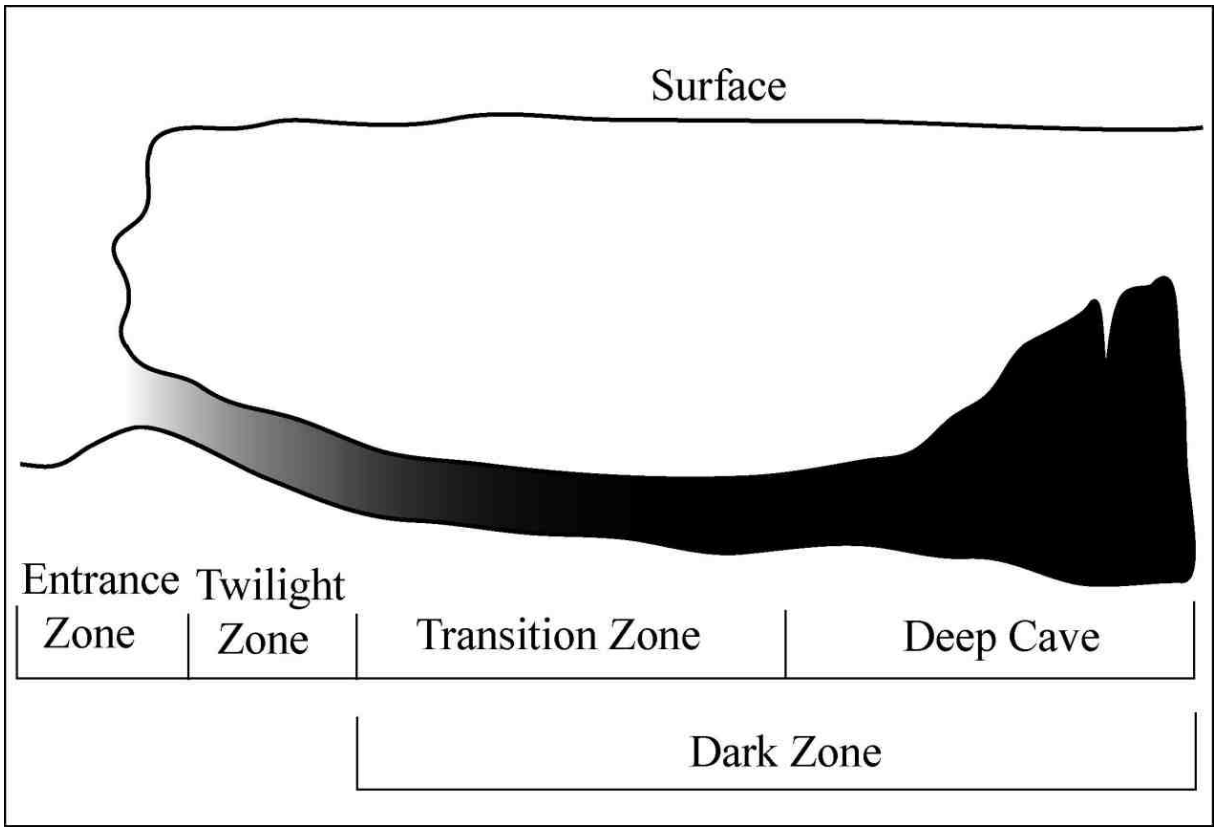

Figure 2 The environmental zones of a cave shown in cross section. (Figure after Moulds, 2006).

Classifications of cave dependence

Cave invertebrates are generally classified according to their degree of cave dependence using a modified version of the Schiner - Racovitza system (Schiner, (1854), Racovitza, (1907)). This system originally relied upon organisms ecological association with subterranean environments, requiring detailed ecological knowledge of animals that is commonly lacking for most species. In order to circumvent this lack of knowledge, the concept of troglomorphy (Christiansen, (1962)), specific morphological adaptations to the subterranean environment, is used to define obligate subterranean species. The term troglomorphy, initially confined to morphology has since been used to describe both morphological or behavioural adaptations (Howarth, (1973)). The most currently accepted term for obligate subterranean fauna is that summarised by Sket (2010).

This combination provides a practical system, easily applied in the field and with minimum of detailed ecological study required. The level of subterranean dependency for different ecological groupings is described below:

- *Troglobionts* are obligate animals that rely on the hypogean (subterranean) environment for survival (Sket, (2010)) These species rely solely on the cave environment for food and reproduction. They are generally restricted to the deep cave zone where conditions are the most stable and are rarely found closer to entrances in the twilight zone.
- *Troglophiles* are animals that can complete their entire lifecycle within a cave but possess no specific adaptations to the cave environment. These species are capable of living outside caves in suitably sheltered and moist epigean habitats. This corresponds to the eutroglophile classification of Sket (2010).
- *Trogloxenes* are animals that regularly use caves for part of their lifecycle or for shelter, but must leave the cave to feed. Common examples of these are bats and cave swiftlets.

- *Accidentals* are animals that do not use caves on a regular basis and cannot survive in hypogean environments.

Aquatic hypogean animals are classified using a similar system to terrestrial hypogean animals except the prefix 'stygo' is used instead of 'troglo' (Humphreys, (2000)).

The Trophic Basis of Cave Ecosystems

Cavernicolous populations are dependant for their survival upon energy inputs into cave systems. These inputs can vary widely, with availability of food usually being the primary limiting factor (Peck, (1976)). Many cave ecosystems revolve around periodic flooding (Hawes, (1939), Humphreys, (1991), Culver *et al.,* (1995)) that carries organic material and accidental epigean animals into cave systems. Tree roots penetrating the roofs and walls are another energy source found commonly in tropical caves and lava tubes (Hoch, (1988), Hoch and Howarth, (1999)). Guano from bats, birds and Orthoptera is an important energy source (Harris, (1970), Poulson, (1972), Decu, (1986), Blyth *et al.,* (2002), Moulds, (2004), Moulds, (2006)) with large, varied and unique ecosystems existing around such deposits. Dead animals can be a source of food for scavengers near cave entrances (Richards, (1971)). Accidentals wandering in from cave entrances also provide a food source, although this is generally periodic in nature and inconsistent in quantity, except in caves with large active rivers that are capable of carrying in large volumes of epigean animals, especially during high water flow periods.

For the most part, cave environments are generally depauperate in food and consequently are sparsely populated by cavernicolous animals. However, caves containing guano deposits differ fundamentally because there is a virtually unlimited food supply, commonly resulting in large populations of guano dependant arthropods known as guanobites. Guanobites possess no specific behavioural or morphological adaptations, presumably because of the lack of selection pressure to minimise energy expenditure that dominates the evolution of troglobites. The colonisation and establishment of guano dependent communities in caves is poorly understood. Mechanisms for the dispersal of guano dependent arthropods are potentially numerous, but most are poorly investigated at best (Moulds, (2004)).

Sources and diversity of cave guano

Cave guano deposits from specific sources can each possess a unique assemblage of taxa (Horst, (1972), Poulson, (1972)). Throughout the world's biogeographic provinces different taxa are responsible for being the most important guano producers.

The most widespread and common guano is that produced by bats and these deposits are generally the largest in volume. The spatial and temporal deposition of bat guano differs from tropical to temperate caves. Cave-dwelling bats in temperate regions show an annual cycle of occupancy over summer months when pups are born, before colonies disperse to cooler, wintering caves where they enter torpor. This annual cycle results in large amounts of guano deposited over summer months and then a cessation of guano input for at least half the year. In contrast, tropical caves generally show constant bat occupancy rather than an annual cycle, and less aggregation of individuals due to warmer ambient temperatures (Trajano, (1996), Gnaspini and Trajano, (2000)). Gnaspini and Trajano (2000) note that many bat populations in tropical Brazil are, however, commonly nomadic, resulting in roaming colonies varying their location in an irregular and non-seasonal fashion. This results in non-continuous guano deposition in a single locality over several years. The diet of bats (either haematophagous, insectivorous, frugivorous, or nectarivorous) also influences the composition of guano piles and, hence, the associated guanophilic communities (Gnaspini, (1992), Ferreira and Martins, (1998), Ferreira and Martins, (1999)).

Birds are common guano producers in the northern parts of South America, the Caribbean and tropical caves of south-east Asia. Cave-dwelling birds nest in the dark zone, providing an important energy resource for many cavernicolous animals.

Swiftlets (*Aerodramus* spp.) nest in the entrance and dark zones of tropical caves in south-east Asia, northern Australia and the Pacific, and are insectivorous (Medway, (1962), Humphreys and Eberhard, (2001), Koon and Cranbrook, (2002)). The volumes of bird guano deposited are comparable to similar sized bat populations.

Previous biospeleological literature relating to Mulu Karst

Royal Geographic Society 1977/1978 Expedition

The Royal Geographical Society (RGS) expedition did not place karst and caves as the foremost objective of the 15 month expedition. In fact only six speleologists were present among the 130 scientists. However, the speleologists present determined that the potential was of such magnitude that follow up expeditions were required and subsequent UK led speleological expeditions occurred. Thus, the 1980 expedition was initiated.

Chapman, 1982

The primary published reference relating to biospeleological investigations at Mulu is Chapman's 1982 study, based upon field investigations undertaken in 1978 and 1980 as part of the RGS expedition and the subsequent Mulu 1980 Speleological Expedition (Eavis *et al.*, 1981). This paper reports the biospeleological investigation of 14 caves divided into four geographical groups. The paper serves primarily as a species inventory of cave invertebrates, and makes commentary on the biogeographical significance of the Mulu cave fauna, including its potential evolutionary explanation.

Chapman (1982) reports a total of at least 136 species, from 129 genera, 104 Families, 34 Orders, nine Classes and four Phyla. The species inventory does not generally distinguish the individual distribution of species between the 14 caves examined. This is the first reference that identifies a significant diversity of troglobiont fauna in a lowland cave in southeast Asia (Deharveng and Bedos, (2000)).

Deharveng and Bedos 2000

This paper provides an overview of subterranean diversity and distribution across South East Asia as a whole and makes specific comment regarding four karst areas studied by the authors over numerous biospeleological expeditions. The karst areas examined and compared are Tham Chiang Do (northern Thailand), Ngalau Surat (central Sumatra, Indonesia), Gua Salukkan Kallang/Towakkalak System (southern Sulawesi, Indonesia), and Batu Lubang (Halmahera Island, Moluccas, Indonesia). All these systems were comprehensively sampled including parallel sampling of outside habitats and soil so as to allow reasonable assignment of troglobiont status to species examined. Much of the detailed comparisons are based on collembolan species which are the taxonomic speciality of the authors. The comparison draws upon the research by Chapman in Mulu caves regarding the relationship between habitat stability, predictability and substrate heterogeneity, rate of food input and proneness to flooding with species richness.

Volshenck and Prendini 2008

This review of subterranean scorpions from around the world characterises *Chaerilus chapmani* (Lourenço and Franke, (1985)) as a true troglobitic scorpion, making it one of only 20 such species in the world. It is the only Malaysian troglobitic scorpion. The remainder of Asia contains four other troglobitic species; *Chaerilus sabinae* (Matampa Caves, India) (Lourenço, (1995)), *Liocheles polisorum* (Christmas Island, Australia) (Volschenk *et al.*, 2001), and two species from the Phong Nha – Ke Bang karst in north central Vietnam, *Vietbocap cahni* and *V. thienduongensis* (Moulds *et al.*, (2010), Lourenço and Pham, (2010), Lourenço and Pham, (2012)).

McFarlane et al. 2011

The paper summarises the knowledge of crab diversity in Borneo with a focus on the subterranean species and especially those species occurring at Mulu. The paper provides records of the six species known from Mulu and the known subterranean distribution of the two obligate species. The

paper also provides a field key and photographs of several species.

Report Limitations and Exclusions

The current report was produced from data collected during a 14 day visit and a subsequent 5 day visit to Mulu in May and December 2012. The survey was intended as a preliminary investigation into the subterranean biodiversity of eight caves examined within the park. Identification of specimens collected were undertaken with limited reference material and equipment and are considered to be preliminary identification for the purposes of the report.

Due to the limitations in both time and available local resources in Mulu, the level of identification of the material collected during the current survey is preliminary and considerable further work is required to determine the number of species new to science collected. This collection can then form the basis for any future surveys to be conducted on the cave fauna of Mulu.

Survey Methodology

Surveys for subterranean fauna may use many different techniques according to the type of fauna being targeted and the amount of time available for the survey. These methods can include:

- pitfall traps (baited and unbaited).
- hand foraging (using forceps and paintbrushes to actively collect observed fauna).
- litter traps left in situ for days or weeks and then fauna extracted in a tullgren funnel.
- net hauling of water for aquatic fauna.
- nets left in situ in narrow streams to sieve water flows for discrete time periods.

Due to the very limited amount of time available for the current preliminary survey it was decided to use active hand searching (hand foraging) to enable a wide variety of different habitats, and caves to be surveyed quickly and detect the majority of species present within. In order to undertake a more comprehensive survey of the subterranean fauna (vertebrate and invertebrate) a combination of multiple techniques in each cave over longer time periods would be required. This was beyond the scope of the current project.

The majority of caves sampled during the current biospeleological survey were not sampled as part of Chapman's survey, with much of his sampling concentrating on the Clearwater System and other associated caves, as well as more remote caves further to the north (Chapman, (1982)). Green Cave, Deer Cave and Deer Water Cave were common to both surveys, albeit in differing sampling intensities.

Microhabitat Sampling

Each cave investigated for invertebrate biodiversity was sampled using a standardised method to enable results between caves to be comparable and also repeatable during any subsequent surveys. Caves were selected for sampling on advice from the Mulu Park Manager, Brian Clarke to provide a mixture of tourist, adventure and wild caves for comparison.

Each cave was sampled in the Entrance Zone, Twilight Zone and Dark Zone (Figure 2), with a selection of the main microhabitats sampled from each zone. The following microhabitats were identified as occurring within the Mulu caves

- Fresh guano
- Old guano
- Massive guano
- Damp sediment
- Dry Sediment
- Walls/Speleothem
- Streamway/Water pools

In each light zone of a cave the overall site was photographed and the location on existing cave maps was recorded to facilitate repeat sampling in the future. Each sampling site was then assessed for the presence of microhabitats, with each microhabitat identified in the site sampled for 20 minutes each. The abundance of each species was recorded using a combination of collection of voucher specimens (maximum of five specimens per morpho-species per cave) for future identification and observation of total species abundance within each microhabitat. The location of

any cave infrastructure, such as paths or lighting was also recorded.

The intensity of sampling varied between caves, as a function of accessibility, diversity of microhabitats, time available for the survey, availability of guides to facilitate access to some caves and other stochastic factors. The level of sampling within each cave is summarised in Table 2.

Cave	Number of Sites Sampled	Notes
Deer Cave	**4**	Collection only in Massive Guano microhabitat, no abundance observations
Deer Water Cave	**1**	
Green Cave	**2**	
Stonehorse Cave	**18**	Visited in May and December 2012, sites resampled
Fruit Bat Cave	**8**	Visited in May and December 2012, sites resampled
Kenyalang Cave	**4**	
Lagang Cave	**19**	Visited in May and December 2012, additional sites sampled in December 2012
Racer Cave	**10**	
Clearwater Cave	**5**	Collection only, no abundance observations

Table 2 Sampling intensity of Mulu Caves

Several other specialised microhabitats that were identified by Chapman (1982) that were encountered very occasionally were bog or mush guano, where guano is deposited into small water pools creating a liquid guano environment. This microhabitat was only seen during the current survey within sections of Clearwater Cave and limited opportunistic sampling was undertaken within it.

Material collected was placed in 70% ethanol for preservation, and sorted using a Premiere (20x - 40x) stereomicroscope. Specimens were identified to lowest practical taxonomic level using the resources available at the time of the survey in Mulu. Preliminary identification of material was identified by Dr Timothy Moulds. All material collected remains the property of the Republic of Malaysia, and has been kept by the Sarawak Department of Forestry office in Mulu NP.

Sample Locations

Sampling locations are shown in Appendix C and includes a photo of each specific area where available.

The location of specific caves sampled is shown in Figure 3.

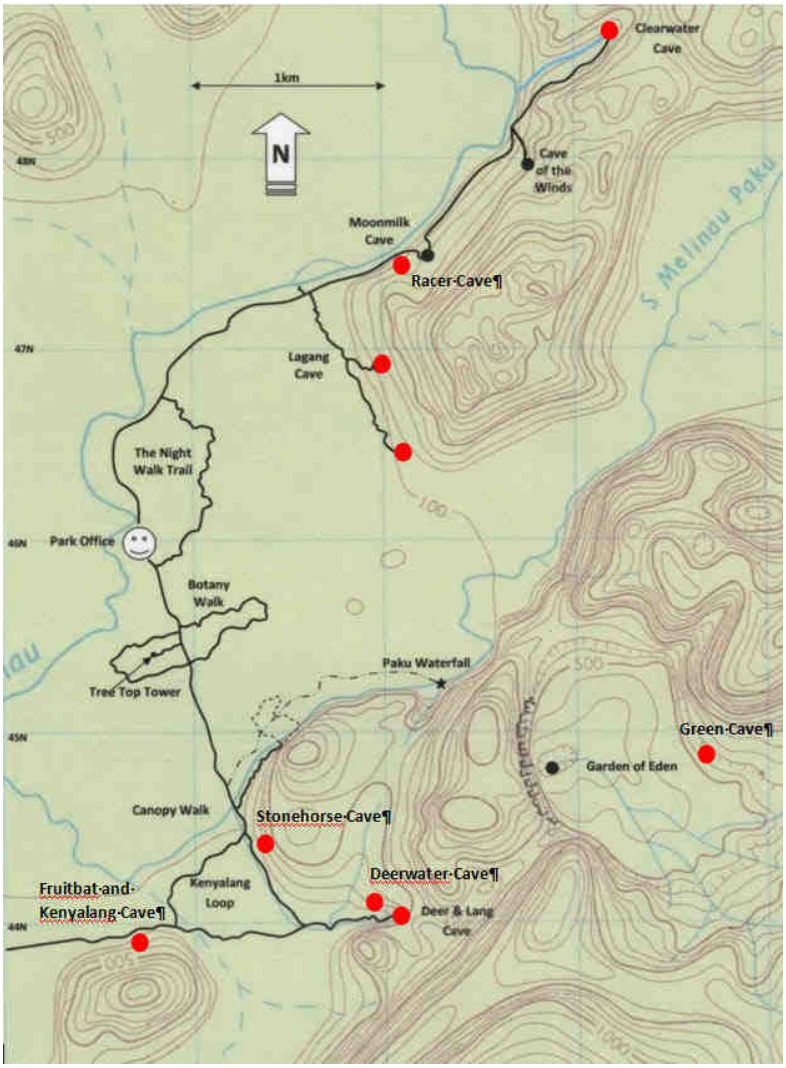

Figure 3 Locations of caves surveyed for invertebrates during the current survey

Survey Results

The survey recorded over 19,000 specimens using a combination of collection and observation of species abundance that presently represents 93 different morpho-species, from 25 orders and 8 classes. The number of morpho-species is expected to increase with additional sampling and further identification effort. Forty different species have been photo-inventoried thus far and are shown in Appendix B.

The spider *Heteropoda* sp. (Sparassidae) was the most widespread species found in all caves sampled, followed by the millipede sp. A, Opilione Phalangodidae? sp.A, Lepidoptera: *Tinea*? sp. and Araneae: Pholcidae sp. A that were recorded in six of the seven caves comprehensively surveyed (excluding Clearwater Cave and Deer Water Caves). The majority of species (44.6%) were recorded from a single cave, with very few species recorded from five or more of the caves surveyed (Figure 4).

The most diverse order was Coleoptera with 13 species recorded, followed by Araneae (10 spp.), Isopoda (10 spp.), Diptera and Hemiptera (9 spp. each) and Diplopoda (8 spp.). Eleven orders are represented by single species (Figure 5).

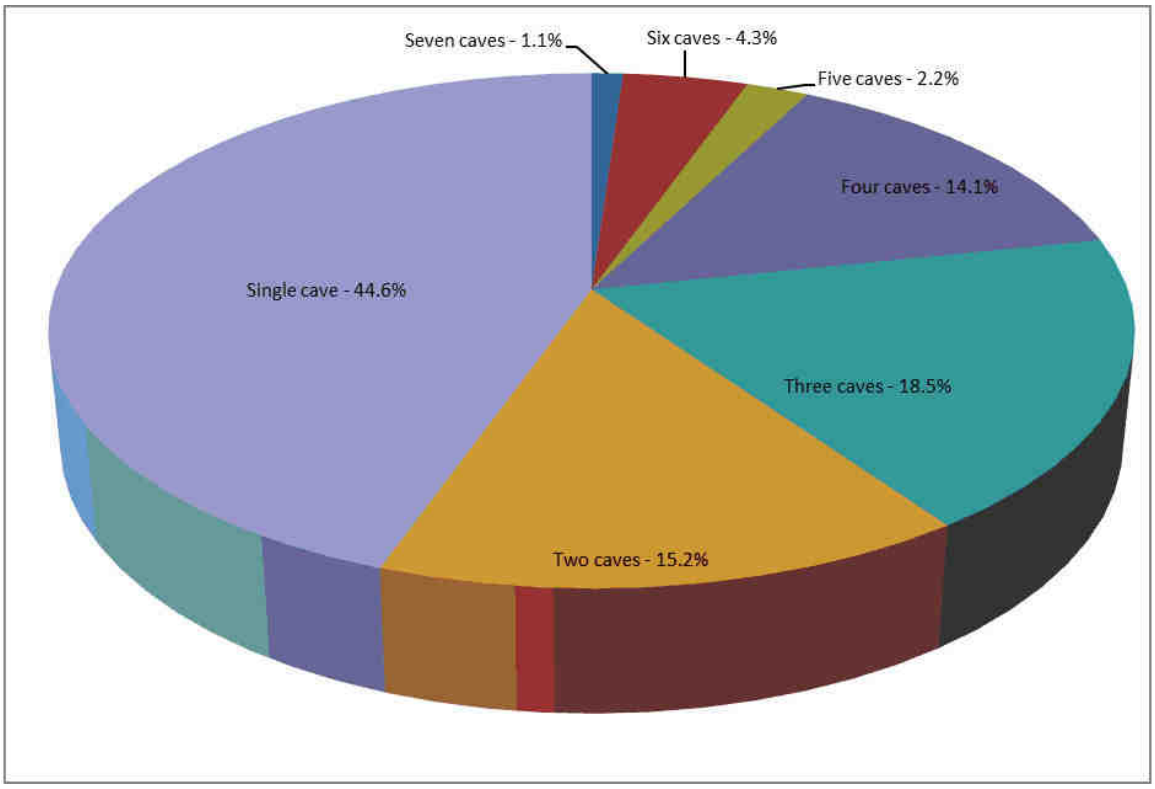

Figure 4 Percentage of species recorded from multiple caves.

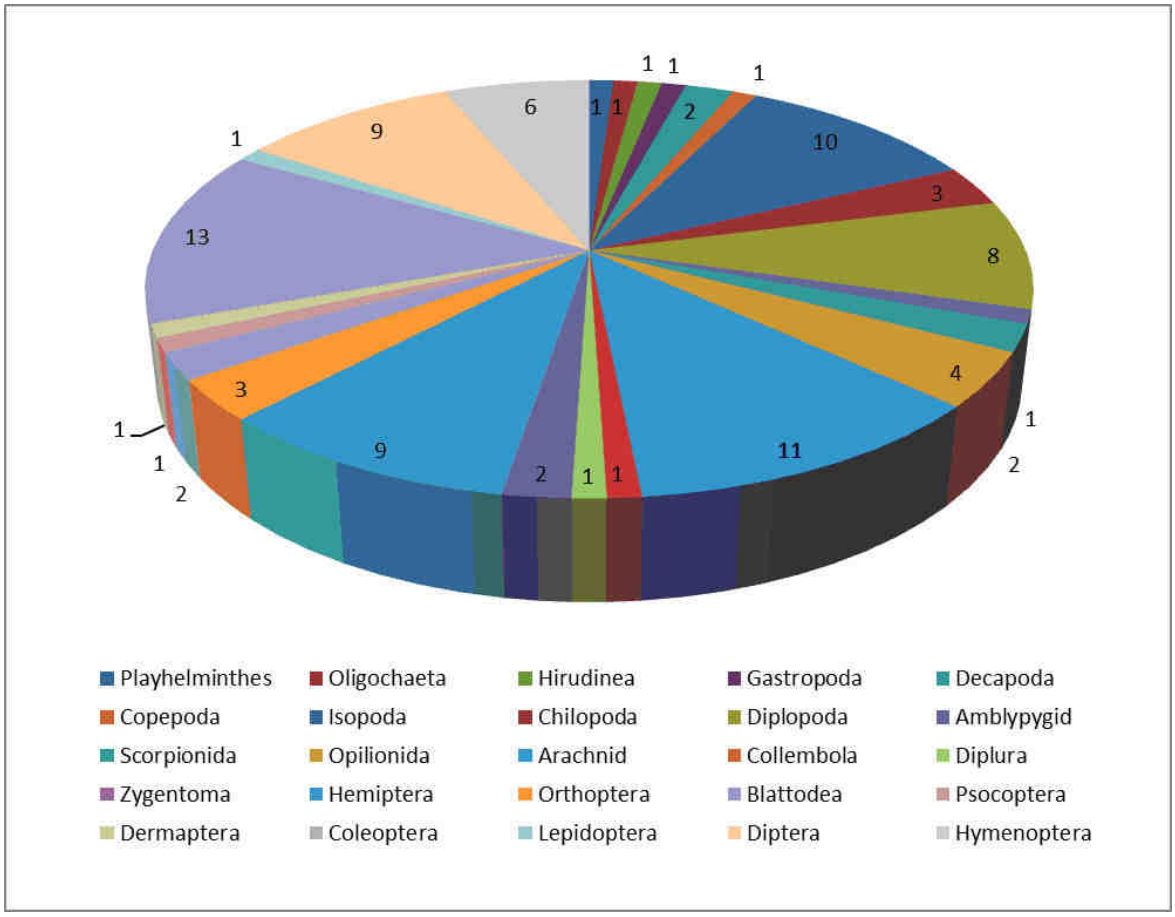

Figure 5 Diversity of species recorded by Order across nine caves.

The key results are presented individually for each cave surveyed, and detailed abundance data is presented as an appendix in Appendix A.

Deer Cave

Deer cave was sampled in three primary areas, the main entrance, Antler passage and the massive guano piles located near the Garden of Eden Track. The massive guano areas were not sampled extensively, and abundance of species was not recorded due to a lack of available time and the immensity of the task due to the extremely high abundance present. These are certainly the habitat for the largest arthropod diversity within the cave.

Antler passage, which is located above the main passage was found to be quite dry, and largely free of guano, providing very different microhabitats to those in the main passage.

Figure 6 Deer cave guide rail with a Naked Bat and numerous symbiotic hairy earwigs. Photo Jane Pulford.

Deer Water Cave

This is the outflow for the river that enters Deer Cave from the Garden of Eden entrance and sampling was limited to a single visit and a single microhabitat of damp sediment. The invertebrates present consisted of several highly abundant dipteran species, including chironomids and phorids. Several beetle species were also present in high abundance including a species of staphylinidae.

Green Cave

Green Cave was sampled in the Entrance zone and in the Dark Zone (lower River Area). The Entrance area contained several species of isopod and also Hemiptera: Vellidae? within a small gour pool, and Rhyparochromid bugs. The area sampled,

although a substantial distance from the entrance still received light for much of the day due to the large entrance size and these species are most likely accidentals to the cave environment.

The dark zone area associated with the small river passage contained a very high abundance of Anobiid beetles, clustering in groups of five to twenty individuals. Two species of cave cricket were also present here, the large *Rhaphidopora oophaga* and the smaller *Diestrammena mjobergi*.

Fruit Bat Cave

The entrance area of Fruit Bat Cave consists of a large chamber with an almost continuous cover of dry guano, with small patches of fresh guano under roof bell holes. This dry guano microhabitat supports an abundant population of the small cockroach *Pyenoscelus indicus*, the cricket *Diestrammena sarawakana* and several species of reduviid bugs. The emesine species is likely to be Baguada? sp. cf. *cavernicola* which was identified by Chapman within Deer Cave and also collected were two species of harpactocoid reduviids, which were unrecorded by Chapman (1982).

The deeper sections of Fruit Bat Cave are dominated by scattered fresh guano throughout, resulting in a series of the more common and widespread species such as *Diestrammena mjobergi* and the widespread millipede sp. A. Some of the small water pools located within formations contained aquatic isopods *Cyathura* sp. nov.

The alternate entrance area of Fruit Bat Cave is a roosting area for Fruit Bats (*Balionycteris maculata*) which gives the cave its name and contains numerous discarded seeds within the associated guano. This area was not sampled for invertebrates.

Figure 7 Seeds and sprouting bodies in Fruit Bat Cave alternate entrance – Photo Tony Veness

Kenyalang Cave

Kenyalang Cave is located in the same limestone block as Fruit Bat Cave and the entrance is located vertically above. The invertebrate assemblage recorded was similar to that of Fruit Bat but due to the lower amounts of guano was slightly different in composition. The cave

contained a high abundance of collembolan, not observed in any other cave examined during the current survey. A possible copepod was observed in a small pool of water which may have been washed out of the epiphreatic zone. It was unable to be collected with the tools available, but if further collections are made in this cave the potential presence of stygofauna within drip pools should be examined.

Stonehorse Cave

This was one of the two most intensely sampled caves undertaken by the expedition, along with Lagang Cave. The cave was sampled throughout the Entrance and main passage to the large pit section where considerable guano is present. The cave showed a very similar assemblage of species as Lagang and Racer cave, with guano areas dominated by Tineidae moths and their larvae, and associated Braconid wasp parasitoids. Schizomid arachnids are also common in guano deposits. Numerous cave crickets are present throughout, as well as amblypygids and scutigerid centipedes. Pools of water associated with speleothem development contained aquatic isopods.

Stonehorse Cave is currently being developed as a tourist cave with a staircase built from the main boardwalk to the cave entrance. No development has thus far been undertaken within the cave, apart from fixed ropes as part of the adventure cave tour infrastructure.

Figure 8 Philosciid? isopod in Stonehorse Cave. Photo Ross Anderson.

Lagang Cave

This cave had the most intense sampling of all caves examined as it shows a wide variety of habitats, with both tourism and wild caving usage. Six separate areas within the cave were surveyed, including the two entrances that form part of the tourist route, one site on the boardwalk, an area of Fast Lane, and two sites away from cave infrastructure including on top of the large blocks near the intersection with the main passage and one sampling site within the extension passage. The ability to sample the newly discovered extension provided an excellent opportunity to record completely undisturbed invertebrate assemblages with no obvious potential impacts from cave infrastructure.

Figure 9 Anobiid? beetles on a piece of fresh guano in Fast Lane, Lagang Cave. Photo Ross Anderson.

The diversity is dominated by the abundant Millipede Polydesmid? sp. A which was associated with both old and fresh guano deposits at both entrance areas, Fast Lane and the extension. Other abundant species include the schizomid, sparassid spider, two species of opiliones, amblypygdid and the cave cricket *Diestrammena sarawakana*. Interestingly the large cave cricket *Rhaphidophora oophaga* was only observed within the extension area.

One of the most notable species recorded from Lagang Cave was collected from the Fast Lane and was a linyphiid spider recorded near fresh guano that upon detailed inspection was found to be blind, depigmented and possessing an elongate process from the centre of the cephalothorax.

Racer Cave

Racer Cave is used for adventure tours and receives moderate visitation. It was found to contain a very similar diversity to Lagang and Stonehorse caves with a few exceptions. The Barychelid trapdoor spider *Idiommata* sp. was relatively abundant in the deeper parts of the cave associated with damp sediments and guano deposits (Figure 10). Isolated drip fed pools associated with speleothems were found to contain two different species of aquatic isopods, Asellidae: *Stenasellus* sp. and Anthuridae: *Cyathura* sp. These species were previously recorded from similar habitats by Chapman (1982) from Water Polo Cave, and the later species from other karst areas in southern Sarawak.

Figure 10 Location of burrows of the Barychelid trapdoor spider Idiommata sp. near the end of Racer Cave. Photo Ross Anderson.

The current survey recorded the scorpion *Chaerilus chapmani* from this cave (Figure 11), a new distribution record, but not unsurprising as it was previously known from the Clearwater system (Chapman, (1982)). Two specimens were collected from the deep cave zone, near the end of the main adventure route, associated with fresh guano and damp sediment. A further two smaller scorpion individuals were also collected and may represent an additional undescribed species or potentially juveniles of *Chaerilus chapmani*. Detailed assessment by a scorpion taxonomist will be required to determine this.

Figure 11 Troglobitic scorpion Chaerilus chapmani from Racer Cave. Photo Ross Anderson.

Clearwater Cave

Invertebrate surveying within the Clearwater system was opportunistic only, and primarily only species that had not been observed by the survey previously in other caves were collected. Several different microhabitats were also observed in this cave and opportunistically sampled including bog (mush) guano and streamway (Figure 12).

Figure 12 Clearwater river streamway in Clearwater System. Photo Ross Anderson.

PATN Analysis

The data were analysed used for similarity using PATN (version 3.12, Blatant Fabrications Pty. Ltd. 2009). Data were analysed using Bray and Curtis association, and nearest neighbour fusion algorithm. Data for two caves which were not comprehensively sampled were removed from the analysis to increase clarity of results. The caves not included in the analysis were Deer Water Cave and Clearwater Cave.

The PATN analysis by total diversity and abundance for each cave shows Racer, Lagang and Stonehorse Caves to contain very similar invertebrate assemblages and are also similar to both Kenyalang and Fruit Bat Caves. Green Cave and Deer Cave are the most dissimilar in their invertebrates assemblages.

The PATN analysis by microhabitat showed strong similarity between invertebrate assemblages within microhabitat, especially fresh guano, with most of the specialised habitats being dissimilar to all others, such as the massive guano in Deer Cave and the streamway sections of Clearwater Cave.

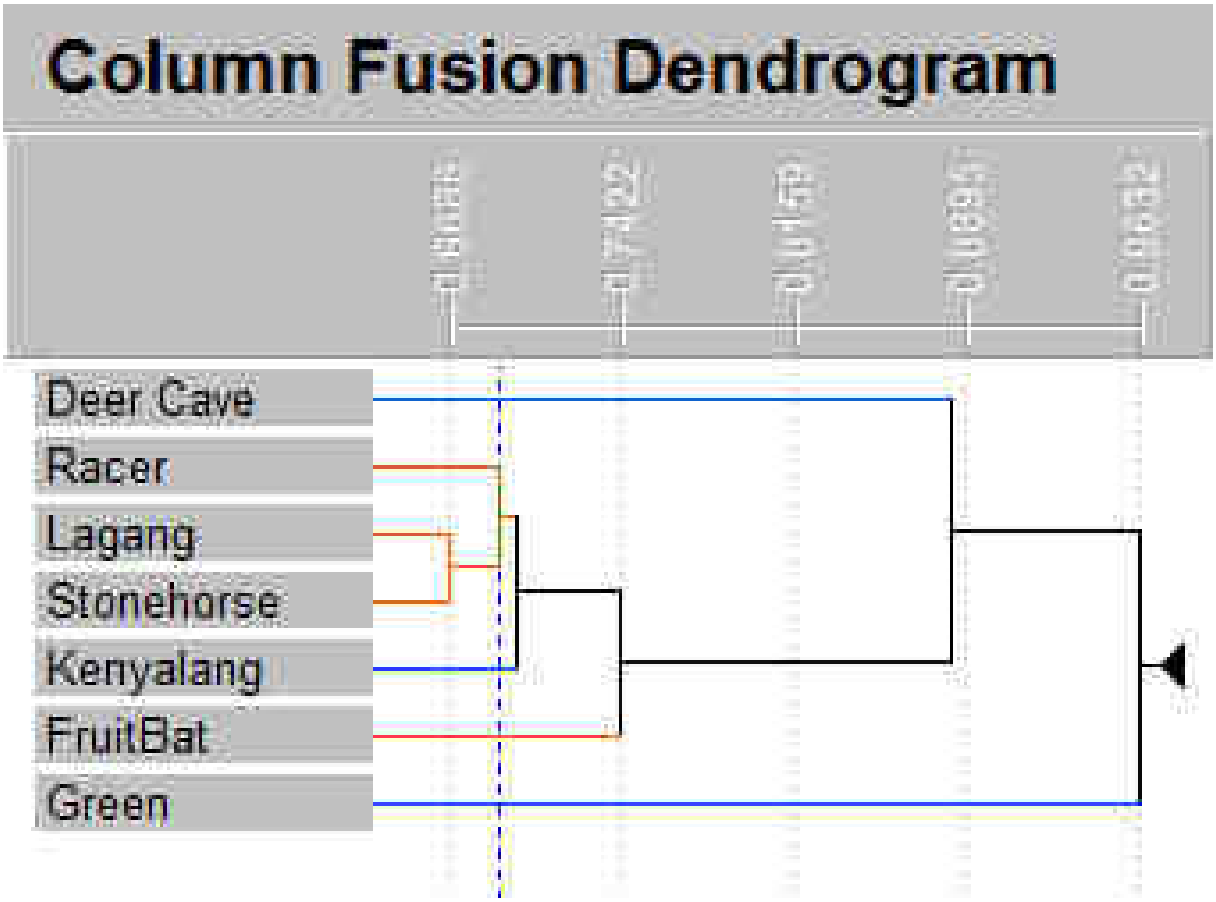

Figure 13 Column Fusion dendogram Nearest neighbour analysis – by cave

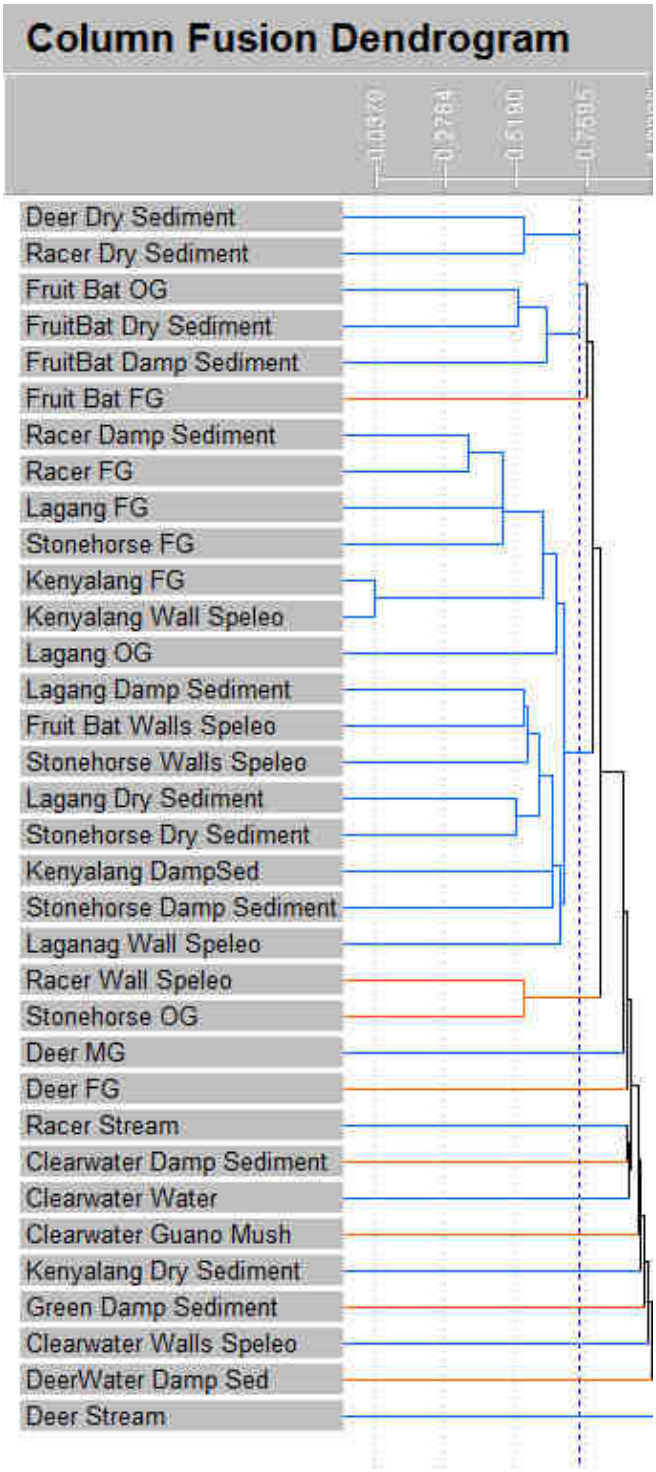

Figure 14 Column Fusion dendogram Nearest Neighbour analysis by microhabitat. FG – Fresh Guano, OG – Old Guano, MG – Massive Guano

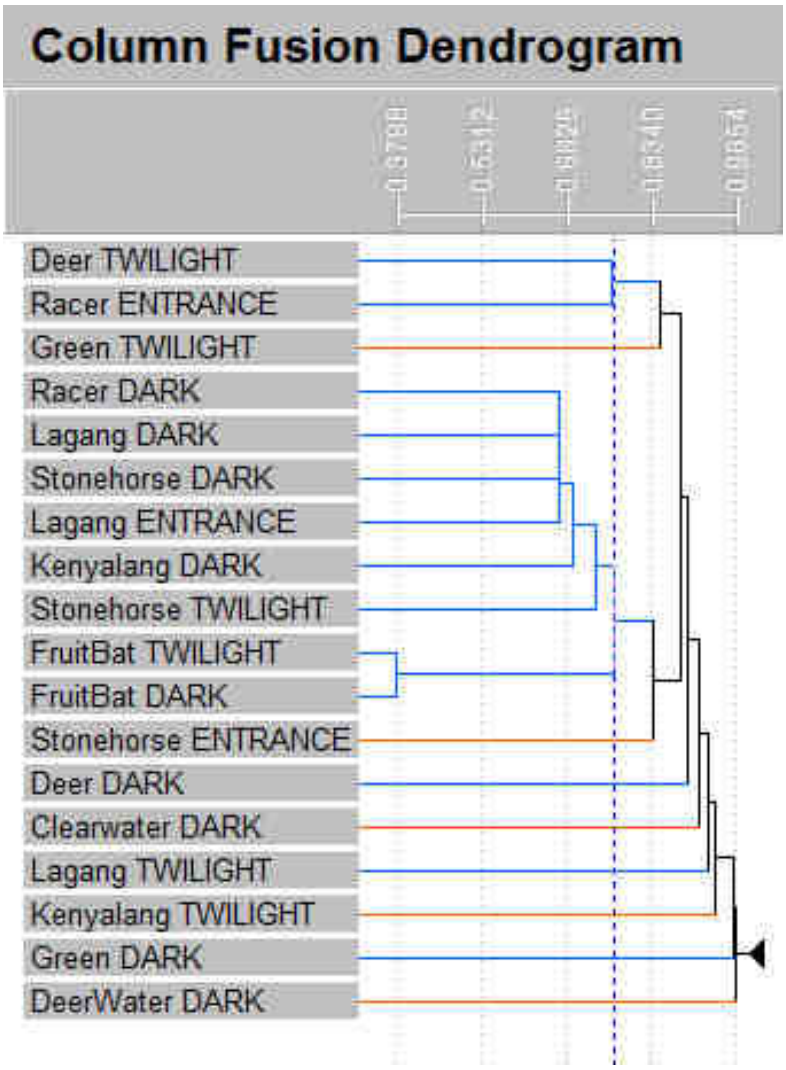

Figure 15 Column Fusion dendogram Nearest Neighbour analysis – Cave Zone

Cave Biodiversity Discussion

Cave Biodiversity in Gunung Mulu World Heritage Area

The diversity of the Mulu karst area is very high and contains numerous obligate subterranean species, although the exact number is still currently unknown. The majority of species collected during the current survey appear to match those recorded by Chapman (1982), however, several previously unknown species were recorded. Further, more detailed identification will be required prior to confirmation.

The patterns of diversity between the caves examined is complex with no obvious patterns evident from similarity analysis (Section PATN Analysis), although it would appear that caves are showing similarity based upon presence of similar micro-habitat rather than similarity of light zones. The Deer Cave, due to its complete dominance by massive guano piles appears to make it distinctly different in invertebrate composition to caves with far less guano such as Stonehorse or Lagang Cave. It is currently unknown whether there exists any difference in invertebrate composition between the different limestone blocks such as Fruit Bat/Kenyalang to Deer Cave/Green Cave to Lagang/Clearwater local areas of Mulu. The caves do show some level of association (Figure 15) but the strength of the current analysis is weak and further data, and identification of existing collected specimens may alter the results significantly. The determination of this will require far greater knowledge of both specific cave diversity and will invariably be linked to the geological history and karst geomorphology of Mulu.

Endemicity

The Mulu karst most certainly contains endemic species, although the exact number is currently hard to determine as many of the invertebrate identifications are still incomplete, for both Mulu and other karst areas in Borneo and South East Asia.

Some of the invertebrate diversity found in Deer Cave could possibly be endemic, including the 'Hairy earwig' *Arixenia esau* that is associated with the naked bat species *Cheiromeles torquatus,* although this is more likely associated with the endemicity of the bat host rather than the cave itself. Much of the other specialised invertebrate fauna recorded by Chapman (1982) was found to occur in other karst areas in Borneo, Java and Sulawesi.

Regional Significance

The results of the current preliminary study allow a cursory comparison with other karst areas, in Borneo or the remainder of Asia. This is primarily due to the often incomplete identification of many of the specimens, both in Mulu and the rest of the vast majority of the South East Asian karst. Comparison of species richness and taxonomic diversity is also difficult due to the highly variable nature of invertebrate collections from tropical caves. Very few surveys are comprehensive in nature, with many focussing on troglobiont species only or a specific taxonomic group or specific habitat such as guano. This leads to inherent bias in collecting focus and methods giving a misleading impression of diversity of richness when considering that most of the species richness in tropical caves is composed of guano associated species and non-troglobiont species (Deharveng and Bedos, (2000)).

As the specimens collected are identified further and additional surveys are undertaken a greater understanding of Mulu's subterranean biodiversity will become apparent, especially within a regional context. The preliminary results do, however, make it abundantly clear that the diversity and biogeographical significance of these species is very high and further work is required to truly appreciate the scientific values of this unique and important karst area.

Management Implications

The currently available data provides an insight into the diversity of subterranean fauna in the Mulu caves. In the future this will provide a greater understanding of localised distribution within the karst system and eventually at a localised cave scale.
The current data does not enable a meaningful interpretation of cave invertebrate biodiversity as it relates to specific cave use for tourism, adventure caving or wild caving, however, it is readily apparent to the authors that existing cave usage is not impacting upon the subterranean fauna observed in Mulu.

The authors note that the cave infrastructure within Mulu is of a very high world standard and promotes minimal impacts to both cave habitats and cave invertebrates generally. The Mulu Park staff provide excellent visitor education and supervision prior to and during cave tours eliminating predicable and avoidable impacts to the caves. The issues of rubbish and floor preservation were the only areas that management should consider some future actions with regard to the specific instances outlined.

Rubbish

Rubbish within caves is almost exclusively associated with illegal bird nester activity. Much of the rubbish was located in the far reaches of wild caves. It appeared historical in nature and was removed by the authors. Due to the complete removal of bird nests in most of these areas, the future accumulation of rubbish is unlikely to occur.

Floor preservation

The compaction of floor sediments is potentially one of the most significant impacts to cave invertebrates. It is most important in high use caves, and due to the excellent pathways and elevated boardwalks throughout the majority of Mulu tourist caves compaction is largely absent. In some adventure caves, while track marking is present to some degree some sections of caves may require additional/ more obvious track marking to reduce potential future impacts. This is evident especially for some aquatic habitats within Stonehorse and Fruit Bat Caves where aquatic fauna may be impacted as the path crosses directly over

water pools. While it may not be practical to divert paths in some instances, these habitats should be noted to cave visitors to help minimise impacts.

Recommendations for Future Work

The current study provides a very preliminary assessment of the general subterranean invertebrate diversity of Mulu since it was initially studied 30 years previously by Chapman (1982). The current study allows the site to be interpreted within a modern biospeleological context. This initial assessment has allowed the authors to gain a substantial understanding of the order of magnitude of the invertebrate diversity of Mulu, and the level of complexity of the biodiversity patterns likely to be present.

Key recommendations and focus for future cave biodiversity studies are:

1. Further photo inventory be undertaken for remaining specimens collected.
2. Further species identification and cross checking of species collected between different caves to further define morpho-species distribution within the various karst blocks in Mulu.
3. Focussed studies on particular microhabitats such as guano or aquatic systems.
4. Undertake species inventories for all major caves in Mulu NP to enable a better comparison of invertebrate diversity both within the Mulu and also with other karst areas in Sarawak, Borneo and the remainder of South East Asia.
5. Dedicated sampling of stygofauna, as only opportunistic specimens collected to date and true diversity is unknown.
6. The specimens collected during the current survey should be held by an appropriate research institute with suitable laboratory space and access to specialised library resources such as the Sarawak Museum to enable their continued identification and study by taxonomic experts.
7. Training of local staff about cave fauna and local invertebrate diversity so they can recognise common species and identify habitats.

Conclusions

The present study has provided a preliminary investigation of the invertebrate diversity across nine different caves within the Gunung Mulu World Heritage Area. This study compliments and builds upon the only other broad scale cave invertebrate diversity study of Mulu by Chapman (1982) and provides a modern context for future research in Mulu. The patterns of diversity are complex in Mulu, invariably due to the very high diversity of species, the large number of microhabitats present within caves, the multitude of energy inputs and the systems and the geomorphological history of the area. It will take considerable further effort to start to unravel these complexities but it should prove very rewarding as Mulu is undoubtedly a premier site of world cave tropical cave invertebrate diversity and provides a superb opportunity to investigate evolutionary processes in such a setting.

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Figure 16 The Australian Mulu 2012 Biospeleology Expedition Team. left to right: Ross Anderson, Patrick Nykiel, Tony Veness, Jane Pulford, Rob Susac, Barbara Zakrzewska, Tim Moulds, Jay Anderson, Sandi Cheema, Stephen Swabey, Toni Lowe, Ian Thwaites and Sharon Thwaites. (Photo Ross Anderson).

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Appendix A

Diversity and Abundance of Mulu Cave Invertebrates

Table 3 Species diversity and abundance from seven caves in the Gunung Mulu World Heritage Area, Sarawak, Malaysia

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage Twilight	Dark Zone - track Massive Guano compacted	Dark Zone Fresh Guano	Dark Zone Streamway	Dark Zone Damp Sediment	Twilight Old Guano	Twilight Dry Sediment	Twilight Walls/Speleothem	Twilight Fresh Guano	Dark Zone Damp Sediment	Dark Zone old Guano	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano	Dark Zone Mushy Guano	Dark Zone Damp Sed. A	Dark Zone Damp Sediment	Dark Zone Water Pool	Dark Zone Speleothem
	Platyhelminthes																			
Observed	Planariidae?	*Mitchellia sarawakana?*																		
Collected																			12	
	Annelida																		1	
Observed	Oligoceate																			
Collected																			3	
Observed	Hirudinea:	Gnathobdellida?																	1	
Collected																				
	Gastropoda																			
Observed	Subulinidae	*Lamellaxis clavulinus?*																		
Collected		Small conical Snail	2																	
	Crustaceans																			
Observed	Decapoda	*Cerebusa tipula*					2													
Collected		Orange/yellow																		
Observed	Decapoda	*Cerebusa caeca*																		
Collected		white																		
Observed	Decapoda					25	2													
Collected		Shrimp																		
Observed	Isopoda	*Cyathura* sp. nov.										35								
Collected		White aquatic										5								
Observed	Isopoda	*Stenasellus* sp. nov.																		
Collected		Pink aquatic																		
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																		
Collected					2															
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																		
Collected		pretty pattern			2															
Observed	Isopoda	slater (spiky)																		
Collected																				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov																		
Collected																			8	
Observed	Isopoda	*Nagarus lavis*																		
Collected					2															
Observed	Isopoda	*Setaphora parvicaputa*																		
Collected		tiny yellow philosid																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																		
Collected		grey to white																1		
	Myriapoda																			
Observed	Chilopoda	*Geophilida* sp.			2															
Collected					1															
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*		1										1						
Collected																				
Observed	Diplopoda	Spirostreptida? sp.										3			21					
Collected		common yellow										1	2							
Observed	Diplopoda	white little																		
Collected																				
Observed	Diplopoda	Doratodesmidae?										3								
Collected		rough dorsal processes										1								
Observed	Diplopoda																			
Collected		Smooth deeply segmented																		
Observed	Diplopoda	brown																		
Collected																				
Observed	Diplopoda	Trichopolydesmidae sp.?																		
Collected		Recurved points to back plates																		
Observed	Diplopoda	*Pseudodesmus sp.?*																		
Collected		Lateral wings curved																		

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage Twilight	Dark Zone - track Massive Guano compacted	Dark Zone Fresh Guano	Dark Zone Streamway	Dark Zone Damp Sediment	Twilight Old Guano	Twilight Dry Sediment	Twilight Walls/Speleothem	Twilight Fresh Guano	Dark Zone Damp Sediment	Dark Zone old Guano	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano	Dark Zone Mushy Guano	Dark Zone Damp Sed. A	Dark Zone Damp Sediment	Dark Zone Water Pool	Dark Zone Speleothem
Observed	Diplopoda																			
Collected		Lateral wings square															1			
	Arachnids																			
Observed	Amblypygdid	*Charius?/Sarax? sp.*							1	2		1			1					
Collected																				
Observed	Opilione	Stylocellidae? sp.																		
Collected		black one																		
Observed	Opilione	Phalangodidae? sp.																		
Collected		Orange long legs												2			1			
Observed	Opilione																			
Collected		Grey																		
Observed	Schizomid	Hubbardiidae sp.							2			1			7					
Collected			2		2				1				2			2				
Observed	Scorpion	*Chaerilus chapmani*																		
Collected																				
Observed	Laelapidae	*Hypoaspis?*					20													
Collected							1						1							
	Araneae																			
Observed	Sparassid	*Heteropoda sp.*	7						5	11										
Collected																				
Observed	Linyphiidae?																			
Collected		no eyes, depigmented, head process																		
Observed	Amaurobiidae?	sp. A																		
Collected		big palps																		
Observed	Zoderiidae?	sp. A																		
Collected		Red Spider																		
Observed	Theridiidae	sp. A																		
Collected		Medium black																		
Observed	Theridiidae	Theridon? sp. B									4									
Collected								1												
Observed	Theridiidae	sp. C																		
Collected		Black																		
Observed	Theriidae	sp. D																		
Collected																				
Observed	Pholcidae	*Spermophora? sp.*		5					3	2			1							
Collected		4 eyes		3								1					1			
Observed	Pholcidae	Pholcid sp. B																		
Collected		2 eyes																		
Observed	Barychelidae	*Idiommata* sp.							2		10									
Collected																				
	Hexapoda																			
Observed	Collembola																			
Collected																				
Observed	Dipluran Campodeidae	*Lepidocampa sp.*																		
Collected															1					
	Insects																			
Observed	Zygentoma	Silverfish Other								1										
Collected																				
Observed	Zygentoma	Silverfish Spotty																		
Collected																				
Observed	Hemiptera: Reduviid																			
Collected																				
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*							1	2	1									
Collected								3												
Observed	Hemiptera: Reduviid	Emesinae																		
Collected		small																		
Observed	Hemiptera: Reduviid	Harpacticoid sp.A			1															
Collected		White with red eyes			1			2												

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage Twilight	Dark Zone - track Massive Guano compacted	Dark Zone Fresh Guano	Dark Zone Streamway	Dark Zone Damp Sediment	Twilight Old Guano	Twilight Dry Sediment	Twilight Walls/Speleothem	Twilight Fresh Guano	Dark Zone Damp Sediment	Dark Zone old Guano	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano	Dark Zone Mushy Guano	Dark Zone Damp Sed. A	Dark Zone Damp Sediment	Dark Zone Water Pool	Dark Zone Speleothem
Observed	Hemiptera: Reduviid	Harpacticoid sp.B								1										
Collected		White and black stripe																		
Observed	Hemiptera: Heteroptera	Cimicid																		
Collected																				
Observed	Hemiptera: Heteroptera	Veliidae? sp.																		
Collected																				
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																		
Collected																				
Observed	Homoptera	Plant Hopper, Large with orange stripes																		
Collected																				
Observed	Orthoptera	*Raphidophora oophaga*																		
Collected																				
Observed	Orthoptera	*Diestrammena mjobergi*	4	10				2	13			3	31							
Collected																				
Observed	Orthoptera	*Diestrammenasarawakana*							6	12	13	25		22	32					
Collected		Stripy legs and body							1											
Observed	Blattodea	*Pyenoscelus indicus*						9	30		250	40	38		187					1?
Collected								1	1											
Observed	Blattodea	*Blattela cavernicola*							24			7	1							
Collected		Golden							1											
Observed																				
Collected	Blattodea	Forest							1											
Observed	Psocoptera																			
Collected																				
Observed	Dermaptera	Hairy			2															
Collected																				
Observed	Dermaptera	other					200													
Collected							3													
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Carabid?																		
Collected		larvae large																		
Observed	Coleoptera	Dermestid larvae						1												
Collected								1												
Observed	Coleoptera	Black round 1mm																		
Collected																				
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Histeridae: *Hister* sp																		
Collected					1		200													
Observed	Coleoptera	Histerid larvae																		
Collected																				
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*	1																	
Collected		tiny small																		
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																		
Collected																				
Observed	Coleoptera	Pselaphidae																		
Collected																				
Observed	Coleoptera	staphylinidae																		
Collected																				
Observed	Coleoptera	small staphylinidid					200													
Collected																				
Observed	Coleoptera	medium staphylinid		100																
Collected				1																
Observed	Coleoptera	Jacobsonnidae?																		
Collected																				
Observed	Lepidoptera	*Tinea sp.*					100		1		1	2	1	2						
Collected		Tineid Moth																		
Observed	Lepidoptera	*Tinea sp.*										20			17					
Collected		Tineid Larvae																		

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage	Dark Zone - track	Dark Zone Fresh	Dark Zone	Dark Zone Damp	Twilight	Twilight Dry	Twilight	Twilight Fresh	Dark Zone Damp	Dark Zone old	Dark Zone	Dark Zone Fresh	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone
			Twilight	Massive Guano compacted	Guano	Streamway	Sediment	Old Guano	Sediment	Walls/Speleothem	Guano	Sediment	Guano	Walls/Speleothem	Guano	Mushy Guano	Damp Sed. A	Damp Sediment	Water Pool	Speleothem
Observed	Diptera	*Chetoneura cavernae*								11										
Collected																				
Observed	Diptera	Tipulidae sp. A																		
Collected		short legged																		
Observed	Diptera	Tipulidae sp. B		300																
Collected				5																
Observed	Diptera	larvae					20													
Collected							1													
Observed	Diptera	sp. A					3000													
Collected		Large					2													
Observed	Diptera	Phoridae					4000													
Collected							3													
Observed	Diptera	Bar fly																		
Collected																				
Observed	Diptera	Midgie					3000													
Collected							1													
Observed	Diptera	Nycteribiidae																		
Collected																				
Observed	Hymenoptera: Formicidae	sp. A											2							
Collected		Tiny																		
Observed	Hymenoptera: Formicidae	sp. B																		
Collected		Ant small brown					1													
Observed	Hymenoptera: Formicidae	sp. C	2										80	16	5					
Collected		ant-small black												1						
Observed	Hymenoptera: Formicidae	sp. D																		
Collected		Ant medium elongate																		
Observed	Hymenoptera: Formicidae	sp. E																		
Collected		Large ant (wasp minic)																		
Observed	Hymenoptera	Braconidae?											4							
Collected								1												

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
	Platyhelminthes																				
Observed	Planariidae?	*Mitchellia sarawakana?*																			
Collected																					
	Annelida																				
Observed	Oligoceate																				
Collected																					
Observed	Hirudinea:	Gnathobdellida?																		55	
Collected																				1	
	Gastropoda																				
Observed	Subulinidae	*Lamellaxis clavulinus?*																			
Collected		Small conical Snail																			
	Crustaceans																				
Observed	Decapoda	*Cerebusa tipula*																			
Collected		Orange/yellow																			
Observed	Decapoda	*Cerebusa caeca*																			
Collected		white																			
Observed	Decapoda																				
Collected		Shrimp																			
Observed	Isopoda	*Cyathura* sp. nov.																			
Collected		White aquatic																			
Observed	Isopoda	*Stenasellus* sp. nov																			
Collected		Pink aquatic																			
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																			
Collected																					
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																			
Collected		pretty pattern																			
Observed	Isopoda	slater (spiky)															4				
Collected																	1				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov																			
Collected																					
Observed	Isopoda	*Nagarus lavis*																			
Collected			1																		
Observed	Isopoda	*Setaphora parvicaputa*	4																		
Collected		tiny yellow philosid	1																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																			
Collected		grey to white																			
	Myriapoda																				
Observed	Chilopoda	*Geophilida* sp.																			
Collected																					
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*																			
Collected																					
Observed	Diplopoda	Spirostreptida? sp.		32					5	1		26	32	2					57		
Collected		common yellow		1								1		1							
Observed	Diplopoda	white little																			1
Collected																					1
Observed	Diplopoda	Doratodesmidae?														2					1
Collected		rough dorsal processes																			
Observed	Diplopoda																				
Collected		Smooth deeply segmented																			
Observed	Diplopoda	brown																			
Collected																					
Observed	Diplopoda	Trichopolydesmidae sp.?																			
Collected		Recurved points to back plates										1									
Observed	Diplopoda	*Pseudodesmus sp.?*																			
Collected		Lateral wings curved																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Diplopoda																				
Collected		Lateral wings square																			
	Arachnids																				
Observed	Amblypygdid	*Charius?/Sarax? sp.*	1				4			1	1	1	1	1	1						
Collected																					
Observed	Opilione	Stylocellidae? sp.				3		7			5	6	8	13							
Collected		black one					1					1									
Observed	Opilione	Phalangodidae? sp.	2			1		4									2				
Collected		Orange long legs	1																		
Observed	Opilione																				
Collected		Grey																			
Observed	Schizomid	Hubbardiidae sp.		4	2			2		3		17	9		1						
Collected				2	1							1									
Observed	Scorpion	*Chaerilus chapmani*																			
Collected																					
Observed	Laelapidae	*Hypoaspis?*																			
Collected																					
	Araneae																				
Observed	Sparassid	*Heteropoda sp.*	3		1			1	1		2	1		3							
Collected																					
Observed	Linyphiidae?											1									
Collected		no eyes, depigmented, head process																			
Observed	Amaurobiidae?	sp. A																			
Collected		big palps	1																		
Observed	Zoderiidae?	sp. A																			
Collected		Red Spider																			
Observed	Theridiidae	sp. A																			
Collected		Medium black																			
Observed	Theridiidae	Theridon? sp. B																			
Collected																					
Observed	Theridiidae	sp. C																			
Collected		Black																			
Observed	Theriidae	sp. D															12			1	
Collected																	2				
Observed	Pholcidae	*Spermophora? sp.*	4					4	1	1	4		6	2							
Collected		4 eyes												1							
Observed	Pholcidae	Pholcid sp. B																			
Collected		2 eyes																			
Observed	Barychelidae	*Idiommata* sp.																			
Collected																					
	Hexapoda																				
Observed	Collembola																	1			
Collected																					
Observed	Dipluran Campodeidae	*Lepidocampa sp.*																			
Collected			1																		
	Insects																				
Observed	Zygentoma	Silverfish Other																			
Collected																					
Observed	Zygentoma	Silverfish Spotty																			
Collected																					
Observed	Hemiptera: Reduviid																				
Collected																					
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																			
Collected																					
Observed	Hemiptera: Reduviid	Emesinae																			
Collected		small															1				
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																			
Collected		White with red eyes																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																			
Collected		White and black stripe																			
Observed	Hemiptera: Heteroptera	Cimicid																			
Collected																					
Observed	Hemiptera: Heteroptera	Veliidae? sp.																			
Collected																					
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																			
Collected																					
Observed	Homoptera	Plant Hopper, Large with orange stripes																		2	
Collected																				1	
Observed	Orthoptera	*Raphidophora oophaga*																			
Collected												3									
Observed	Orthoptera	*Diestrammena mjobergi*																			
Collected																					
Observed	Orthoptera	*Diestrammenasarawakana*																			
Collected		Stripy legs and body	15	12			4	3	10	6	46	18	24	16		8	11				
Observed	Blattodea	*Pyenoscelus indicus*																			
Collected					1																
Observed	Blattodea	*Blattela cavernicola*																			
Collected		Golden																			
Observed																					
Collected	Blattodea	Forest																			
Observed	Psocoptera			100	10					1											
Collected																					
Observed	Dermaptera	Hairy																			
Collected																					
Observed	Dermaptera	other																			
Collected																					
Observed	Coleoptera	Grey 1mm						3													
Collected													1								
Observed	Coleoptera	Carabid?								1											
Collected		larvae large								1											
Observed	Coleoptera	Dermestid larvae		2																	
Collected				1																	
Observed	Coleoptera	Black round 1mm																			
Collected																	1				
Observed	Coleoptera	Grey 1mm																			
Collected																					
Observed	Coleoptera	Histeridae: *Hister* sp	4																		
Collected				1																	
Observed	Coleoptera	Histerid larvae										2									
Collected				1																	
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*																			
Collected		tiny small					30 1		180 3									30			5
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																			
Collected							40 1														
Observed	Coleoptera	Pselaphidae																			
Collected																	2				
Observed	Coleoptera	staphylinidae																4			
Collected																					
Observed	Coleoptera	small staphylinidid																			
Collected																					
Observed	Coleoptera	medium staphylinid			4		40		2												
Collected					1																
Observed	Coleoptera	Jacobsonnidae?							1												
Collected																					
Observed	Lepidoptera	*Tinea sp.*		1					1								1			1	
Collected		Tineid Moth							1												
Observed	Lepidoptera	*Tinea sp.*							1												
Collected		Tineid Larvae																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Diptera	*Chetoneura cavernae*																			
Collected			50											6			25				
Observed	Diptera	Tipulidae sp. A	1																		
Collected		short legged																			
Observed	Diptera	Tipulidae sp. B																			
Collected			4								2			1			15			9	
Observed	Diptera	larvae																			
Collected																					
Observed	Diptera	sp. A																			
Collected		Large																			
Observed	Diptera	Phoridae						10	1			1								3	
Collected													2							4	
Observed	Diptera	Bar fly																			
Collected																				1	
Observed	Diptera	Midgie																			
Collected																					
Observed	Diptera	Nycteribiidae																			
Collected																					
Observed	Hymenoptera: Formicidae	sp. A		7	20																
Collected		Tiny		1																	
Observed	Hymenoptera: Formicidae	sp. B																			
Collected		Ant small brown																			
Observed	Hymenoptera: Formicidae	sp. C																			
Collected		ant-small black		2								2									
Observed	Hymenoptera: Formicidae	sp. D																			
Collected		Ant medium elongate																			
Observed	Hymenoptera: Formicidae	sp. E																			
Collected		Large ant (wasp minic)											1								
Observed	Hymenoptera	Braconidae?																			
Collected									1												

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
	Platyhelminthes																	
Observed	Planariidae?	*Mitchellia sarawakana?*		1														
Collected																		
	Annelida																	
Observed	Oligoceate																	
Collected																		
Observed	Hirudinea:	Gnathobdellida?																
Collected																		
	Gastropoda																	
Observed	Subulinidae	*Lamellaxis clavulinus?*			4								4					
Collected		Small conical Snail																
	Crustaceans																	
Observed	Decapoda	*Cerebusa tipula*																
Collected		Orange/yellow																
Observed	Decapoda	*Cerebusa caeca*					1						1	4				
Collected		white																
Observed	Decapoda																	
Collected		Shrimp																
Observed	Isopoda	*Cyathura* sp. nov.				15												
Collected		White aquatic				3												
Observed	Isopoda	*Stenasellus* sp. nov.																
Collected		Pink aquatic				1												
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																
Collected																		
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																
Collected		pretty pattern																
Observed	Isopoda	slater (spiky)																
Collected																		
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov															9	
Collected																	3	
Observed	Isopoda	*Nagarus lavis*											9					
Collected				1									1					
Observed	Isopoda	*Setaphora parvicaputa*											14					
Collected		tiny yellow philosid											4					
Observed	Isopoda	*Paraperiscyphis platyperaeon*				2		7		2		1		1				
Collected		grey to white					1				2	1	1	1				
	Myriapoda																	
Observed	Chilopoda	*Geophilida* sp.																
Collected								1	1									
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*															1	5
Collected																		
Observed	Diplopoda	Spirostreptida? sp.			1	3	3	1	5	19		2		3		8	100	
Collected		common yellow							1					1		2	1	
Observed	Diplopoda	white little																
Collected										1								
Observed	Diplopoda	Doratodesmidae?															5	
Collected		rough dorsal processes															2	
Observed	Diplopoda						5											
Collected		Smooth deeply segmented					2											
Observed	Diplopoda	brown																
Collected																		
Observed	Diplopoda	Trichopolydesmidae sp.?																
Collected		Recurved points to back plates					1											
Observed	Diplopoda	*Pseudodesmus sp.?*																
Collected		Lateral wings curved	1															

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Diplopoda																	
Collected		Lateral wings square	1										1					
	Arachnids																	
Observed	Amblypygdid	*Charius?/Sarax? sp.*			3	1	2	2		3		10						
Collected																		
Observed	Opilione	Stylocellidae? sp.			1			4	12					5				
Collected		black one						1						1				
Observed	Opilione	Phalangodidae? sp.				1	1									1		
Collected		Orange long legs																
Observed	Opilione																	
Collected		Grey																
Observed	Schizomid	Hubbardiidae sp.																
Collected							2											
Observed	Scorpion	*Chaerilus chapmani*																
Collected								3	1									
Observed	Laelapidae	*Hypoaspis?*																
Collected								1										
	Araneae																	
Observed	Sparassid	*Heteropoda sp.*				1		3		2	8		1	3	1			
Collected																		
Observed	Linyphiidae?																	
Collected		no eyes, depigmented, head process																
Observed	Amaurobiidae?	sp. A																
Collected		big palps																
Observed	Zoderiidae?	sp. A																
Collected		Red Spider	1															
Observed	Theridiidae	sp. A																
Collected		Medium black																
Observed	Theridiidae	Theridon? sp. B																
Collected																		
Observed	Theridiidae	sp. C																
Collected		Black											1					
Observed	Theriidae	sp. D																
Collected																		
Observed	Pholcidae	*Spermophora? sp.*				4	14	16		5		10						
Collected		4 eyes						1		1		1						
Observed	Pholcidae	Pholcid sp. B									8							
Collected		2 eyes									2							
Observed	Barychelidae	*Idiommata* sp.					1	1		1								
Collected							1		1									
	Hexapoda																	
Observed	Collembola													1		100s		
Collected														1			2	
Observed	Dipluran Campodeidae	*Lepidocampa sp.*																
Collected																		
	Insects																	
Observed	Zygentoma	Silverfish Other																
Collected																		
Observed	Zygentoma	Silverfish Spotty																
Collected																		
Observed	Hemiptera: Reduviid																	
Collected				2														
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																
Collected																		
Observed	Hemiptera: Reduviid	Emesinae																
Collected		small																
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																
Collected		White with red eyes																

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																
Collected		White and black stripe																
Observed	Hemiptera: Heteroptera	Cimicid																
Collected							2											
Observed	Hemiptera: Heteroptera	Veliidae? sp.											8					
Collected													3					
Observed	Hemiptera: Heteroptera	Rhyparochrominae?											3					
Collected													2					
Observed	Homoptera	Plant Hopper, Large with orange stripes																
Collected																		
Observed	Orthoptera	*Raphidophora oophaga*																
Collected												1		3				
Observed	Orthoptera	*Diestrammena mjobergi*																
Collected					19	3	4	10	10	7	10	15		5				
Observed	Orthoptera	*Diestrammenasarawakana*																
Collected		Stripy legs and body														50 1	100s	
Observed	Blattodea	*Pyenoscelus indicus*																
Collected																3 1		1
Observed	Blattodea	*Blattela cavernicola*																
Collected		Golden									1							
Observed																		
Collected	Blattodea	Forest																
Observed	Psocoptera																	
Collected																		
Observed	Dermaptera	Hairy																
Collected																		
Observed	Dermaptera	other																
Collected																		
Observed	Coleoptera	Grey 1mm																
Collected													?1					
Observed	Coleoptera	Carabid?																
Collected		larvae large																
Observed	Coleoptera	Dermestid larvae																
Collected								1		1								
Observed	Coleoptera	Black round 1mm																
Collected																		
Observed	Coleoptera	Grey 1mm																
Collected																		
Observed	Coleoptera	Histeridae: *Hister* sp																
Collected																		
Observed	Coleoptera	Histerid larvae																
Collected																		
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*						300		250				850		1000s		1000s
Collected		tiny small						2		2				3		2		2
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																
Collected																		
Observed	Coleoptera	Pselaphidae																
Collected																		
Observed	Coleoptera	staphylinidae												1				
Collected																		
Observed	Coleoptera	small staphylinidid											6					
Collected													1					
Observed	Coleoptera	medium staphylinid											1					
Collected													1					
Observed	Coleoptera	Jacobsonnidae?																
Collected																		
Observed	Lepidoptera	*Tinea sp.*														1		
Collected		Tineid Moth																
Observed	Lepidoptera	*Tinea sp.*									70	300				2		
Collected		Tineid Larvae										1				2		

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Diptera	*Chetoneura cavernae*																
Collected																		
Observed	Diptera	Tipulidae sp. A																
Collected		short legged																
Observed	Diptera	Tipulidae sp. B																
Collected																		
Observed	Diptera	larvae																
Collected																		
Observed	Diptera	sp. A																
Collected		Large													20			
Observed	Diptera	Phoridae																
Collected													1					
Observed	Diptera	Bar fly																
Collected													1					
Observed	Diptera	Midgie		1														
Collected																		
Observed	Diptera	Nycteribiidae																
Collected																		
Observed	Hymenoptera: Formicidae	sp. A								3								
Collected		Tiny																
Observed	Hymenoptera: Formicidae	sp. B																
Collected		Ant small brown																
Observed	Hymenoptera: Formicidae	sp. C			3							1						
Collected		ant-small black																
Observed	Hymenoptera: Formicidae	sp. D																
Collected		Ant medium elongate																
Observed	Hymenoptera: Formicidae	sp. E						1		4						1		
Collected		Large ant (wasp minic)														1		
Observed	Hymenoptera	Braconidae?																
Collected																		

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
	Platyhelminthes																			
Observed	Planariidae?	*Mitchellia sarawakana?*																		
Collected																				
	Annelida																			
Observed	Oligoceate																			
Collected																				
Observed	Hirudinea:	Gnathobdellida?																		
Collected																				
	Gastropoda																			
Observed	Subulinidae	*Lamellaxis clavulinus?*						1												
Collected		Small conical Snail						1												
	Crustaceans																			
Observed	Decapoda	*Cerebusa tipula*												1						
Collected		Orange/yellow																		
Observed	Decapoda	*Cerebusa caeca*												1						
Collected		white																		
Observed	Decapoda																			
Collected		Shrimp																		
Observed	Isopoda	*Cyathura* sp. nov.											7		10					
Collected		White aquatic											3		1					
Observed	Isopoda	*Stenasellus* sp. nov.																		
Collected		Pink aquatic																		
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																		
Collected																				
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																		
Collected		pretty pattern																		
Observed	Isopoda	slater (spiky)																		
Collected																				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov											1							
Collected													1							
Observed	Isopoda	*Nagarus lavis*						3							1					
Collected								1							1					
Observed	Isopoda	*Setaphora parvicaputa*											4	5						1
Collected		tiny yellow philosid																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																		
Collected		grey to white																		
	Myriapoda																			
Observed	Chilopoda	*Geophilida* sp.																		
Collected																				
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*		1		1				1	2			1		1		1		3
Collected																				
Observed	Diplopoda	Spirostreptida? sp.		1				7					1							
Collected		common yellow						1												
Observed	Diplopoda	white little					3													
Collected																				
Observed	Diplopoda	Doratodesmidae?						3					1							
Collected		rough dorsal processes						1					1							
Observed	Diplopoda																			
Collected		Smooth deeply segmented																		
Observed	Diplopoda	brown						2												
Collected								1												
Observed	Diplopoda	Trichopolydesmidae sp.?																		
Collected		Recurved points to back plates																		
Observed	Diplopoda	*Pseudodesmus sp.?*																		
Collected		Lateral wings curved																		

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Diplopoda																			
Collected		Lateral wings square																		
	Arachnids																			
Observed	Amblypygid	*Charius?/Sarax? sp.*						1		3	9	2			2			5		5
Collected																				
Observed	Opilione	Stylocellidae? sp.										5	3	3	1			3	2	1
Collected		black one																		
Observed	Opilione	Phalangodidae? sp.	8					1				4							3	
Collected		Orange long legs	2																	
Observed	Opilione																			
Collected		Grey		2																
Observed	Schizomid	Hubbardiidae sp.		2				3		2			7	1	1	1	1		1	
Collected								2					1	1						
Observed	Scorpion	*Chaerilus chapmani*																		
Collected																				
Observed	Laelapidae	*Hypoaspis?*																		
Collected																				
	Araneae																			
Observed	Sparassid	*Heteropoda sp.*	2		1	3	1		4		1		2					2	1	6
Collected																				
Observed	Linyphiidae?																			
Collected		no eyes, depigmented, head process																		
Observed	Amaurobiidae?	sp. A																		
Collected		big palps																		
Observed	Zoderiidae?	sp. A																		
Collected		Red Spider																		
Observed	Theridiidae	sp. A		1																
Collected		Medium black		1																
Observed	Theridiidae	Theridon? sp. B	5			13	5													
Collected			1																	
Observed	Theridiidae	sp. C																		
Collected		Black																		
Observed	Theriidae	sp. D																		
Collected																				
Observed	Pholcidae	*Spermophora? sp.*						1					2		1		2		1	
Collected		4 eyes													1				1	
Observed	Pholcidae	Pholcid sp. B																		
Collected		2 eyes																		
Observed	Barychelidae	*Idiommata* sp.																		
Collected															1					
	Hexapoda																			
Observed	Collembola						1													
Collected																				
Observed	Dipluran Campodeidae	*Lepidocampa sp.*								5		6			1					
Collected												3			1					
	Insects																			
Observed	Zygentoma	Silverfish Other						1												
Collected																				
Observed	Zygentoma	Silverfish Spotty																		
Collected				1																
Observed	Hemiptera: Reduviid																			
Collected																				
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																		
Collected																				
Observed	Hemiptera: Reduviid	Emesinae																		
Collected		small																		
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																		
Collected		White with red eyes																		

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																		
Collected		White and black stripe																		
Observed	Hemiptera: Heteroptera	Cimicid																		
Collected																				
Observed	Hemiptera: Heteroptera	Veliidae? sp.																		
Collected																				
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																		
Collected																				
Observed	Homoptera	Plant Hopper, Large with orange stripes																		
Collected																				
Observed	Orthoptera	*Raphidophora oophaga*																		
Collected				1						1	1	1		1						1
Observed	Orthoptera	*Diestrammena mjobergi*																		
Collected																				
Observed	Orthoptera	*Diestrammenasarawakana*																		
Collected		Stripy legs and body	3	1	4	18	1		11	9	30	6	65			8	17	44	20	10
Observed	Blattodea	*Pyenoscelus indicus*																		
Collected				1																
Observed	Blattodea	*Blattela cavernicola*																		
Collected		Golden																		
Observed																				
Collected	Blattodea	Forest																		
Observed	Psocoptera																			
Collected																				
Observed	Dermaptera	Hairy																		
Collected																				
Observed	Dermaptera	other																		
Collected																				
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Carabid?																		
Collected		larvae large																		
Observed	Coleoptera	Dermestid larvae																		
Collected																				
Observed	Coleoptera	Black round 1mm																		
Collected																				
Observed	Coleoptera	Grey 1mm														1	1			
Collected																				
Observed	Coleoptera	Histeridae: *Hister* sp												50						
Collected														2						
Observed	Coleoptera	Histerid larvae																		
Collected																				
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*																		
Collected		tiny small										1								1
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																		
Collected																				
Observed	Coleoptera	Pselaphidae																		
Collected																				
Observed	Coleoptera	staphylinidae																		
Collected																				
Observed	Coleoptera	small staphylinidid																		
Collected																				
Observed	Coleoptera	medium staphylinid																		
Collected																				
Observed	Coleoptera	Jacobsonnidae?																		
Collected																				
Observed	Lepidoptera	*Tinea sp.*								5	4					20				
Collected		Tineid Moth																		
Observed	Lepidoptera	*Tinea sp.*									5				1	200				
Collected		Tineid Larvae									1									37

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Diptera	*Chetoneura cavernae*																		
Collected			3						31		2							6		
Observed	Diptera	Tipulidae sp. A		15																
Collected		short legged		3																
Observed	Diptera	Tipulidae sp. B																		
Collected									1		1		10	30					1	
Observed	Diptera	larvae																		
Collected																				
Observed	Diptera	sp. A																		
Collected		Large																		
Observed	Diptera	Phoridae														1				
Collected																				
Observed	Diptera	Bar fly																		
Collected																				
Observed	Diptera	Midgie												1	1					
Collected																				
Observed	Diptera	Nycteribiidae																		
Collected									40											
Observed	Hymenoptera: Formicidae	sp. A																		
Collected		Tiny																		
Observed	Hymenoptera: Formicidae	sp. B																		
Collected		Ant small brown		1																
Observed	Hymenoptera: Formicidae	sp. C																		
Collected		ant-small black																		
Observed	Hymenoptera: Formicidae	sp. D																		
Collected		Ant medium elongate		3																
Observed	Hymenoptera: Formicidae	sp. E		1																
Collected		Large ant (wasp minic)																		
Observed	Hymenoptera	Braconidae?																		
Collected													7							

Appendix B

Photo Inventory of Mulu Cave Invertebrates

Mollusca: Gastropoda: ?Stylommatophora: Subulinidae: *Lamellaxis clavulinus* (Deer Cave) Photo Ross Anderson	
Crustacea: Isopoda: Anthuridae: ?*Cycthura* sp. nov. TB (Fruit Bat Cave) Photo Ross Anderson	

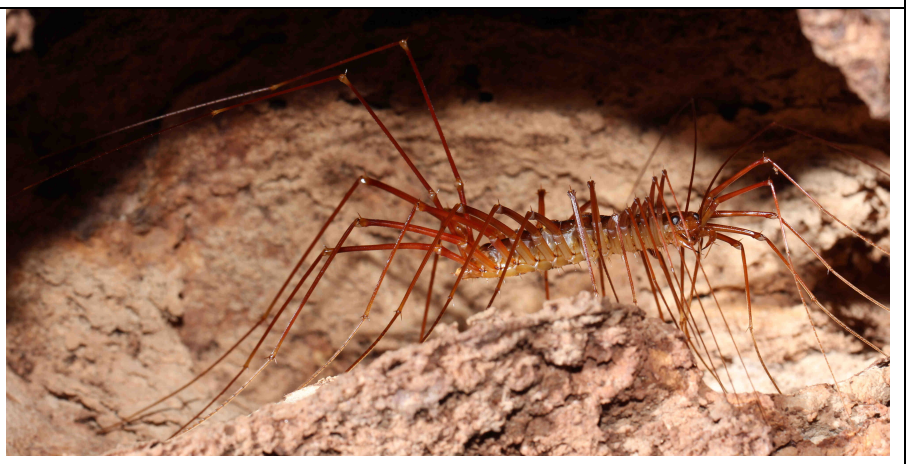
Crustacea: Isopoda: Armadillidae: ?*Tuberillo sarawakensis* (Deer Cave) Photo Ross Anderson	
Crustacea: Isopoda: (Deer Cave) Photo Ross Anderson	

Crustacea: Isopoda: Philloscidae: *?Setaphora parvicaputa* (Stonehorse Cave) Photo Ross Anderson	
Crustacea: Isopoda: Aramadillidae: *Triadillo annandalei* (Unknown Cave) Photo Ross Anderson	

Crustacea: Isopoda: sp. (Green Cave) Photo Jane Pullford	
Crustacea: Decapoda: Potamidae: *Cerebusa tipula* (Fruit Bat Cave) Photo Ross Anderson	

Crustacea: Decapoda: Potamidae: *Cerebusa caeca* (Green Cave) Photo Jane Pullford	
Crustacea: Diplopoda: Polydesmoidea? (Fruit Bat Cave) Photo Ross Anderson	

Crustacea: Diplopoda: Doratodesmidae? (Fruit Bat Cave) Photo Ross Anderson	
Diplopoda: Spirastreptida? sp. A (Lagang Cave) Photo Ross Anderson	

Diplopoda: recurved plates? sp.A() Photo Jane Pulford	
Chilopoda: Scutigeridae: *Thereuopoda longicornis*? (Stonehorse Cave) Photo Ross Anderson	

Chilopoda: Scolopendromorpha: sp. (Unknown Cave) Photo Jane Pullford	
Chilopoda: Geophilomorpha: ?Geophilidae: *Orphnaeus brevilabiatus* (Deer Cave) Photo Ross Anderson • Emits luminous green fluid when disturbed	

Arachnida: Amblypygid: *Charinus*? or *Sarax*? sp. (Stonehorse Cave) Photo Ross Anderson	
Arachnida: Shizomida Hubbardiidae sp. (Deer Cave) Photo Ross Anderson	

Arachnida: Scorpione: Buthidae: *Chaerilus chapmani* (Racer Cave) Photo Ross Anderson	
Arachnida: Opilione: Stylocellidae sp. (Lagang Cave) Photo Ross Anderson	

Arachnida: Opilione: Phalangodidae? sp. A (Stonehorse Cave) Photo Ross Anderson	
Arachnida: Araneomorphae: Sparassidae: Heteropoda sp. (Lagang Cave) Photo Ross Anderson	

Arachnida: Araneae: ?Amaurobiidae (Lagang Cave) Photo Ross Anderson	
Arachnida: Araneae: Pholcidae: ?*Spermophora* sp. (Lagang Cave) Photo Ross Anderson	

Hexapoda: Diplura: Campodeidae: *Lepidocampa ?weberi* (Stonehorse Cave) Photo Ross Anderson	
Insecta: Blattodea: *Blattella cavernicola* (Deer Cave) Photo Ross Anderson	

Insecta: Orthoptera: Rhaphidophoridae: *Rhaphidophora oophaga* (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Orthoptera: *Diestrammena sarawakana* (Fruit Bat Cave) Photo Ross Anderson • Banded legs • close to entrances • associated with guano when *D. mjobergi* is absent	

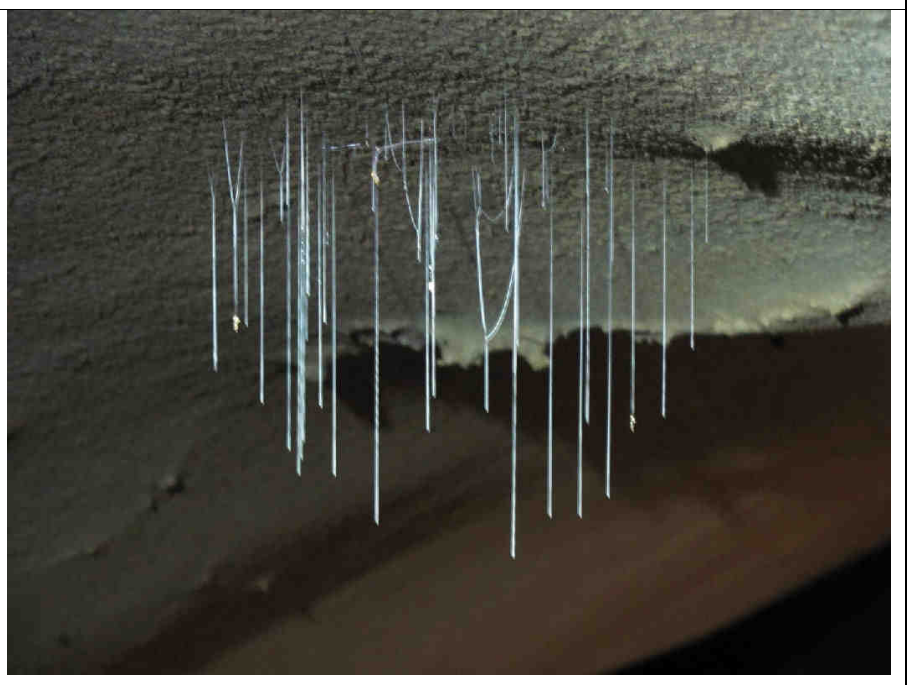
Insecta: Orthoptera: *Diestrammena mjobergi* (Lagang Cave) Photo Ross Anderson • Light brown • Deeper high humidity cave environment • associated with guano	
Insecta: Dermaptera: Arixeniidae: *Arixenia esau* (Deer Cave) Photo Ross Anderson	

Insecta: Hemiptera: Reduviidae: Harpactocoid? (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Hemiptera: Reduviidae: (Fruit Bat Cave) Photo Ross Anderson	

Insecta: Hemiptera: Reduviidae: Emesinae: ?*Baguada cf. cavernicola* (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Lepidoptera: Tineidae: Tinea? sp. (Fruit Bat Cave) Photo Ross Anderson (*Crypsithyrodes concolorella* / *Tinea porphyropa* / *Tinea antricola*)	

Insecta: Lepidoptera: Tineidae sp. larvae (Lagang Cave) Photo Ross Anderson (*Crypsithyrodes concolorella* / *Tinea porphyropa* / *Tinea antricola*)	
Insecta: Coleoptera: Trogidae: *Trox costatus* (Deer Cave) Photo Ross Anderson	

Insecta: Coleoptera: Leiodidae: *Ptomaphaginus chapmani* (Lagang Cave) Photo Ross Anderson	
Insecta: Diptera: (Deer Cave) Photo Ross Anderson	

Insecta: Diptera: (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Diptera: Keroplatidae *Chetoneura* ?*cavernae.* (Fruit Bat Cave) Photo Tony Veness • non-glowing family similar in habit to glowworms	

Insecta: Hymenoptera: Ichnuemonoidea? (Fruit Bat Cave?) Photo Ross Anderson	
Insecta: Hymenoptera: Formicidae: *Pachycondyla tridentata* (Lagang Cave) Photo Ross Anderson	

Appendix C

Cave Sample Locations

Fruit Bat Cave – Dark Zone sample site Photo Ross Anderson	
Fruit Bat Cave – Entrance and Twilight sample area Photo Ross Anderson	

Green Cave – Dark Zone near lower river area Photo Ross Anderson	
Green Cave – Entrance Area near gour pool and formation Photo Ross Anderson	

Lagang Cave – Entrance and Twilight sampling area Photo Ross Anderson	
Lagang Cave – Dark zone Fast Lane area Photo Ross Anderson	

Lagang Cave – Dark zone, block area at end of Fast Lane. Photo Ross Anderson	
Lagang Cave – Dark zone Extension passage Photo Ross Anderson	

Stonehorse Cave – Entrance and Twilight Photo Ross Anderson	
Stonehorse Cave – Dark Zone site 1 Photo Ross Anderson	

Stonehorse Cave – Dark Zone Site 2 Photo Ross Anderson	
Stonehorse Cave – Dark Zone Site 3 Photo Ross Anderson	

Lagang – Dark Zone path guano pile May 2012 Photo Stephen Swabey	
Racer Cave – Entrance area Photo Jane Pulford	

Racer Cave – Dark Zone Site 4? Photo Tony Veness	
Kenyalang cave – Dark zone Photo Tony Veness	

Deerwater Cave – Dark zone Photo Jane Pulford	
Deer Cave – Dark Zone Photo Ross Anderson