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A REVIEW OF THE BIOSPELEOLOGY OF MEGHALAYA, INDIA

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Abstract This paper reviews the current state of knowledge of the biospeleology of the northeast Indian hill state Meghalaya. Since the early 1990s the Meghalayan Adventurers Association (based in Shillong), in partnership with European speleologists, has conducted a series of projects with the objective of mapping and documenting caves. To date over 320 km of cave passage have been mapped and much more remains to be discovered. The quantity and length of caves in Meghalaya exceeds that of any other known karst region of India. An exhaustive search of historical records yielded one highly detailed biological survey of a single cave in the west of the state and a few records of opportunistic specimen collection from caves at other locations. This data is supplemented by a review of numerous biological observations made during the Meghalayan Adventurers Association cave mapping program. Taxa with pronounced troglomorphic characteristics appear to be relatively common in the Jaintia Hills region of eastern Meghalaya and rare elsewhere in the state. In contrast, taxa with partial troglomorphy are widespread throughout Meghalaya. There is a range of taxa which occur regularly within caves and should be considered as significant components of the cave ecosystem regardless of troglomorphy. In some cases there is evidence of reproductive activity and opportunity for feeding which indicates that a proportion of the population complete their lifecycle within the caves and can be regarded as troglophiles. Sources of nutrition are primarily composed of flood borne debris, although dense colonies of bats (or cave-nesting swiftlets at some sites) can also contribute. The composition of cavernicole communities is not constant throughout the region and varies due to environmental and geographic factors. A major expansion of the limestone extraction industry is underway in the Jaintia Hills and elsewhere in Meghalaya. This will inevitably cause significant destruction and perturbation of cavernicole habitat. It would be prudent to implement formal studies to document the biospeleology of the region before significant loss or damage occurs.

Introduction

Meghalaya is situated in the far northeast of India on the northern border of Bangladesh (Figs. 1 and 2). Over most of the state the topography is that of a hilly plateau which reaches altitudes of over 1000 m. The plateau is bounded to the north and to the west by the river plains of the Bramaputra and to the south by the plains of Bangladesh. Along the southern and eastern margins of the plateau there is a band of limestone interstratified with sandstone beds. This band is discontinuous due to divisions caused by differential tectonic uplift, associated faulting and deep concordant river valleys that run southwards off the plateau to the plains of Bangladesh. The limestone band extends from west to east along the southern boundary of the state and is approximately 200 km long and 30 km wide. It runs from the West Garo Hills in the west through the West Khasi Hills, East Khasi Hills and into the Jaintia Hills in the east. During the monsoonal months of May to October the region experiences some of the world's highest recorded rainfall, while during the rest of the year, the climate is mild and dry.

Until relatively recent times only a handful of the Meghalayan caves had been formally documented. The first systematic program to explore, map and catalogue the Meghalayan caves was initiated in 1992 by the Meghalayan Adventures Association. The program subsequently expanded and partnerships were formed with speleologists from several European countries and the USA. The program is ongoing, and to date, over 320 kilometers of cave passage have been mapped and over a thousand cave entrances have been documented. It is thought that this accounts for only a small proportion of the caves that remain to be discovered in the state (Brooks and Brown, 2008). It is undisputable that the quantity and length of caves in Meghalaya far exceed that of any other known karst region of India.

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Figure 1. Location of Meghalaya showing approximate distribution of limestone.

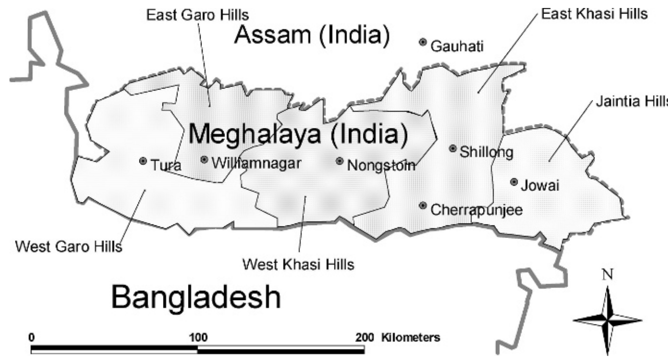

Figure 2. Outline map of Meghalaya showing main towns and boundaries of hill regions.

Pre-Existing Literature

The coverage of existing published literature on the biota of Meghalayan caves is sparse. By far the most thorough of the studies was made in February 1922 by Kemp, Chopra and Hodgart of the Zoological Survey of India. They spent three weeks conducting a comprehensive survey of the fauna of Siju Cave in the West Garo Hills. The survey covered areas from the entrance to a point 1200 m within the cave and topography is described. The habitats and distribution of species within the cave are reported, and abundance, behavioural and ecological notes are given for selected species. The findings of this study were subsequently published in a series of papers (Andrewes, 1924; Annandale and Chopra, 1924; Blair, 1924; Brunetti, 1924; Cameron, 1924; Carpenter, 1924; Chopard, 1924; Chopra, 1924; Edwards, 1924; Fage, 1924; Fletcher, 1924; Fleutiaux, 1924; Gravely, 1924; Hora, 1924; Kemp, 1924a; Kemp, 1924b; Kemp and China, 1924; Kemp and Chopra, 1924; Lamb, 1924; Meyrick, 1924; Ochs, 1925; Patton, 1924; Roewer, 1924; Rohwer, 1924; Silvestri, 1924; Stephenson, 1924; Wheeler, 1924).

The Siju survey recorded the presence of 102 taxa within the cave. The presence of 16 of these taxa was judged to be accidental and a further 53 were restricted to the threshold zone. Of the remaining 33 taxa only four species were thought to show troglomorphic traits. These included a terrestrial gastropod (*Opeas cavernicola*), two species of terrestrial isopod (*Philoscia dobakholi* and *Cubaris cavernosus*) and an aquatic decapod (*Macrobrachium cavernicola*). The troglomorphy was not pronounced and consisted of a variable degree of reduction in eye size and pigmentation as related to comparable epigean species.

A number of other published records also relate to the biological communities of Siju Cave. There is early literature describing a species of reduviid bug from Siju Cave (Paiva, 1919) and this species was subsequently re-recorded during the 1922 survey. In 1971 Dr Yazdani collected fish from the stream issuing from the entrance of Siju Cave. Specimens collected at an unspecified distance within the cave were identified as *Schistura multifasciata* (Pillai and Yazdani, 1977) and it was suggested that these corresponded to the nemacheiline loach reported by Hora (1924). However, Hora's material has also been identified as *Schistura beavani* (Hora 1935) and described as *Schistura sijuensis* (Menon, 1987). There is clearly some uncertainty regarding the identity of the *Schistura* species reported from Siju Cave (Kottelat et al., 2007) but it can be stated that the specimens showed no significant troglomorphy and that there is insufficient information to establish their status as cavernicoles. A more recent survey of Siju Cave (Sinha, 1999) was primarily aimed at documenting the bat fauna but also includes some records of other organisms found in the vicinity of the cave entrance.

The majority of the remaining literature consists of taxonomic descriptions of cavernicoles with little contextual information. Several records relate to caves in the Cherrapunji area of the East Khasi Hills. Collinge (1916) described two species of cavernicolous isopods from the area. These were *Burmoniscus kempi* (name revised to *Rennelloscia kempi* (Vandel, 1972), now accepted under original name [Schotte et al., 1995]), collected from Mawsmai Cave by S.W. Kemp and *Cubaris cavernosus* collected from unspecified caves by R. Friel. Both taxa show some degree of troglomorphy including reduced eye size and depigmentation. The cavernicolous orthopteran *Eutachycines brevifrons brevifrons* (*Diestrammena brevifrons*) was described by Chopard (1919) also based on material collected from Mawsmai Cave. The species does not show marked troglomorphy. In 1947 Lindberg collected

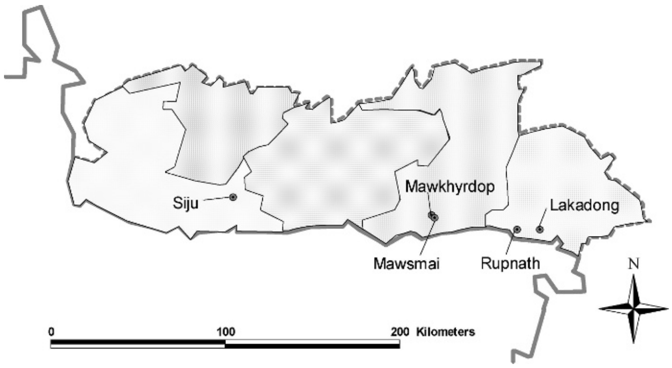

Figure 3. Locations of Meghalayan caves covered by previous biospeleological literature.

biological material from a cave near Cherrapunji. This was named as Mawsmai in the subsequent publications but from the description given it is thought that the actual location was Mawkhyrdop Cave (Gebauer, 2003, p. 73). Lindberg's work yielded records of the isopods *Burmoniscus kempi* and *Cubaris cavernosus* (Lindberg, 1960), the slightly troglomorphic shrimp *Macrobrachium cavernicola* (Lindberg, 1960), a cavernicolous millipede, *Assamodesmus lindbergi* (Manfredi, 1954), and also unspecified Hydras, oligochaetes, insect larvae and cosmopolitan cyclopoid and harpacticoid copepod species (Lindberg, 1949).

There are records relating to two caves in the Jaintia Hills. Two cavernicolous orthopterans were described from material collected in 1921 by R. Friel from Lakadong Cave (Chopard, 1924). These were *Eutachycines brevifrons frieli* (originally *Diestrammena brevifrons frieli*) which does not show marked troglomorphy, and *Eutachycines caecus* (originally *Diestrammena caeca*) which is strongly troglomorphic being both depigmented and anopthalmous.

A troglomorphic dictyopteran, *Typhloblatta caeca* (previously *Spelaeoblatta caeca*), was described from Rupnath Cave (Krem Jognindra) in the Jaintia Hills (Chopard, 1921). The species is totally depigmented, anopthalmous and is clearly a troglobite. The cavernicolous orthopteran *Eutachycines brevifrons frieli* has also been recorded from Rupnath Cave (Chopard, 1921). The specimens were collected by R. Friel and W. Ballantine.

In summary, the literature covers one cave in the West Garo Hills, two caves in the East Khasi Hills and two caves in the Jaintia Hills (Fig. 3). It is notable that the relatively rigorous examinations of Siju Cave (West Garo) and caves near Cherrapunji (East Khasi) yielded no species with well developed troglomorphy, whereas the opportunistic collecting from the two caves in the Jaintia Hills yielded two species with strongly developed troglomorphy.

Recent Data

The cave mapping program that has been ongoing since 1992 has yielded numerous additional records of biological observations made within caves. These records have been collated into a database and plotted using GIS software to assess trends in the geographic distribution of cavernicoles within Meghalaya. The database currently includes in excess of 1000 records representing ~90 distinct taxa and 80 separate caves (Fig. 4).

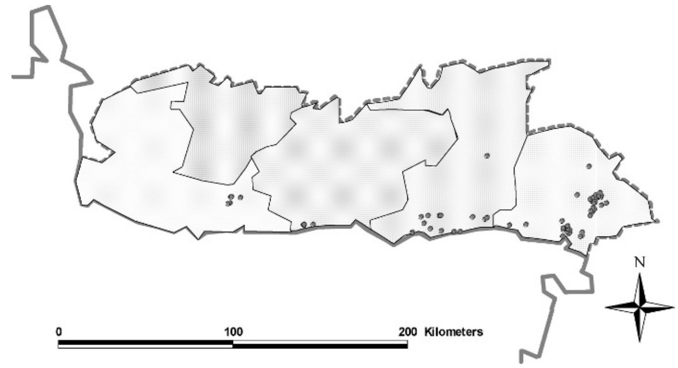

Figure 4. Locations of caves represented in database.

Coverage is discontinuous and reflects the distribution of cave mapping effort. There is a concentration of records in the Jaintia Hills and sparse coverage in the western parts of the state. The quality of records is also variable and some represent broadly defined taxa (e.g., crickets) which are of little value in determining geographic trends. Most records refer only to relatively large taxa. Small inconspicuous fauna such as copepods, nematodes and mites are known to occur but are under-represented in the data. It is probable that a sampling program targeted at the smaller taxa would yield interesting new discoveries.

For the majority of caves, biological records were made as incidental observations during the course of cave mapping. Targeted biological surveys have been conducted at six caves (Fig. 5). In these caves species abundances were estimated at defined locations, and meat baits were used to attract scavenging fauna. The survey locations within the caves were selected to represent different environmental conditions and different degrees of remoteness from the

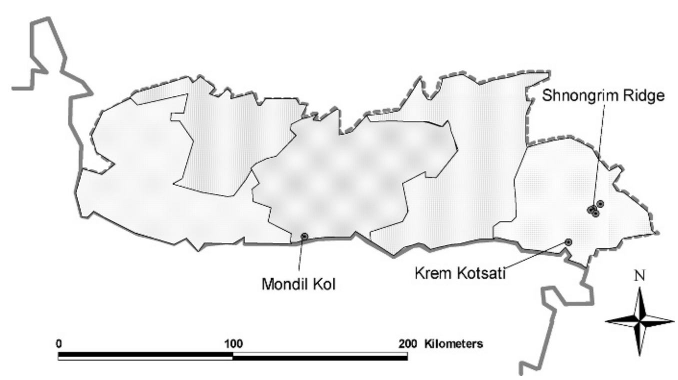

Figure 5. Locations of caves where targeted biological surveys were conducted.

Table 1. Taxa exhibiting pronounced troglomorphy.

Taxonomic group	Provisional name in database	Probable identity	Troglomorphy	Number of caves
Arachnida - Spider	Oonopidae sp.	unknown	Depigmented & anopthalmous.	1
Arachnida - Opiliones	Opiliones sp. 1	Assamidae indet.	Depigmented & anopthalmous.	4
Arachnida - Opiliones	Opiliones sp. 2	Assamidae indet.	Depigmented & anopthalmous.	1
Insecta - Orthoptera	Rhaphidophoridae sp. 2	*Eutachycines caecus*	Depigmented & anopthalmous.	10
Insecta - Dictyoptera	Blattoidea sp. 1	*Typhloblatta caeca*	Depigmented & anopthalmous.	12
Teleostei	*Nemachilus* sp. 1	*Schistura papulifera*	Depigmented & anopthalmous.	16

surface. Four of these caves are within a relatively small area on the Shnongrim Ridge of the Jaintia Hills. A fifth (Krem Kotsati) is in a lower altitude area near the village of Lumshnong and the sixth (Mondil Kol) is in the West Khasi Hills.

Data Overview — Troglomorphic Taxa

A review of the data indicates that Meghalayan cavernicolous taxa exhibit varying degrees of troglomorphy. Taxa with pronounced troglomorphy occur most frequently in the Jaintia Hills in the eastern part of the state while taxa with partial troglomorphy tend to have a broader distribution.

We have categorised degree of troglomorphy based on pigmentation and degree of eye reduction. Taxa categorised as displaying pronounced troglomorphy are shown in Table 1. These taxa are totally depigmented and anopthalmous with the exception of *Schistura papulifera* where tiny vestigial eyes are present in juveniles. Taxa categorised as displaying partial troglomorphy are shown in Table 2. These taxa exhibit varying degrees of depigmentation and reduction of eye size. None are both totally depigmented and anopthalmous. The anopthalmia of *Assamodesmus lindbergi* is not necessarily a troglomorphic trait as it is a member of the polydesmida all of which are anopthalmous.

Taxa with pronounced troglomorphy have been recorded in 20 caves in the Jaintia Hills, and more than half of these caves had multiple troglomorphic taxa (Fig. 6). The only records outside of the Jaintia Hills are of dictyopterans and opiliones in two caves in the West Khasi Hills.

Taxa with partial troglomorphy have been recorded from caves throughout the state (Fig. 7). There is a greater frequency of records from the caves of the Jaintia Hills, but this may be due to uneven survey effort rather than a true trend in the distribution in the fauna.

Data Overview — Characteristic Cavernicoles

A number of taxa occur within caves with sufficient frequency and abundance to be considered ecologically important cavernicoles regardless of troglomorphy.

Arachnida (Spiders)

Large, conspicuous spiders of the genus *Heteropoda* are among the most commonly recorded of the Meghalayan cave fauna (Fig. 8). They are often abundant and tend to be most common on passage walls and ceilings near cave entrances, but can also occur much deeper within the caves. At least two species of *Heteropoda* are present. *H. robusta* (Fage, 1924) predominates in the western part of the state (Garo and West Khasi Hills) while *H. fischeri* (Jager, 2005) appears to be more widespread, particularly in the eastern part of the state (Jaintia Hills).

In Siju in 1922, *H. robusta* was abundant and seen to be reproducing, but they were not seen feeding (Fage, 1924;

Table 2. Taxa exhibiting partial troglomorphy.

Taxonomic group	Provisional name in database	Probable identity	Troglomorphy	Number of caves
Gastropoda	*Opeas* sp.	*Opeas cavernicola*	Eyes reduced.	3
Arachnida - Pseudoscorpiones	Pseudoscorpiones Sp. 1	unknown	Pigmented & anopthalmous.	1
Arachnida - Spider	*Amauropelma* sp.	unknown	Pigmented & anopthalmous.	3
Crustacea - Decapoda	Caridea sp. 1	*Macrobrachium cavernicola*	Depigmented & eyes reduced.	22
Crustacea - Isopoda	*Cubaris cavernosus*?	*Cubaris cavernosus*	Depigmented & eyes reduced.	11
Crustacea - Isopoda	*Philoscia* sp.	*Philoscia dobakholi*	Depigmented & eyes reduced.	13
Crustacea - Isopoda	Not recorded	*Burmoniscus kempi*	Depigmented & eyes reduced.	2
Myriapoda - Diplopoda	Not recorded	*Assamodesmus lindbergi*	Depigmented & anopthalmous.	1
Insecta - Coleoptera	Trechinae sp 1	unknown	Pigmented & eyes reduced.	3

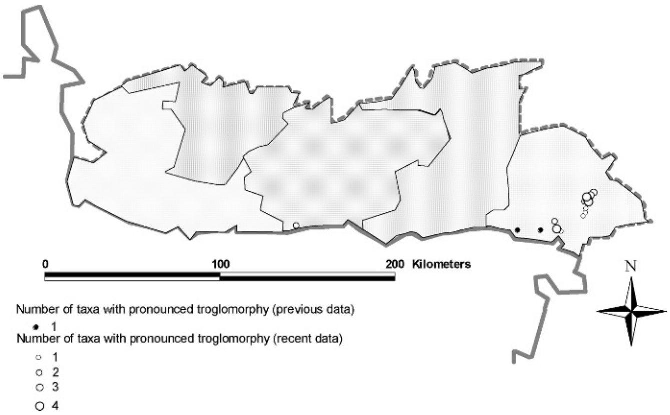

Figure 6. Distribution of caves where taxa with pronounced troglomorphy have been recorded.

Kemp and Chopra, 1924). We have records of *H. robusta* carrying egg sacks in caves in the West Khasi Hills and a record of what appears to be *H. fischeri* carrying egg sacks in a cave in the East Khasi Hills. We also have records of *H. fischeri* feeding on the brown Rhaphidophorid cave crickets in a cave in the Jaintia Hills.

Brachyura (Crabs)

The freshwater crab *Maydelliathelphusa falcidigitis* (formerly *Paratelphusa (Barytelphusa) falcidigitis)* was found to be common in Siju in 1922 (Kemp, 1924b) and was present deep into the cave (730 m). The species was also common in the surface stream outside of the cave and the author considered it to be "a mere straggler into subterranean waters" (accidental trogloxene). We have found similar crabs to be widespread and a distinctive component of the cave fauna (Fig. 9). They are often present deep into the caves and can be abundant in some wet gravelly passages where crab burrows may occur at densities of several burrows per 10 m^2.

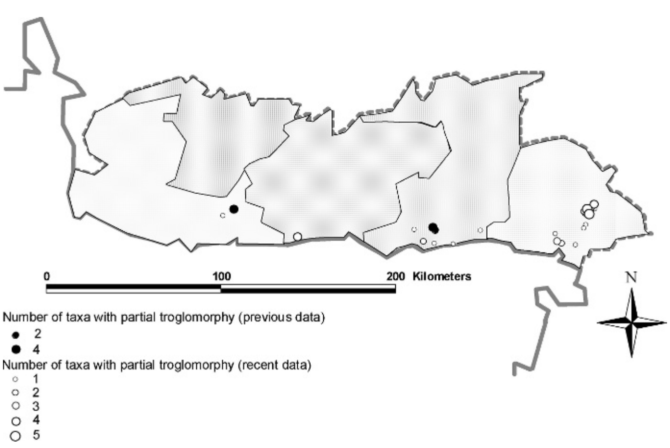

Figure 7. Distribution of caves where taxa with partial troglomorphy have been recorded.

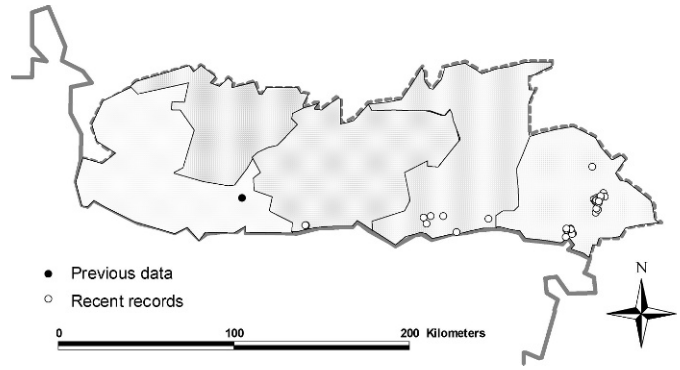

Figure 8. Distribution of *Heteropoda* spp. (43 caves).

In view of their abundance, frequency of occurrence, and deep distribution within the caves, we believe that these crabs should be considered to be troglophiles. In the dry season (November to April) there is very little surface water in the Shnongrim area and the streams feeding the caves on the ridge are totally dry. Consequently it is improbable that the abundant subterranean population of crabs exists as a result of accidental wash-in from the epigean population. In fact it is more plausible to suggest that the epigean population is replenished from the subterranean population which can survive the dry months in the subterranean pools and streams. A comparable process is known to occur in certain fish in the Dinaric karst (e.g. Mrakovčić and Mišetić, 1990).

Palaemonidae (Shrimp)

The shrimp *Macrobrachium hendersoni* and *Macrobrachium cavernicola* were recorded from Siju in 1922 (Kemp, 1924b). The population of *M. cavernicola* appeared to be reproductively active because ovigerous females and juveniles were present. *M. cavernicola* has also been reported from the East Khasi Hills (Lindberg, 1960).

We have found shrimp that approximate to the description of *M. cavernicola* to be widespread and a characteristic component of the cave fauna (Fig. 10). They are often abundant and are present wherever there is water,

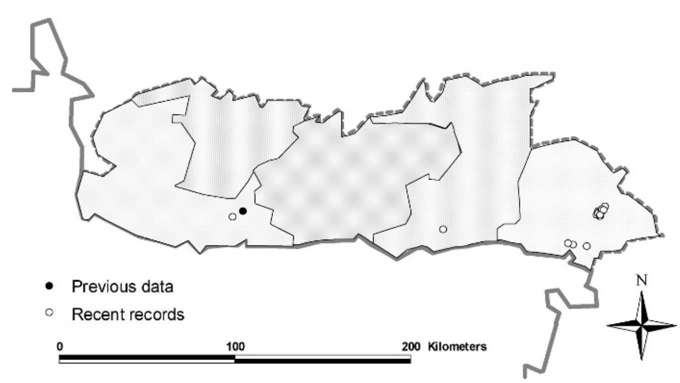

Figure 9. Distribution of *Brachyura* spp. (19 caves).

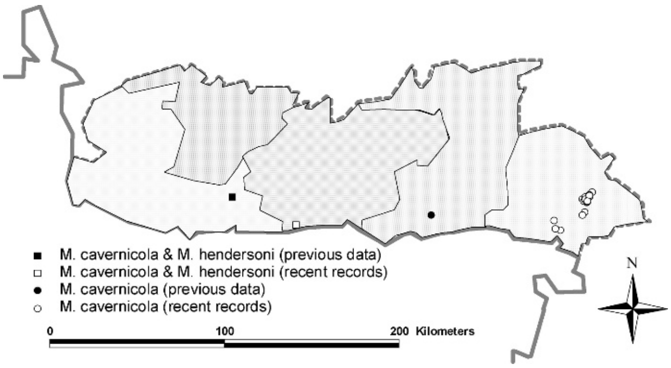

Figure 10. Distribution of *M. cavernicola* (22 caves) and *M. hendersoni* (2 caves).

including small isolated pools of standing water as well as active flowing streamways. Juveniles are frequently present and ovigerous females were noted in one of the caves in the West Khasi Hills. We have no information on the occurrence of these shrimp in surface streams but believe they should be regarded as troglophilic if not troglobitic. The only location where we have recorded shrimp that match the description of *M. hendersoni* was in the West Khasi Hills. They co-occurred with *M. cavernicola* but were immediately distinguishable due to their dark colouration and larger eyes.

Isopoda (Woodlice)

Four isopods (*Porcellio assamensis*, *Cubaris cavernosus*, *Philoscia dobakholi*, *Burmoniscus kempi*) have been recorded within Meghalayan caves (Collinge, 1916; Chopra, 1924; Lindberg, 1960). We have recorded isopods which are a close match to *Cubaris cavernosus* and to *Philoscia dobakholi*. Both appear to be widespread and are characteristic members of the cave fauna (Figs. 11 and 12). Both taxa can become abundant in certain environments. *Cubaris* sp. is much more strongly attracted to meat bait than *Philoscia* sp. and has been found to occur in high abundance in areas below bat roosts. *Cubaris* sp. also appears to have a greater degree of environmental tolerance to desiccation than *Philoscia* sp. and can occur in relatively dry passage. *Philoscia* sp. is typically abundant in wet areas particularly where there are deposits of decomposing vegetation. Small depigmented isopods which appear to match neither of these species have been noted in various caves in the Jaintia and Khasi Hills. Further study is likely to document additional species of cavernicolous isopods.

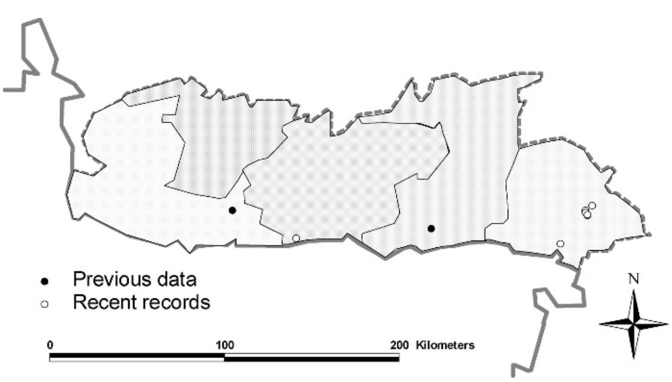

Figure 11. Distribution of *Cubaris* sp. (10 caves).

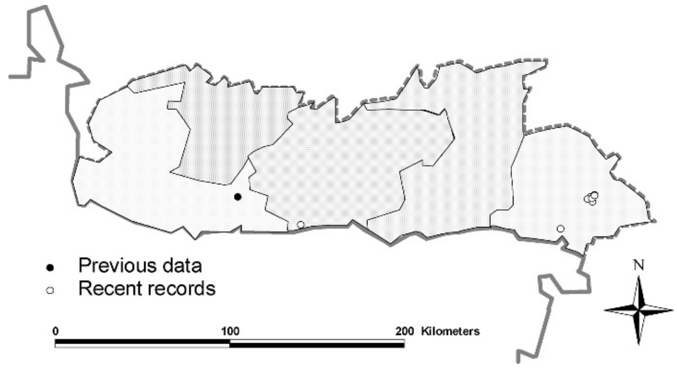

Figure 12. Distribution of *Philoscia* sp. (9 caves).

Diplopoda (Millipedes)

The millipede *Trachyiulus mimus* was recorded from Siju in 1922 (Silvestri, 1924). It was found throughout the cave and the author comments that there is no evidence of troglomorphy and considers that it is a "recent inhabitant of the cave".

We have found that *Trachyiulus* is widespread, often abundant and is a characteristic member of the Meghalayan cave fauna (Fig. 13). It is normally found throughout the caves from the threshold area to deep within the cave. It can occur in both wet and dry areas but tends to be more abundant in drier areas away from flood prone active streamways. *Trachyiulus* is strongly attracted to meat bait and large numbers have been observed feeding on dead bats, snakes, insects and on guano and faeces. *Trachyiulus* should certainly be regarded as a troglophile and is undoubtedly an important component of the Meghalayan cave fauna.

Orthoptera (Crickets)

Orthoptera are frequently encountered and often abundant in the Meghalayan caves. Three distinct main taxa are represented in the database. Rhaphidophoridae sp. 1 approximates to the published description of *Eutachycines brevifrons*. It is a characteristic member of the cave fauna in the Jaintia Hills (Fig. 14a) and is not markedly troglomorphic. It tends to be most abundant on walls and ceilings within a few hundred metres of cave entrances but can also occur in significant numbers much deeper within the caves. It is strongly attracted to meat bait. It appears tolerant of desiccating conditions and occurs in strongly draughting dry passage where few other

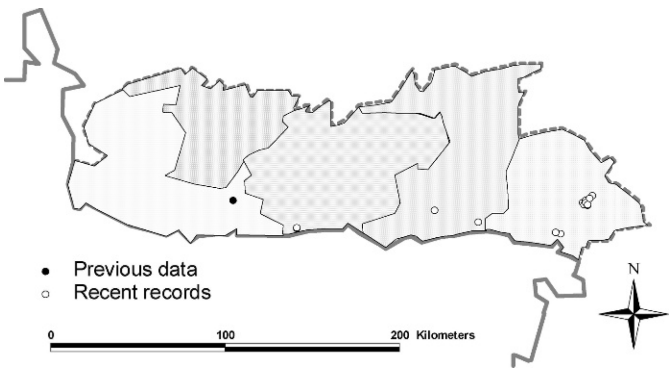

Figure 13. Distribution of *Trachyiulus* sp. (17 caves).

taxa are present. Rhaphidophoridae sp. 2 approximates to the published description of *Eutachycines caecus* and is also a characteristic member of the cave fauna in the Jaintia Hills (Fig. 14b). Size and morphology are similar to Rhaphidophoridae sp. 1 but it is totally depigmented and anopthalmous. It can occur in significant numbers and is particularly common below bat roosts. It tends to be absent from areas close to cave entrances and strongly draughting passages. Both of these taxa can be regarded as significant components of the cave ecosystem in the Jaintia Hills and often co-occur in the same location. They were notably absent from caves in the West Khasi Hills where a third orthopteran of a similar size predominated (Fig. 14c). This taxon (Orthoptera sp. 3) approximates to the published description of *Kempiola longipes* and is not markedly troglomorphic. It was common on rock walls and ceilings in both wet and dry passages and was present throughout the caves including the entrances and inner reaches.

Dictyoptera (Cockroaches)

Troglomorphic dictyopterans have been recorded in 11 caves in the Jaintia Hills (Fig. 15) and approximate to the published description of *Typhloblatta caeca* (Chopard, 1921). There is also a single unverified record of the taxon from a cave in the West Khasi Hills. They generally occur in low numbers but are occasionally common. They are found deep within the caves in both wet and dry passages but appear to be more common in areas that are not flood prone.

Coleoptera (Beetles)

A range of coleopterans have been recorded in the caves but in most cases the level of discrimination between different taxa is too low for their distribution to be examined. Two exceptions are a partially troglomorphic Trechinae and a species of Cholevidae.

Trechinae sp 1 has a strongly pigmented cuticle and vestigial eyes. It has been recorded in low abundances from three separate caves on the Shnongrim Ridge of the Jaintia Hills. It does occur near entrances but is more frequently found deeper in the caves in both wet and dry cave passages.

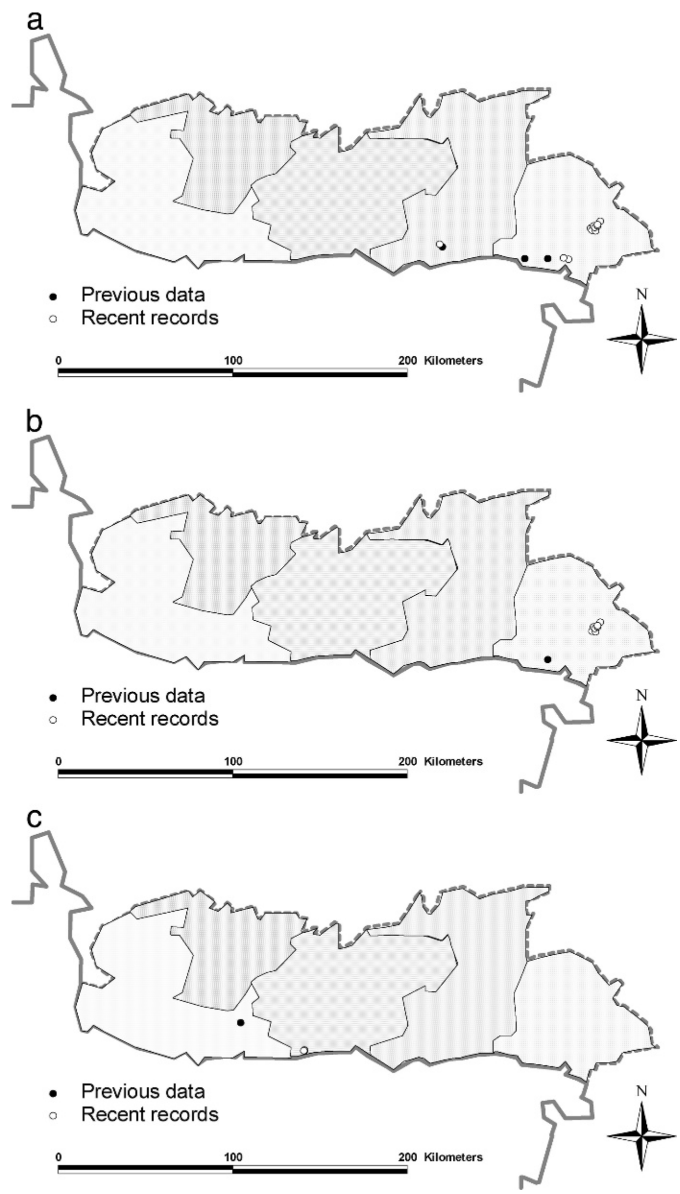

Figure 14a. Distribution of Rhaphidophoridae sp. 1 / *Eutachycines brevifrons* (20 caves).

Figure 14b. Distribution of Rhaphidophoridae sp. 2 / *Eutachycines caecus* (10 caves).

Figure 14c. Distribution of Orthoptera sp. 3 / *Kempiola longipes* (4 caves).

Cholevidae sp 1 is not troglomorphic but has been recorded in locally high abundances deep within three caves on the Shnongrim Ridge of the Jaintia Hills and in one cave near Rongdangi in the West Khasi Hills (Fig. 16). They occur in both wet and dry areas of the caves and are particularly abundant near bat colonies. They have been observed in flight and are strongly attracted to meat bait. It is likely that they represent a sustainable population of troglophiles and feed on the carcasses of dead bats.

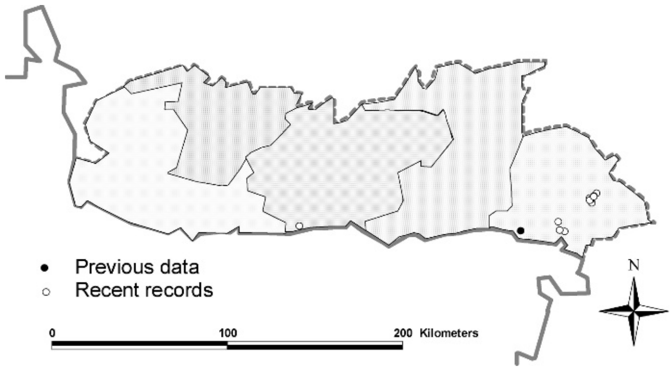

Figure 15. Distribution of troglomorphic dictyopterans (13 caves).

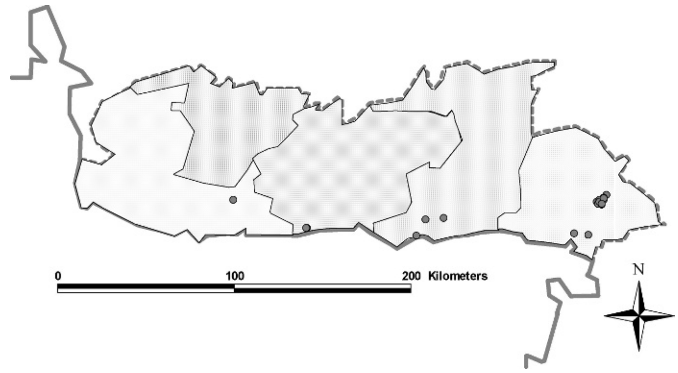

Figure 17. Distribution of Mycetophilidae larvae (19 caves).

Diptera (Flies)

We have records of two significant (disregarding records of single individuals) dipteran taxa. Larval mycetophilidae are commonly recorded in the caves (Fig. 17) and build webs of delicate draperies of vertical sticky strands with the larva living on the upper supporting strand of the web. The webs are suspended from ceilings or overhanging rock and can occur close to entrances and also deep within the caves. The webs are often abundant particularly in passages that carry a substantial air flow.

Conicera kempi was originally described from Siju Cave (Brunetti, 1924). We have records of this species from five additional caves (Fig. 18). They occurred throughout the caves and were sometimes common near bat roosts. They were attracted to meat bait on which they laid eggs and larvae developed. It is probable that these represent a sustainable population of troglophiles. Other species of the family Phoridae also occurred in some of the caves where *Conicera kempi* was present. These were also attracted to meat bait but their distribution tended to be restricted to the areas near cave entrances.

Pisces (Fish)

We have frequent records of unidentified fish within caves, with three taxa occurring on a regular basis. *Schistura papulifera* (Kottelat et al., 2007) is depigmented and has vestigial eyes. It tends to occur in gravelly pools of still water deep within the caves and is often abundant (Fig. 19). *Glyptothorax* sp. is darkly pigmented with small eyes. It is often abundant and can occur deep within the caves both in pools of standing water and in fast flowing streamways (Fig. 20). Large pale carp with well developed eyes (Cyprinidae spp.) are often common and can occur deep within the caves, generally in large pools of standing water (Fig. 21).

The frequency of records, distribution and abundance of both *Glyptothorax* sp. and Cyprinidae spp. would indicate that they are a significant component of aquatic ecosystems within the caves, and it is probable that they exert an influence on the aquatic invertebrate community through predation. In view of this, it is justifiable to regard them as troglophiles. Although their presence in the caves may be attributable to accidental wash-in from surface rivers, this clearly occurs with sufficient frequency to make them regularly occurring and ecologically important components of the cave fauna.

Data Overview — Community Variation

The subjective impressions of the authors suggest that there are distinct differences in the faunal composition of

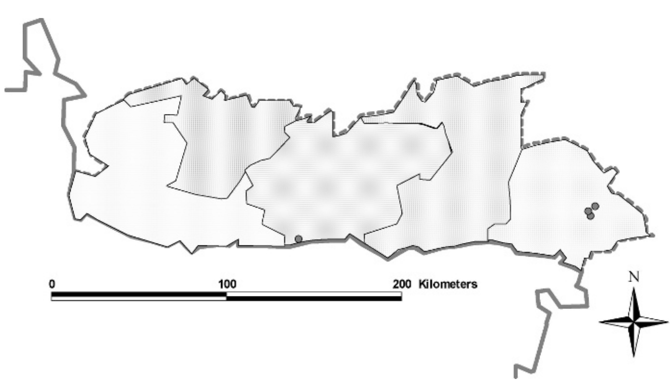

Figure 16. Distribution of Cholevidae sp 1 (4 caves).

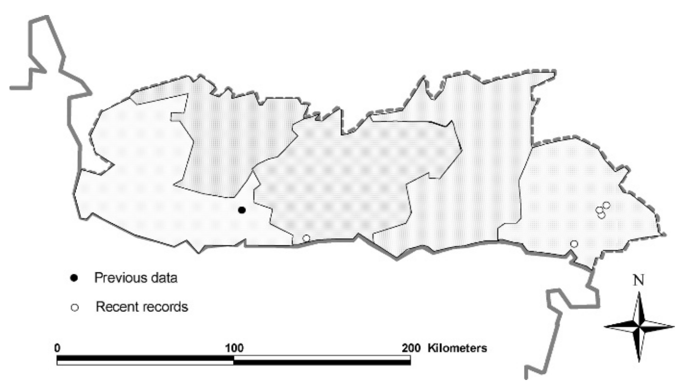

Figure 18. Distribution of *Conicera kempi* (6 caves).

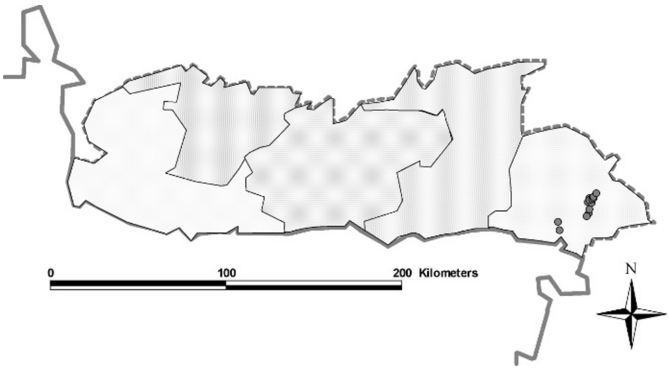

Figure 19. Distribution of *Schistura papulifera* (16 caves).

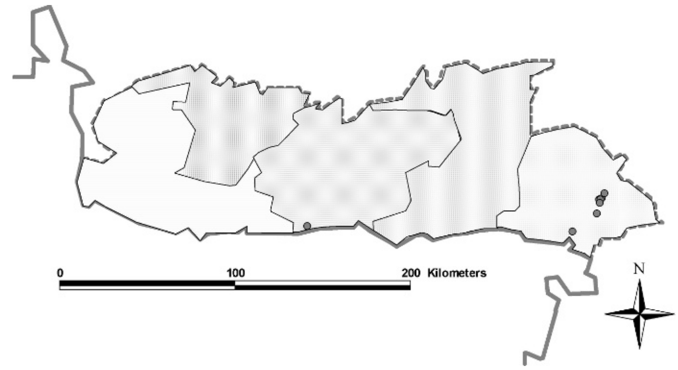

Figure 21. Distribution of Cyprinidae spp. (8 caves).

the Meghalayan caves depending on geographic region and perhaps also on altitude. Attempts to submit the data to an objective analysis are hampered by unbalanced survey effort and inconsistencies in the estimates of faunal abundance between different caves.

Sixteen caves were selected for a comparison of faunal composition. The criteria for selection were that a minimum of ten distinct taxa had been recorded in each cave. Multidimensional scaling analysis (MDS) was performed on species presence within the caves and the results are shown graphically in Fig. 22. It is not possible to assess the significance level of apparent differences in faunal composition due to lack of adequate replication of specific categories of cave.

The plot indicates twelve caves are relatively similar in faunal composition. Eleven of these are from the Shnongrim Ridge in the Jaintia Hills. These all located within a relatively small area (~3 km by ~8 km) at an altitude of about 1000 m to 1100 m above sea level. The twelfth (Synrang Pamiang) is situated some 25 km south west of the Shnongrim Ridge at a somewhat lower altitude of ~800 m. Nevertheless, the faunal composition appears to be broadly similar to the caves of the Shnongrim Ridge.

Two caves (Mondil Kol and Rong Kol) are separate from this main group. These are located in the West Khasi Hills some 150 km west of the main group and are at a considerably lower altitude of ~100 m above sea level. The MDS plot indicates that the faunal composition of these caves is distinct from that of the Shnongrim Ridge caves thus supporting the subjective impressions of the authors. The most obvious differences in the West Khasi Hills fauna are fewer troglomorphic taxa, the presence of *Macrobranchium hendersoni* in addition to *M. cavernicola* and different species of the dominant orthopterans.

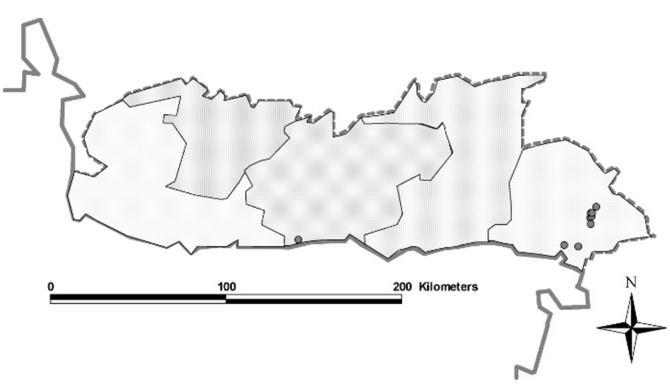

Figure 20. Distribution of *Glyptothorax* sp. (9 caves).

Two outliers remain. Krem Pyrda is located at the foot of the Shnongrim Ridge. We attribute its distinct faunal composition to its small size (length ~250 m as opposed to >1 km in the case of the other caves) and its shallow nature (much of the cave is within a few meters of the overlying surface). Krem Kotsati is located near Synrang Pamiang and its situation contrasts with that of the Shnongrim Ridge caves in a number of ways. The altitude is lower (~650 m ASL), surrounding land is densely vegetated and the cave carries a substantial stream which is likely to flood severely during the rainy season.

With current data it is not possible to establish if the differences between Jaintia and West Khasi cave faunal composition represent geographical distribution trends or if it is a consequence of environmental differences. The West Khasi caves are at much lower altitude than the Shnongrim Ridge caves. The main biological significance of this is that lower altitude caves are likely to be subject to a much greater volume of flood water during the rainy season. There is clear visible evidence of this in some of the West Khasi caves, with substantial tree trunks wedged in cave ceilings many meters above the dry season water level. By contrast, the Shnongrim Ridge caves have a more limited catchment area and watercourses within the caves tend to be steeper with more vertical sections. Consequently they are likely to receive smaller volumes of floodwater with a more rapid transit time through the cave, thus increasing the potential for survival of fauna intolerant of immersion. Other factors may also be significant. The West Khasi caves are at a higher temperature and are in a more densely forested area than the Shnongrim Ridge caves. These factors are likely to result in differences in the composition and abundance of potential colonizing fauna.

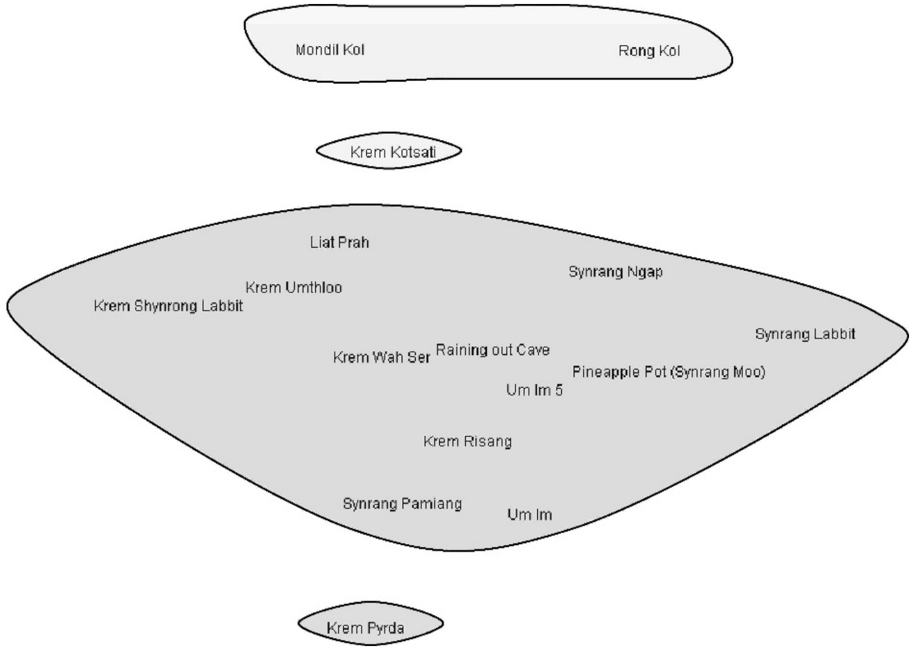

Figure 22. MDS plot illustrating similarities in species composition for 16 caves.

Data Overview — Other Taxa

A range of other taxa have been recorded less frequently, but occur at sites deep within the caves and are possibly troglophilic. Aquatic gastropods (*Paludomus* spp.) occur occasionally (four caves), with numerous individuals found in pools or streamways. Oligochaete faecal casts are a common sight in damp fine sand or mud, particularly in areas close to deposits of decomposing vegetation. Their presence may be attributable to accidental wash-in, but the high proportion of organic detritus in the streamway sediments will provide a locally abundant food source and it is highly probable that persistent reproducing populations are maintained within the caves. These oligochaetes undoubtedly play an important role in breaking down vegetation deposited in the caves by floods and so form a significant component of the cave ecosystem functioning. A variety of spider species occur in the caves, including those of the genus *Pholcus* which are frequently encountered (seven caves) on webs built between boulders and suspended on rock walls. A large distinctive orange coloured variety of opiliones are frequently (seven caves) encountered deep within Jaintia caves. A large distinctive chilopod of the genus *Scolopendra* has been recorded in three caves in close proximity to standing water. In one of these cases the centipede was observed moving rapidly around on a submerged rock surface within a pool of standing water, once disturbed it left the pool and moved with equal facility over the exposed rock surfaces giving the appearance of being semi aquatic. Scutigeromorpha have also been recorded from three caves occurring as single individuals on rock walls deep within the caves. Collembola have been recorded in significant numbers within several caves and some appear to be anopthalmous. It is probable that a more thorough examination of the collembolan fauna will reveal troglobitic species.

Certain taxa appear to be primarily associated with cave entrances and might be regarded as characteristic threshold fauna. Examples include large planarians (four caves), black opiliones forming dense aggregations (six caves), scorpions (three caves) and geckos (Gekkonidae spp.) (four caves).

Meghalaya has a diverse and abundant bat fauna (Thabah, pers. comm.) and a full consideration of the group is beyond the scope of this paper. The main reason for this is that many of the published records are derived from data collected by mist net surveys on the surface. It is highly probable that many of these recorded bat species utilize caves as roost sites, but there is often no direct evidence that this is the case. Our records indicate that bats are present in the majority of caves throughout the state and at some locations there are dense colonies of many hundreds of individuals.

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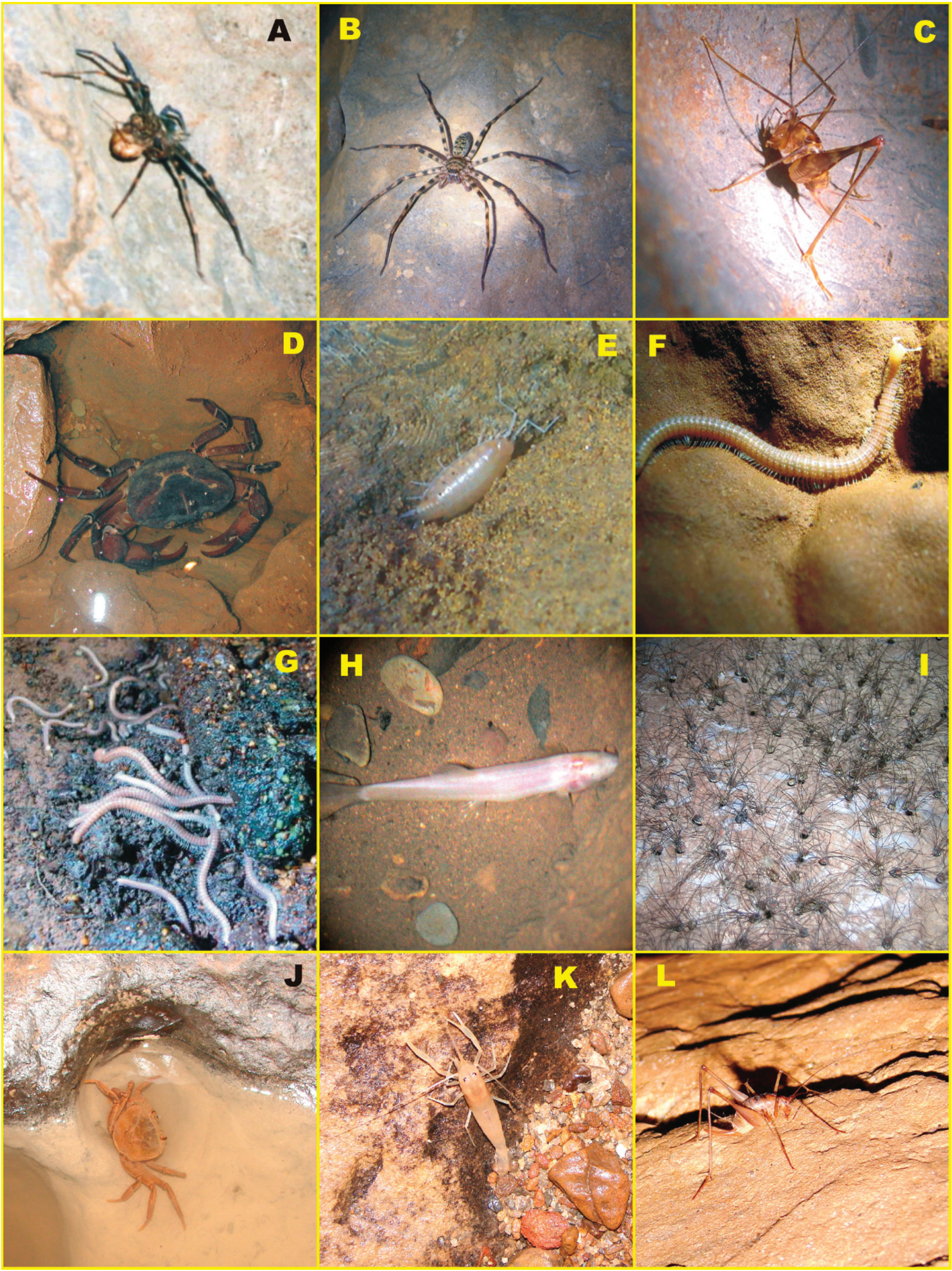
Figure 23. Representative photographs of Meghalayan cave biota. (A - *Heteropoda* sp. feeding on cave cricket (Krem Um Lawan 2002); B - *Heteropoda* sp. (Krem Wah Ser 2005); C - Rhaphidophoridae sp. 1. (Krem Wah Ser 2005); D - Crab (Krem Krang Maw 2003); E - *Philoscia* sp. (Krem Wah Ser 2005); F - *Trachyiulus* sp. (Krem Umthloo 2005); G - *Trachyiulus* sp.



feeding on faecal matter (Krem Umthloo 2005); H - Schistura papulifera. (Krem Krang Maw 2003); I - Black Opiliones at cave entrance (Krem Wah Tylliang 2004); J - Crab (Krem Mawkhyrdop/Mawmluh 2007); K – *Macrobranchium* sp. (Krem Mawkhyrdop/Mawmluh 2007); L – Rhaphidophoridae indet (Krem Mawkhyrdop/Mawmluh 2007)).

These colonies may be associated with extensive guano deposits which support abundant populations of invertebrates. However, many cave systems are subject to seasonal flooding which can prevent the accumulation of significant quantities of guano. Despite the lack of accumulated guano at such sites, the abundance of many invertebrate taxa was significantly higher in the vicinity of bat colonies than in other areas of the caves. The fauna associated with guano deposits in the West Khasi caves was distinct in composition from comparable sites in the Jaintia Hills. It included abundant moth (Tineidae) larvae and ants (Formicidae), as well as snails that appear identical to the figured specimens of *Opeas cavernicola* var. *vamana* recorded in Siju Cave (Annandale and Chopra, 1924). None of these taxa have been documented within the caves of the Jaintia Hills.

We have recorded swiftlets (assumed to be *Collocalia brevirostris*) within three caves on the Shnongrim ridge of the Jaintia Hills. We are unaware of published records of birds inhabiting Meghalayan caves, but colonies of swiftlets (*Collocalia brevirostris*) are known from caves in Uttaranchal (formerly Uttar Pradesh), Northern India (Glennie, 1944; Glennie, 1969). In the Jaintia Hills, the birds were particularly abundant at a cave that consisted of vertical shafts and high rifts. At this site we recorded over forty birds on the rock walls and innumerable others entered the cave at nightfall. They were found deep in the cave in total darkness and their echolocation clicks were clearly audible. At the base of the cave and on ledges higher in the rift we found deposits of guano and nest debris with an abundant associated population of invertebrates.

Frogs (Anura spp.) are frequently recorded within caves (11 caves) in the vicinity of streamways and pools, with tadpole larvae sometimes occurring as well as adults. Although the abundant invertebrate fauna within the caves may allow individual frogs to sustain themselves for a considerable period, the low abundance of frogs is unlikely to allow for reproduction and establishment of a breeding population within the caves. Snakes (Ophida spp.) have been recorded within six caves occurring as isolated individuals sometimes deep within the caves. It is unlikely that snakes would find sufficient suitable prey species to sustain themselves within the caves and some of the individuals encountered appeared emaciated. In most cases these snakes should be regarded as accidental trogloxenes. However, on the Lum Iawpaw Plateau in the West Khasi Hills there are shallow sandstone caves where numerous snakes were recorded. At this location it is possible that the snakes use the caves as hibernacula or refuges during the dry season.

A range of mammalian skulls and bones has been recorded in various caves. The species include mongoose, Assamese macaque, Nilgai, Temminck's golden cat, Asian black bear, human and various domestic animals. Most of these are likely to have been present through accidental falls down entrance shafts or by carcasses being washed into the caves. There are reports of bears using cave entrances as dens in some parts of the state, but we have no direct evidence of this. Rats are known to frequent areas well beyond cave entrances and living individuals, nest material and skulls have been recorded. The only other mammalian species to show a significant association with caves are porcupine. Evidence of porcupine presence has been reported from four caves in the Jaintia Hills. This includes evidence of long term regular use with rock walls and cave floors highly polished by the passage of porcupines. It is well known that Indian crested porcupines (*Hystrix indica*) use natural caves as dens (e.g., Alkon, 1999).

Discussion

Previously published data has conveyed the general impression that Meghalaya is of limited biospeleological interest with most species present in caves only as accidental trogloxenes and with just a few species displaying minor troglomorphic traits. This impression is erroneous and has arisen because the only detailed and best known biospeleological survey was conducted in Siju Cave in the western part of the state. Records presented in this paper, together with a detailed examination of published literature on Meghalayan cave fauna, indicate that taxa with pronounced troglomorphy are widespread and commonly occurring in the caves of the Jaintia Hills in the eastern part of the state but rare or absent elsewhere. Additionally, there is a range of partially troglomorphic taxa which occur regularly in caves throughout the state and a range of non-troglomorphic taxa which are regularly reported in abundance from different caves. Where such taxa are frequently recorded, abundant and present deep within cave systems there is a high probability that they should be regarded as true components of the cave ecosystem or characteristic cavernicoles for the area. This conclusion is supported if feeding activity or the presence of a source of nutrition can be identified within the cave or if there is evidence of reproduction within the cave.

Many of the recorded taxa meet these criteria, with larval or juvenile forms present and an abundance of potential sources of nutrition. The seasonal floods produced by monsoonal rain are likely to provide the primary source of nutrition by washing in vegetation and organically rich detritus and by redistributing deposits of bat guano within the caves. Fungal growth can occur on flood debris and tall etiolated seedlings are not uncommon on sand banks deep within caves. Such features provide living vegetation to supplement the nutrition source provided by the dead vegetation. The presence of dense colonies of bats (and swiftlets at some sites) provides a rich source of nutrition through guano, organic detritus and carcasses. These areas support significantly higher abundances of fauna than other areas of the caves.

The monsoonal floods are likely to impose a pronounced seasonality on the cavernicoles but due to access difficulties we have yet to visit the area during the wet season. In many areas there is very little water on the surface during the dry season. There is a distinct possibility that the caves act as a seasonal refuge for some aquatic and hygrophilic taxa that recolonise the epigean environment when monsoonal rains create humid conditions and replenish aquatic habitats on the surface.

In terms of communities, we have found that within a given area there is a high degree of similarity in the composition of the cavernicoles within different caves and the communities of caves in widely separated areas (e.g., West Khasi and Jaintia Hills) are distinctly different in composition. However, environmental factors (e.g., altitude, flood regime, etc.) also differ in the separate areas and currently it is not possible to establish if the difference in communities is due to differences in the geographic distribution of cavernicole species or to differences in prevailing environmental conditions.

Trends in community composition within cave systems remain unclear. We have noted significantly increased abundance of invertebrates in association with bat roosts. We found strongly drafting passages tended to support a community of low species diversity and abundance and attribute this to the desiccating effect of the draft. The distribution of certain taxa appears to be linked to factors such as distance from the entrance, presence of water or probable frequency of flooding. Where tentative conclusions on distribution can be reached, they have been referred to in the text relating to the taxon in question.

Rapid ongoing industrial development within Meghalaya is creating a new urgency to conduct research on the biospeleology of the region with a view to assessing conservation status (Biswas, 2007). Progressive and widespread deforestation has taken place across the state over the years resulting in what has been called a colossal loss of biodiversity in the entire region (Ramakantha et al., 2003). This deforestation has potential to alter subterranean ecosystems through altered run-off rates for rainfall and altered inputs of flood debris and nutrients. In recent years a major development of the limestone extraction industry has been implemented throughout Meghalaya. This is clearly a matter of concern as direct destruction of cavernicole habitat is inevitable and pollution of subterranean watercourses with industrial effluent is probable. It is of particular concern that significant levels of industrial development are occurring in the Jaintia Hills, which appears to be the region of greatest potential biospeleological interest within Meghalaya. We consider that it would be prudent to implement a program of formal biospeleological surveys within the region to document subterranean communities which are likely to become radically altered or eradicated over the next few decades.

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