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Tham Chiang Dao: A Hotspot of Subterranean Biodiversity in Northern Thailand

Louis Deharveng [1], Martin Ellis [2], Anne Bedos [1] and Sopark Jantarit [3,*]

[1] Institut de Systématique, Evolution, Biodiversité (ISYEB)—UMR 7205 CNRS, Museum National d'Histoire Naturelle, Sorbonne Université, 45 rue Buffon, 75005 Paris, France; dehar.louis@wanadoo.fr (L.D.); bedosanne@yahoo.fr (A.B.)
[2] 212, m8, Wat Pha, Lom Sak 67110, Phetchabun, Thailand; thailandcaves@gmail.com
[3] Excellence Center for Biodiversity of Peninsular Thailand, Faculty of Science, Prince of Songkla University, Hat Yai 90110, Songkhla, Thailand
* Correspondence: fugthong_dajj@yahoo.com

Abstract: The Doi Chiang Dao massif, which became a UNESCO Biosphere Reserve in 2021, is the highest karst mountain in Thailand. Tham Chiang Dao cave is located at the foot of this massif and is among the best-known caves in Thailand, having been visited since prehistoric times, and being a sacred place for the local Shan and Thai people. The cave consists of five main interconnected passages with a total length of 5342 m which ranks it as the 11th longest cave in Thailand. Tham Chiang Dao is the best studied cave in Thailand with a long series of explorations, investigations and zoological collecting. Here, we summarize the 110 years of biological exploration and investigation devoted to this cave. A total of 149 taxa have been recognized in Tham Chiang Dao, of which 61 have been identified to species level. The cave is the type locality for 14 species. The obligate subterranean fauna includes 37 species, of which 33 are troglobionts and 4 are stygobionts. Conservation issues are addressed in the discussion. This work is intended to provide a reference for the knowledge of cave fauna of the Chiang Dao Wildlife Sanctuary and a tool for its management by the local cave management committee, the National Cave Management Policy Committee, and the Department of Mineral Resources. It also documents the biological importance of Tham Chiang Dao in the Doi Chiang Dao UNESCO Biosphere Reserve.

Keywords: biosphere reserve; cave fauna; karst; troglobionts; stygobionts

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1. Introduction

Doi Chiang Dao mountain in Chiang Mai province, northern Thailand, is the highest karst mountain in Thailand (2195 m asl.) and is connected to other karst massifs, forming the Daen Lao mountain range. It is the third highest peak in the country after Doi Inthanon (2565 m asl.) and Doi Pha Hom Pok (2285 m asl.). The Doi Chiang Dao massif is formed by the Doi Chiang Dao Limestone which consists of mainly pale gray, massive limestone with occasional dark colored and moderately bedded limestones, particularly in the lowermost part of the massif, with frequent dolomitic levels. This limestone is essentially free from siliciclastic materials throughout the thick succession. The total thickness is at least 1000 m in total. Fossil foraminifers show that the Doi Chiang Dao Limestone ranges from the Visean (Mississippian/Early Carboniferous) to the Changhsingian (Late Permian), a period of about 90 Ma [1–7], Figure 1B. It rests on a basal pillow basalt of Tournaisian–Visean age [6,7]. Doi Chiang Dao was originally an oceanic sea mount in the Paleotethys Ocean and developed as carbonates capped the sea mount. These carbonates were later structurally incorporated within a closed remnant sea of the Paleotethys Ocean [6,7].

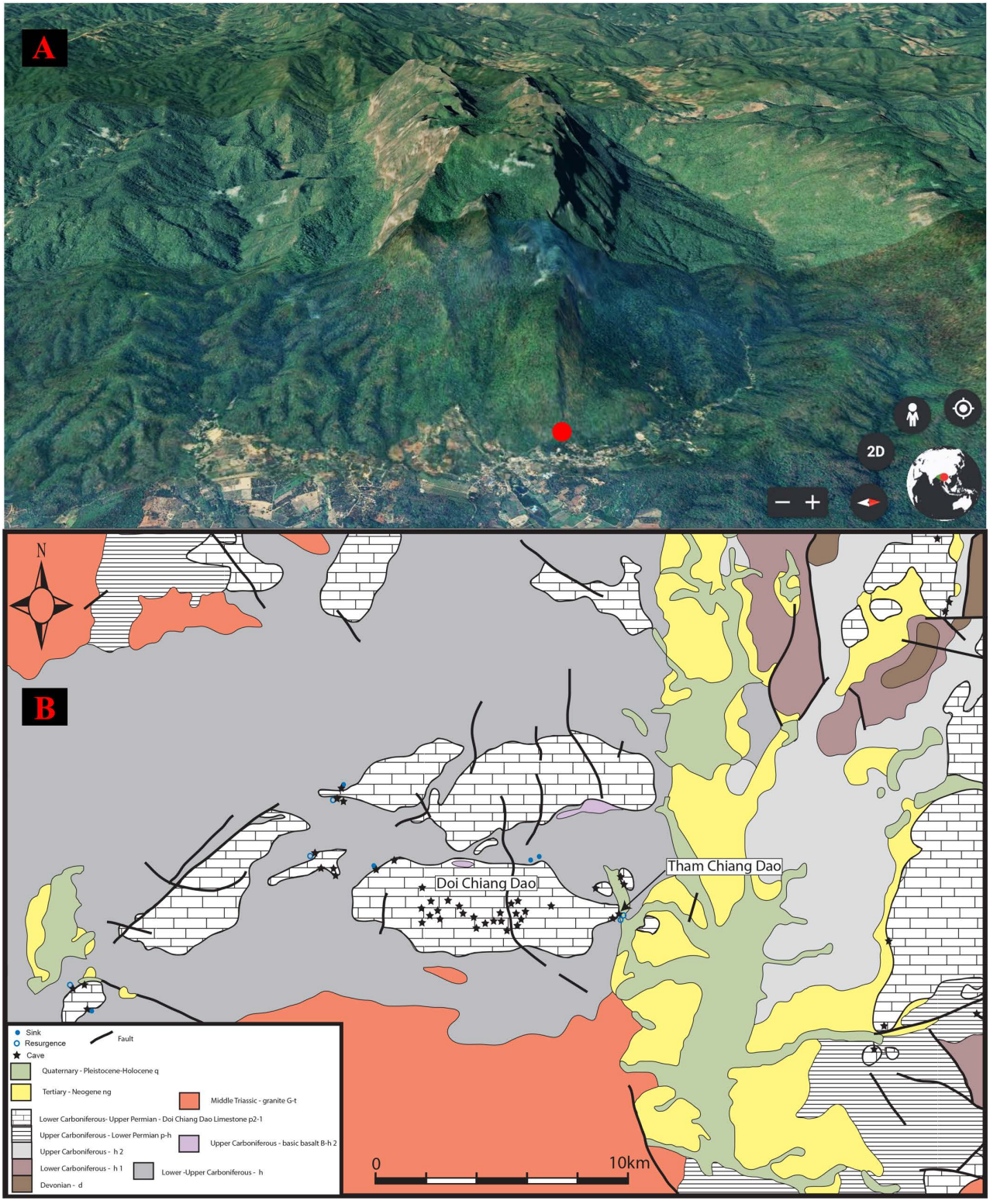

Figure 1. (**A**) Aerial view of Doi Chiang Dao. Red dot indicates cave entrance at the base of the mountain (from Google Earth Pro); (**B**) Geological map of Doi Chiang Dao and Tham Chiang Dao.

Doi Chiang Dao is a protected area as part of the Chiang Dao Wildlife Sanctuary which is managed by the Department of National Parks, Wildlife and Plant Conservation (DNP). In 2021 it was recognized as a UNESCO Biosphere Reserve, the fifth one in Thailand, with an area of 85,909 ha. It is the only region in the country to be covered with a sub-alpine ecosystem (with flora similar to the Himalayas and the southern part of China) and is

home to an abundance of rare, endangered, and vulnerable species of plants and animals along with a constellation of tribal peoples. At least 821 plant species and 697 vertebrate animal species are recognized from Doi Chiang Dao with many uncounted invertebrate species [8,9]

In the large limestone massif of Doi Chiang Dao at least 40 caves and shafts have been documented [5], and there are many other unknown and unexplored caves. Among these caves, Tham Chiang Dao is the largest and most famous, being a popular tourist attraction, and it is the best-known cave in northern Thailand. The cave is located at the base of Doi Chiang Dao (the entrance is at 460 m asl.). It has been known for over 1000 years and has a long history of speleological exploration and investigation, with most caving expeditions to the region having visited it. Tham Chiang Dao was the first cave to be speleologically explored in northern Thailand when 2.1 km of high-grade mapping was done in 1972 by Windecker and his team [10]. The cave was also mapped by Deharveng and Gouze in 1980 [11] and was mapped again in 1983 by the American Thailand Karst Hydrologic Project expedition (unpublished). The Association Pyrénéenne de Spéléologie (APS) from France carried out the most detailed exploration and survey in 1985 when 5.1 km was mapped [12]. The most recent, and most complete, mapping has been done by Chiang Mai Rock Climbing Adventures in 2021 (unpublished data).

The cave fauna of Tham Chiang Dao is among the best studied and surveyed of all the Thailand caves. The first biological collecting for bats was done in 1913, mosquitoes were studied in 1969, and in the 1970s, several speleobiologists visited the cave and made limited fauna collections. Since the 1980s, more thorough collections have been made by several expeditions conducted by both national and international organizations (see details in Table 1). This is because the cave is a very popular tourist attraction, is easily accessible, has impressive natural cave formations, has subterranean habitats with both terrestrial and aquatic ecosystems within a complex of interconnected passages, and is of high biological interest.

Tham Chiang Dao is among the eleven pilot caves of Thailand designated in 2019 by the National Cave Management Policy Committee (NCMPC) to be studied as references to set up policies and guidelines for cave management. The goal is to increase public awareness and to support operations beneficial to cave natural resources, maintenance, conservation, rehabilitation, and environment-friendly tourist attractions. These pilot schemes are undertaken by the Department of Mineral Resources (DMR). Hence, the present work will not only document the first hotspot of subterranean biodiversity in Thailand, but also serve as a primary database on Tham Chiang Dao for the NCMPC and DMR development objectives.

2. Materials and Methods

2.1. A Historical Overview of Tham Chiang Dao

Tham Chiang Dao has probably been known for several thousand years as there is archeological evidence that Chiang Dao town, less than 5 km away, has been an important settlement since prehistoric times [13]. In the nearby cave of Tham Bia (1 km away) prehistoric evidence such as pottery, stone tools (polished stone axes), and human and animal skeletal fragments have been found. It is assumed that these items are from the Neolithic period, 3500 to 4500 years ago [14]. Tham Chiang Dao is a sacred place for the local Shan and Thai people and is used for important religious rituals. The oldest religious objects found in the cave are a Buddha image and a 200 kg bronze bell which was made in 1615, indicating that Tham Chiang Dao has been an important religious site for many centuries. Under a skylight near the entrance, which is known as Plong Jaeng, the Shan built several Buddha images and shrines in 1635. The earliest published record of a visit to Tham Chiang Dao by a foreigner is by the American missionary Daniel McGilvary in June or July 1876 [15]. In the 1880s, the abbot of the temple blasted a new horizontal entrance to the cave which is still in use today. Prior to this, the only entrance was through the skylight at Plong Jaeng, which involved a risky 10 m vertical descent on bamboo ladders. Since

then, the cave and temple have been restored, developed with shrines, statues, and Buddha images inside the cave, and nowadays it is a major tourist attraction in the region.

2.2. A Brief History of Cave Fauna Investigation

The cave fauna of Tham Chiang Dao has been of scientific interest for over a century, since the first collection of bats was conducted in 1913 by Thomas Harold Lyle, who was the British consul in Nan. Subsequently, many visits have been made for biological collecting as presented in Table 1.

Table 1. A historical overview of cave fauna investigation and study in Tham Chiang Dao.

Date	Researchers	Institution	Biological Survey	Notes	Reference
January 1913	T. H. Lyle	British consul, Nan	Bats		[16]
25 June 1914	N. Gyldenstolpe	Swedish Zoological Expeditions to Siam	Biological survey	No bats seen in the cave, but there were large deposits of guano	[17]
March–June 1937		Harvard Asiatic Primate Expedition, USA	Bats		[18]
19 January 1958	T. Umesao and K. Yoshikawa	Osaka City University, Japan	General cave fauna collecting		[19]
18 July 1958	B. Degerbøl Hansen	Zoological Museum, University of Copenhagen, Denmark	General cave fauna collecting		[20]
1967	F. Stone and R. Montgomery	Cornell University, USA	General cave fauna collecting		[21]
11 and 19 December 1969	B. A. Harrison and K. Mongkolpanya	SEATO Laboratory, Bangkok	Mosquitos		[22]
1968–1971	C. Boutin	Faculté des Sciences de Phnom Penh	Diptera		[23]
27 December 1972	F. Stone	Bishop Museum, Honolulu, USA	Invertebrates		[24]
May 1974	J. Sedlacek	Bishop Museum, Honolulu, USA	General cave fauna collecting		[25]
15 February 1975	P. Strinati	Switzerland	General cave fauna collecting		[26]
December 1980–January 1981	L. Deharveng and A. Gouze	Université Paul Sabatier, Toulouse, France	General cave fauna collecting	Cave exploration and survey	[11]
1980–1987	M. Kottelat	Laboratoire d'Ichthyologie, Delémont, Switzerland	Fish		[27]
July 1981	F. Stone	Bishop Museum, Honolulu, USA	Invertebrates		[28]
14 and 16 August 1981	F. Stone	Bishop Museum, Honolulu, USA	Invertebrates		[29]
24 December 1983	R. Hemperly	Thailand Karst Hydrologic Project, USA	Bats	Cave exploration and survey	[30]
10 June 1984 and November 1984	P. Beron and S. Andreev	National Museum of Natural History, Bulgaria	General cave fauna collecting		[31]
July 1985	L. Deharveng, P. Leclerc, A. Bedos, J.-P. Besson et al.	Association Pyrénéenne de Spéléologie, France	General cave fauna collecting	Cave exploration and survey	[32]

Table 1. *Cont.*

Date	Researchers	Institution	Biological Survey	Notes	Reference
5 and 31 July 1986	F. Stone	Bishop Museum, Honolulu, USA	General cave fauna collecting		[24,28]
10 January 1989	J. Trautner and K. Geigenmüller	Staatliches Museum für Naturkunde, Stuttgart, Germany	General cave fauna collecting		[33]
6 March 1989	M. Anderson and H. Read	Natural History Museum of Denmark	Spiders		[34]
2007–2010	S. Watiroyram	Nakhon Phanom University, Nakhon Phanom	Copepods		[35]
2010	L. Chintapitasakul and colleagues	National Institute of Animal Health, Bangkok	Bat viruses		[36]
24, 25 and 28 June 2014	P. Jaeger, S. Li, E. Shaw and E. Grall	Senckenberg Museum, Frankfurt am Main, Germany	Spiders		[37]
25 October 2015	Animal Systematics Research Unit	Chulalongkorn University, Bangkok	Molluscs		[38]
10 March 2019	S. Jantarit	Prince of Songkla University, Hat Yai	Collembola		[39]
8–11 January 2023	S. Jantarit, R. Promdam, P. Pitaktunsakul, N. Boonkanpai, B. Noipracha, Y. Tokiri, C. Siripornpibul, W. Jaitrong, T. Jeenthong, K. Thongsri	DMR/Kanchanaburi Rajabhat University	General cave fauna collecting	First field visit	[14]
9–11 June 2023	S. Jantarit, R. Promdam, P. Pitaktunsakul, N. Boonkanpai, B. Noipracha, Y. Tokiri, C. Siripornpibul, W. Jaitrong, T. Jeenthong, K. Thongsri	DMR/Kanchanaburi Rajabhat University	General cave fauna collecting	Second field visit	[14]

2.3. Cave System

Tham Chiang Dao is located in Ban Tham subdistrict, Chiang Dao district, Chiang Mai province in northern Thailand (19.3942° N 098.9277° E). The peak of the Doi Chiang Dao karst mountain has an elevation of 2195 m asl., but the cave is situated at the base of the mountain with the main entrance at 460 m asl. (Figures 1 and 2). This entrance is on the grounds of a Buddhist temple (Wat Tham Chiang Dao) which is built in the Lanna style. Covered steps lead up to the gated entrance from a man-made pond of crystal-clear water, fed by the streams resurging from the cave, which is home to numerous fish. The cave extends sub-horizontally directly into the mountain and has a total length of 5342 m, updated [5,12], which ranks it as the 11th longest cave in Thailand and the 6th longest cave in northern Thailand, [5] and Figure 2. A short distance inside the entrance, the cave splits into two branches which head north and south. Each branch has an active phreatic system, and these hydrological systems are not connected until the resurgence. No water tracing has been done, but the northern branch is thought to be fed by sinks 3.5 km to the

north-west (700 m asl.), while the source of the water in the southern branch is unknown. Each branch has a network of seasonally flooded and dry passages at different levels above the phreatic system. The cave is divided into five main passages (Figure 2):

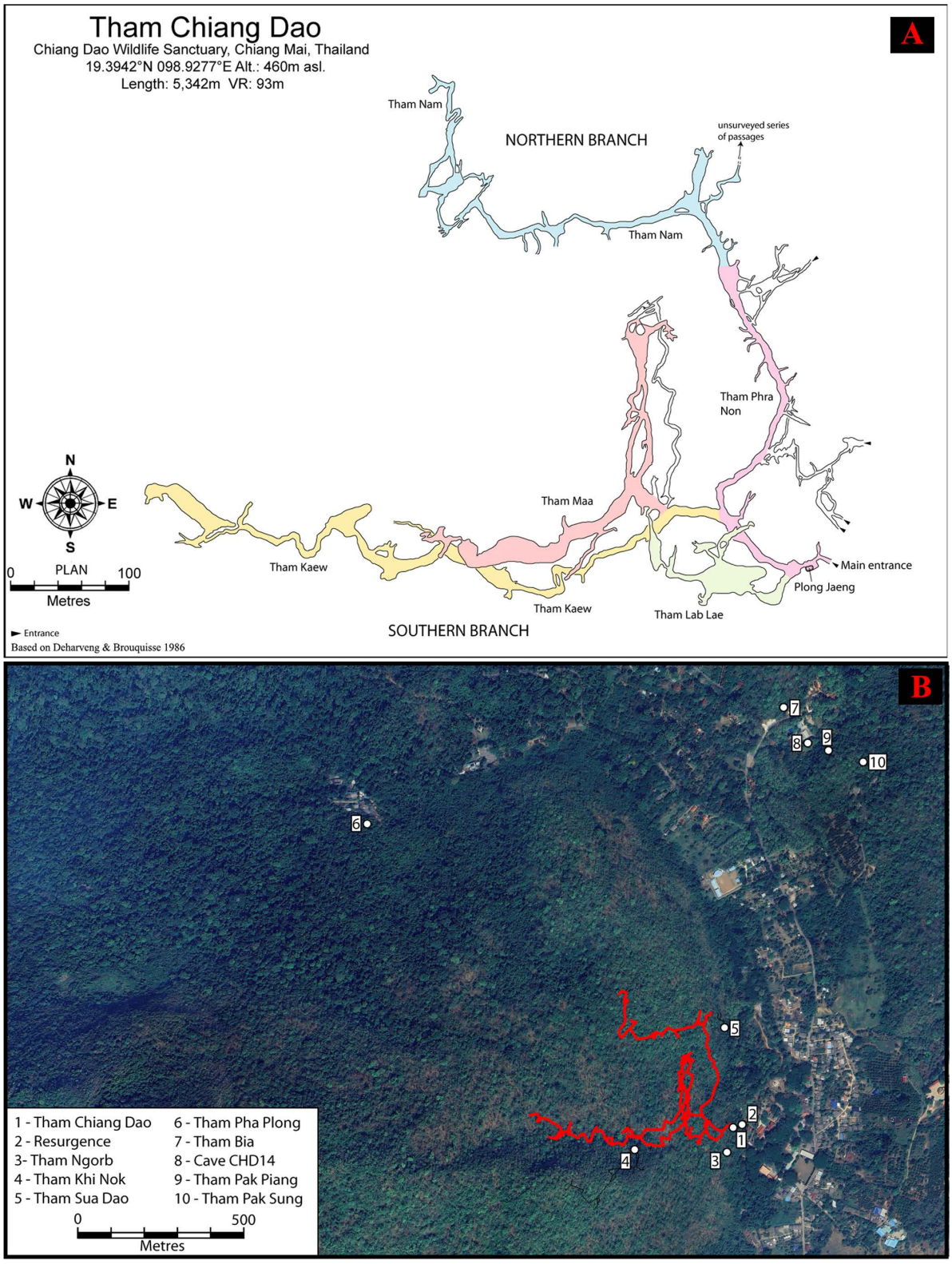

Figure 2. (**A**) Map of Tham Chiang Dao system, modified from Deharveng and Brouquisse (1986); (**B**) Tham Chiang Dao system with nearby cave entrances overlaid on Doi Chiang Dao (from Google Earth Pro).

(1) Tham Phra Non (Sleeping Buddha Cave) in the northern branch is the main tourist cave for self-guided tours with a concrete path, bridges, and electric lighting throughout this horizontal passage. Further into the cave, most of the passage floor is fine sand and the passages are flooded to a depth of 1 m to 2 m during the wet season. This passage is decorated by several natural cave formations as well as many historical statues, shrines, and Buddha images, including a Reclining Buddha built in 1913 which is located at the end of the tourist section. The length of Tham Phra Non is 450 m.

(2) Tham Nam (Water Cave) is the continuation of Tham Phra Non. This passage is without electric lighting and is not developed for tourism. Its length is about 1000 m and it has numerous speleothems throughout. To the north of the main Tham Nam passage is a series of dry passages extending for over 600 m which are infrequently visited as the entrance to this section is an obscure low crawl (these passages are not on the 1985 survey by the APS). Towards the end of Tham Nam are sump pools into the underlying phreatic system. In the wet season, these passages become active and the water backs up to near the start of Tham Phra Non. The floor of Tham Nam is either sand or thick mud and it is home to a variety of cave fauna, both terrestrial and aquatic.

(3) Tham Lab Lae (Secret Cave) and (4) Tham Maa (Horse Cave) are in the southern branch and are a series of dry upper levels branching off from Tham Phra Non near Plong Jaeng, with a total length of 1500 m. These two sections form a longer guided tour, without a path or electric lighting, through passages that are larger and better decorated than Tham Phra Non. Towards the end of Tham Maa, holes in the floor connect with Tham Kaew.

(5) Tham Kaew (Crystal Cave) in the southern branch is at the same level as Tham Phra Non, but it is associated with a separate stream system. This passage has not been developed for tourism and has a length of 900 m. Tham Kaew remains in a more natural condition than the tourist parts of the cave and supports a diversified cave fauna. Similar to Tham Nam, this section of the cave floods seasonally and has thick clay and sand deposits and has sump windows into the underlying phreatic system.

2.4. Checklist and Sampling of Cave Fauna

A checklist of the cave fauna of Tham Chiang Dao has been compiled from the available taxonomic, biological, and speleological literature published until July 2023. The checklist of cave fauna in Table 2 only includes the taxa identified to species. Taxa identified as morphospecies (sp., spp.), referring to a named species (*cf.*) and those of unidentified/undetermined species (i.e., *Gen.* sp. *Gen.* spp.), as well as those which are only identified to a higher taxonomic level, are excluded from the list. However, for the obligate cave species listed in Table 3, the morphospecies, *cf*, and those which are only identified at a higher taxonomic level are counted as troglobionts or stygobionts.

The subterranean fauna that had been reported in the previous studies was re-investigated during January and June 2023 as part of a joint Department of Mineral Resources/Kanchanaburi Rajabhat University biodiversity project with the senior author (SJ) as part of the team. The subterranean fauna (troglobiotic species) was searched for carefully in almost all the passages in both aquatic and terrestrial habitats and were collected by hand, with an entomological aspirator and a net for aquatic fauna, as well as in situ photographed with an Olympus Tough 4 or 6 camera.

3. Results and Discussion

3.1. Diversity of Cave Fauna in Tham Chiang Dao

Overall, a total of 149 taxa have been recognized from Tham Chiang Dao. Most of the collected specimens (88 taxa, 59%) are unstudied or are only identified at a high taxonomic level, while 61 have been identified to species level (Table 2). Tham Chiang Dao is the type locality for 14 species with 13 of the species being endemic to the cave (Table 2). Of these 61 known species, 21 are troglobionts/stygobionts, 23 are troglophiles/stygophiles, and 17 are trogloxenes (Table 2). Among the 149 taxa there are 37 troglobionts/stygobionts

(Table 3), 54 troglophiles/stygophiles, 27 trogloxenes, and 29 species with an unknown ecological category (not listed).

Tham Chiang Dao today has the richest cave fauna in Thailand reported so far. Other caves in the country which have been well-studied include Tham Le Stegodon in Satun province with 126 documented taxa [40], Tham Khao Chang Hai in Trang province with 102 taxa [41,42], Tham Phu Pha Phet and Tham Loko in Phatthalung province with 94 and 79 taxa, respectively [42], and Tham Thalu and Tham U-Rai Thong, Satun Province, with 85 and 66 taxa, respectively [40]. The high value of alpha diversity in Tham Chiang Dao reflects, however, primarily the zoological collecting effort, as the cave has been sampled for a long time and its fauna studied by several specialists (Table 1). These numbers are underestimates, as many mites, spiders, springtails, crustaceans and insects have not been worked up beyond family or genus level and several are expected to be new to science [14,43].

The 61 named species of Tham Chiang Dao (including 21 troglobionts/stygobionts) represent a steep increase from the 47 previously known in December 2020 (including 19 troglobionts/stygobionts) [44]. Despite numerous samplings, covering various kinds of microhabitats, large sections of Tham Chiang Dao remain unexplored (e.g., passages with high levels of carbon dioxide, permanently flooded sections, and vertical passages) and several groups are clearly undersampled (e.g., Copepoda, Insecta). More species, including troglobionts/stygobionts, may therefore be expected to be found in the cave.

In Southeast Asia many caves have been zoologically investigated reasonably thoroughly. In Indonesia, Ngalau Surat, Sumatra, had 74 species (of which 20 were troglo/stygobionts); Batu Lubang, Halmahera, had 72 species (of which 16 were troglo/stygobionts [43]; and Towakkalak and Saripa System, Sulawesi, had 93 species (of which 28 were troglo/stygobionts) [45]. The Batu Caves of Malaysia is the best studied cave system in Southeast Asia with 314 taxa with 183 identified to species (type locality for 63 species) [46]. The high species richness of the Batu Caves is the result of intensive samplings and studies since the end of the 19th century and almost all groups of animals have been diagnosed at a species level. However, only 50 troglo/stygobionts are known from this cave (accounting for only 14.6% in the total fauna of a cave), a relatively low number compared to the caves cited above (Batu Lubang = 22%, Tham Chiang Dao = 25%, Ngalau Surat = 27% and Towakkalak = 30%), which indicates an artifact of collecting bias, in that more common surface species have been identified from the comparatively smaller and shallower Batu Caves system, and further suggesting that sampling effort alone may be a poor predictor of cave-obligate species richness even in a climatically homogeneous region.

Table 2. List of known species from Tham Chiang Dao, Chiang Mai, Thailand; TB: troglobiont, TP: troglophile, TX: trogloxene, SB: stygobiont, SP: stygophile, TL: type locality; *: type locality and only recorded locality; SMF: Senckenberg Museum, Frankfurt am Main, Germany.

Phylum	Class	Order	Family	No.	Species	Reference(s)	Status
Mollusca	Gastropoda	Architaenioglossa	Pupinidae	1	*Pupina artata* Benson, 1856	[38]	TP
		Stylommatophora	Achatinidae	2	*Allopeas gracile* (Hutton, 1834)	[14]	TP
Annelida	Clitellata	Haplotaxida	Haplotaxidae	3	*Heterochaetella glandularis* (Yamaguchi, 1953)	[47,48]	SB
Arthropoda	Arachnida	Opiliones	Assamiidae	4	*Bandona palpalis* Roewer, 1927	[14,29]	TP
				5	*Neopygoplus siamensis* Suzuki, 1985	[20]	TP
		Pseudoscorpiones	Chernetidae	6	*Megachernes trautneri* Schawaller, 1994 *	[33]	TP, TL
		Palpigradi	Eukoeneniidae	7	*Eukoenenia thais* Condé, 1988 *	[49]	TB, TL

Table 2. *Cont.*

Phylum	Class	Order	Family	No.	Species	Reference(s)	Status
		Araneae	Clubionidae	8	*Systaria lannops* Jäger, 2018	[37]	TB
			Psilodercidae	9	*Althepus tibiatus* Deeleman-Reinhold, 1985 *	[24]	TB, TL
			Ochyroceratidae	10	*Theotima minutissima* (Petrunkevitch, 1929)	[24]	TP
			Sparassidae	11	*Heteropoda venatoria* Linnaeus, 1767	[14]	TP
			Nesticidae	12	*Sinopoda ruam* Grall & Jäger, 2020 *	[34]	TB, TL
				13	*Nesticella beccus* Grall & Jäger, 2016	[34]	TP
				14	*Nesticella mogera* (Yaginuma, 1972)	[43]	TP
			Theridiidae	15	*Nesticodes rufipes* (Lucas, 1846)	[43]	TP
			Gnaphosidae	16	*Micythus anopsis* Deeleman-Reinhold, 2001 *	[50]	TB, TL
			Liocranidae	17	*Jacaena schwendingeri* (Deeleman-Reinhold, 2001)	Unpublished record. Specimen in SMF	TX
	Chilopoda	Scolopendromorpha	Scolopendridae	18	*Scolopendra dehaani* Brandt, 1840	[51]	TP
	Diplopoda	Polydesmida	Paradoxosomatidae	19	*Tylopus perarmatus* Hoffman, 1973	[14,52]	TX
			Haplodesmidae	20	*Eutrichodesmus gremialis* (Hoffman, 1982) *	[14,26]	TB, TL
	Maxilliopoda	Cyclopoida	Cyclopidae	21	*Tropocyclops prasinus* (Fischer, 1860)	[43]	SP
		Harpacticoida	Canthocamptidae	22	*Elaphoidella namnaoensis* Brancelj, Watiroyram & Sanoamuang, 2010	[53]	SB
				23	*Epactophanes richardi* Mrázek, 1893	[53]	SP
	Malacostraca	Bathynellacea	Parabathynellidae	24	*Siambathynella janineana* Camacho & Leclerc, 2022 *	[54]	SB
		Isopoda	Oniscidae	25	*Exalloniscus beroni* Taiti & Ferrara, 1988 *	[14,31]	TB, TL
		Decapoda	Palaemonidae	26	*Macrobrachium yui* Holthuis, 1950	[14]	SP
	Collembola	Entomobryomorpha	Isotomidae	27	*Folsomides parvulus* Stach, 1922	[14,43]	TB
				28	*Folsomina onychiurina* Denis, 1931	[43]	TP
			Paronellidae	29	*Salina pulchella* Goto, 1955	[19,55]	TX
				30	*Troglopedetes fredstonei* Deharveng 1988 *	[14,56]	TB, TL
				31	*Troglopedetes leclerci* Deharveng, 1990 *	[28]	TB, TL
			Entomobryoidae	32	*Pseudosinella chiangdaoensis* Deharveng, 1990 *	[14,28,55]	TB, TL
				33	*Coecobrya guanophila* Deharveng, 1990 *	[28]	TB, TL
				34	*Coecobrya similis* Deharveng, 1990	[14,28,55]	TB
		Poduromorpha	Hypogastruridae	35	*Acherontiella colotlipana* Palacios-Vargas & Thibaud, 1985	[14,57]	TB
		Symphypleona	Arrhopalitidae	36	*Arrhopalites anulifer* Nayrolles, 1990	[58]	TP

Table 2. *Cont.*

Phylum	Class	Order	Family	No.	Species	Reference(s)	Status
				37	*Arrhopalites chiangdaoensis* Nayrolles, 1990 *	[15,58]	TB, TL
	Insecta	Coleoptera	Carabidae	38	*Itamus castaneus* Schmidt-Goebel, 1846	[14]	TP
			Staphylinidae	39	*Bironium troglophilum* Löbl, 1990	[25]	TB
		Lepidoptera	Tineidae	40	*Crypsithyris spelaea* Meyrick, 1908	[43]	TP
				41	*Tinea antricola* Meyrick, 1924	[14,43]	TB
				42	*Wegneria cerodelta* (Meyrick, 1911)	[43]	TP
		Pscoptera	Liposcelididae	43	*Liposcelis bostrychophilus* Badonnel, 1931	[14,43]	TP
				44	*Liposcelis entomophilus* Enderlein, 1907	[43]	TP
			Psyllipsocidae	45	*Psocathropos lachlani* Ribaga, 1899	[43]	TP
		Diptera	Culicidae	46	*Culex harrisoni* Sirivanakorn, 1977 *	[22]	TB, TL
		Hymenoptera	Formicidae	47	*Carebara diversa* (Jerdon, 1851)	[14]	TX
				48	*Anoplolepis gracilipes* Smith, 1857	[14]	TX
Chordata	Actinopterygii	Cypriniformes	Cyprinidae	49	*Neolissochilus stracheyi* (Day, 1871)	[14]	TX
	Reptilia	Squamata	Colubridae	50	*Elaphe taeniura* (Cope 1861)	[14]	TP
	Mammalia	Chiroptera	Soricidae	51	*Suncus murinus* (Linnaeus, 1766)	[59]	TX
			Hipposideridae	52	*Aselliseus stoliczkanus* Dobson, 1871	[14,30]	TX
				53	*Hipposideros armiger* (Hodgson, 1835)	[14,16,59]	TX
				54	*Hipposideros diadema* (Geoffroy, 1813)	[60]	TX
				55	*Hipposideros lylei* Thomas, 1913	[14,16,59]	TX, TL
			Pteropodidae	56	*Eonycteris spelaea* (Dobson, 1871)	[60]	TX
				57	*Macroglossus sobrinus* Andersen, 1911	[60]	TX
				58	*Rousettus leschenaulti* (Desmarest, 1820)	[60]	TX
			Rhinolophidae	59	*Rhinolophus pusillus lakkhanae* Yoshiyuki, 1990	[14,59]	TX
			Vespertilionidae	60	*Ia io* Thomas 1902	[18]	TX
				61	*Pipistrellus paterculus* (Thomas, 1915)	[59]	TX

Note: *Nesticella mogera* was originally described as *Howaia mogera* and *Psocathropos lachlani* was originally described as *Psocathropos microps*.

3.2. The Subterranean Fauna of Tham Chiang Dao

The obligate cave fauna of Tham Chiang Dao belongs to 3 phyla, 8 classes, 23 orders, 33 families, 36 genera, and 37 species, of which 33 are troglobionts and 4 are stygobionts (Table 3). The best represented class is Arachnida (12 species), followed by Insecta (10 species) and Collembola (6 species) (Table 3). The Araneae are the most diversified order with five species, followed by Entomobryomorpha with four species. Troglobiotic species are much more numerous than stygobiotic species, as in other Thai caves studied so far. In contrast, temperate caves often have more stygobionts than troglobionts [43,61–67]. This difference is clearly linked to different sampling efforts in terrestrial versus aquatic habitats and the real pattern remains unknown for tropical caves.

3.2.1. Terrestrial Fauna

(1) Gastropoda

A single troglobiotic microsnail *Acmella* sp. has been recently discovered in Tham Chiang Dao [14]. It was mainly found in the cave hygropetric where thin biofilms of bacteria and fungi are probably the main food source for this minute snail. Specimens were found in Tham Lab Lae, Tham Maa, and Tham Nam (Figure 3).

Figure 3. Gastropoda. A troglobiotic microsnail *Acmella* sp., photo by R. Promdam with permission.

(2) Acari

A white, long-legged mite has been collected in oligotrophic habitats (on the surface of standing rock pools and on the mud floor) which is probably a Leeuwenhoekiidae, similar to those encountered in many caves of Southeast Asia (Figure 4).

(3) Araneae

Five troglobiotic spiders from five different families have been reported from this cave: *Systaria lannops*, *Micythus anopsis*, *Spermophora* sp., *Althepus tibiatus*, and *Sinopoda ruam*. *Systaria lannops* were collected in the dark zone by P. Jäger, S. Li, and E. Grall in June 2014 and are also known from two other caves in Chiang Mai: Tham Tab Tao (the type locality) 35 km to the NE and Tham Pha Daeng 25 km ENE of Tham Chiang Dao [37]. *Micythus anopsis* was collected in July 1985 by L. Deharveng [50]. Deharveng and Bedos [43] listed a blind *Scotophaeus* sp. (Gnaphosidae) in their table of terrestrial cave fauna, which probably refers to this specimen. A blind unidentified *Spermophora* species was collected in Tham Chiang Dao by the APS (Deeleman-Reinhold identification). *Althepus tibiatus* was collected from the dark zone by F.D. Stone in December 1972 [24], with further specimens collected in July 1985 by L. Deharveng and in July 1986 by F.D. Stone. The only other known locality of this species is Tham Pha Daeng 2 which is 25 km to the ENE [24]. *Sinopoda ruam* is only known from Tham Chiang Dao. It was collected by M. Anderson and H. Read in March 1989 and by P. Jäger, E. Shaw, S. Li, and E. Grall in June 2014 [34]. *Heteropoda* sp. and *Sinopoda ruam* distributions in the cave narrowly overlap, which is rare for Sparassidae spiders [68].

Figure 4. Acari. A troglobiotic Leeuwenhoekiidae, photos by S. Jantarit.

(4) Opiliones

The single troglobiotic species of Opiliones recorded from the cave is an unidentified microphthalmic and troglomorphic *Paratakaoia* sp. [43]. The troglophilic species *Bandona palpalis* Roewer, 1927 is abundant in Tham Chiang Dao [29].

(5) Palpigradi

Two micro-whipscorpions have been reported from Tham Chiang Dao: *Eukoenenia thais* and *Eukoenenia* cf. *lyrifer*. *Eukoenenia thais* is a troglobiotic species that was collected by L. Deharveng and A. Gouze in December 1980 and in July 1985 in Tham Maa [49,69]. *Eukoenenia* cf. *lyrifer* was collected by P. Leclerc as an adult female, on the wall of Tham Kaew in July 1985. Despite the proximity of the place of collection, it is not possible to relate this specimen to *E. thais*, which is larger and exhibits significant differences in morphology. As for *E. lyrifer* from Tham Ku Kaeo in Chiang Rai province [69], *Eukoenenia* cf. *lyrifer* seems to be intermediate between the *euedaphic E. siamensis* and the troglomorphic *E. thais*.

(6) Pseudoscorpion

A blind troglobiotic species of *Tyrannochthonius* is recorded by Deharveng and Bedos [43] and DMR [14]. In addition, two troglophilic pseudoscorpion species are reported from Tham Chiang Dao (Figure 5). *Megachernes trautneri* Schawaller, 1994, was collected by J. Trautner and K. Geigenmüller in January 1989 and has also been found in surface habitats on other mountains in Chiang Mai province [48]. *Megachernes* cf. *grandis* (Beier, 1930) was listed by Deharveng and Bedos [43] as an unidentified guanophilic pseudoscorpion that was referred to *M. grandis*, but it is probably *M. trautneri* or another species of the genus as several species of *Megachernes* are sometimes present in caves in Afghanistan, China, Japan, and Turkmenistan, some being associated with guano [70].

Figure 5. Pseudoscorpiones. A troglobiotic *Tyrannochthonius* sp., photos by S. Jantarit.

(7) Schizomida

A single species of Hubbardiidae, presumably troglobiotic, is recorded from guano by Deharveng and Bedos and DMR [14,43] under the name *Schizomus* sp.

(8) Diplopoda

Two species of troglobiotic millipedes are found in Tham Chiang Dao. *Eutrichodesmus gremialis* is a small, blind, pale species that was found mainly in Tham Nam and Tham Keaw on the cave walls and cave floor in oligotrophic habitats. Another micropolydesmoid millipede is an undescribed species of the family Opisotretidae which is rarer than *E. gremialis* and sometimes co-occurs with it (Figure 6). Only two species of the species-rich genus *Eutrichodesmus* are described from Thai caves and cave Opisotretidae were unknown from Thailand [44].

Figure 6. Diplopoda. (**Left**) *Eutrichodesmus gremialis* (Hoffman, 1982); undescribed species of Opisotretidae sp. (**Right**), photos by S. Jantarit.

(9) Isopoda

Three troglobiotic species of isopods have been found in Tham Chiang Dao: *Exalloniscus beroni*, *Cubaris* sp., and a blind Philosciidae (Figure 7). The first species is found throughout the caves, except in Tham Phra Non. It is a colorless and blind species that was collected mainly on the cave mud floor and sometimes in scattered bat feces. *Cubaris* sp. is more abundant with large colonies that gather on the cave walls and floor throughout the cave except in Tham Phra Non. Both genera have cave species in several regions of Southeast Asia. The Philosciidae is blind, but its ecological status is uncertain, as another blind Philosciidae has been found in the soil on Doi Chiang Dao.

Figure 7. Isopoda: Oniscidea. (**Left**) Philosciidae sp.; *Cubaris* sp. (**Right**), photos by S. Jantarit.

(10) Collembola

Springtails are often numerically dominant in Thai caves. Tham Chiang Dao is amongst the richest caves in the tropics for its collembolan fauna with 17 species, including six troglobionts [43]. This is the highest number of species found in a Thai cave, as the highest richness in other caves of the country does not exceed 10 species per cave, with an average of 3–5 species per cave [71]. Collembola are well represented in tropical caves across Southeast Asia. For example, 14 species are listed from Batu Caves in Malaysia, including 2–3 troglobionts [46], 12 species from Batu Lubang in Halmahera including 5 troglobionts, 22 from Ngalau Surat in Sumatra including 5 troglobionts [43], and 24 from the Towakkalak System in Sulawesi including 6 troglobionts [45]. The Tham Chiang Dao springtail fauna is, therefore, in line with other Southeast Asian caves. It is also the type locality for five species which are endemic to the cave. *Coecobrya guanophila* is a white, blind, and guanobiotic springtail only known from Tham Chiang Dao. There are several records of this endemic species from the Tham Kaew part of the cave, where it is abundant in humid guano deposits, collected by P. Leclerc, F. D. Stone, and L. Deharveng in December 1980, July 1981, and July 1985 [28,72]. *Coecobrya* has many cave species in Southeast Asia. *Pseudosinella chiangdaoensis* is a white, eyeless, slightly troglomorphic springtail that is only known from Tham Chiang Dao. Specimens were caught in July 1985 by P. Leclerc and L. Deharveng in Tham Maa [28]. The genus is very diversified in temperate caves, but rare in tropical caves, and *P. chiangdaoensis* is the only cave *Pseudosinella* of continental Southeast Asia. *Troglopedetes fredstonei* is a troglomorphic species with no eyes, no pigment, long appendages, large body size, and slender claws. It was collected by the APS in July 1988 and by F.D. Stone, and was found on humid mud banks with scattered bat guano in the lower levels of Tham Kaew and Tham Nam. It was not found in the upper level Tham Maa or outside the cave [56]. *Troglopedetes leclerci* was collected in December 1980 and July 1985 by L. Deharveng and P. Leclerc on the walls of Tham Kaew and in Tham Maa [28]. *Acherontiella colotlipana* (Palacios-Vargas and Thibaud, 1985) is a troglobiotic and guanobiotic springtail that was originally found in guano in a Mexican cave. As the species seems to be well characterized morphologically, we provisionally assume that this disjunct

distribution reflects sampling gaps in the cave guano habitats of tropical caves. Such a wide distribution among cave guano species is known in several other species of Collembola, such as *Xenylla yucatana*. Four specimens were collected in Tham Chiang Dao by the APS from guano and soil [57]. *Arrhopalites chiangdaoensis* is a pale, troglobiotic collembola that is only known from Tham Chiang Dao. It was collected by L. Deharveng in December 1980 and July 1985 in Tham Nam/Tham Phra Non, Tham Maa, and Tham Kaew. This species was shown to be polyphagous after the dissection of its gut, which was found to contain clay or mycelia mixed with clay, and sometimes fragments of collembola or pieces of scale, probably from Tineoidea (Lepidoptera) which are abundant in the cave [58].

(11) Diplura

A single species of unidentified Japygidae was reported by Deharveng and Bedos [43] as slightly troglomorphic. Although no Japygidae have been described from Thai caves, they can be found in caves throughout the country.

(12) Blattodea

Two troglomorphic Nocticolidae are present in Tham Chiang Dao: *Helmablatta* sp. and *Spelaeoblatta* sp. Nocticolidae are widespread in Southeast Asian caves, but few species have been described. The genus *Helmablatta*, originally characterized by extremely modified upstanding tergal glands [73], was only known by a single species from a Vietnamese cave. The presence of a species of *Helmablatta* in Tham Chiang Dao is an interesting discovery. Nocticolidae are very common on muddy cave floors with scattered guano in Tham Nam and Tham Keaw. Another guanobiotic cockroach, *Blattella* cf. *cavernicola* (Shelford, 1907), is rather common in the dry upper parts of Tham Lab Lae and Tham Maa, especially on guano deposits and under the mats near the statues and Buddha images (Figure 8).

Figure 8. Blattodea. Troglomorphic cave cockroaches: (**above left**) *Spelaeoblatta* sp. and *Helmablatta* sp. (**above right**); photos by S. Jantarit and guanobiotic cockroach *Blattella* cf. *cavernicola* (**below**), photos by T. Jeenthong with permission.

(13) Orthoptera

At least one species of cricket found in Tham Chiang Dao is troglobiotic, the ant cricket *Myrmecophilus* sp. which is reported for the first time in a Thai cave [14]. This ant cricket is rare and found on the mud floor in Tham Nam. Two additional species of cave cricket are also recognized from this cave, *Rhaphidophora* sp. and *Paradiestrammena* sp. (Figure 9). They are abundant in almost all the cave passages, except in Tham Phra Non which is a main tourist passage and has electric lighting. Cave crickets are often troglophiles which leave the cave at night for feeding. We here omit them in the list of cave-obligate species, though further studies on their ecology may change their status.

Figure 9. Orthoptera. (**A**) A troglomorphic ant-cricket *Myrmecophilus* sp. (photo by T. Jeenthong with permission); two troglophilic crickets (**B**) *Rhaphidophora* sp. and *Paradiestrammena* sp. (**C**), photos by S. Jantarit.

(14) Hymenoptera

An interesting species of ant was found in the cave throughout the undisturbed passages, especially in Tham Lab Lae, Tham Maa, and Tham Keaw. It is a *Brachyponera* sp. which exhibits a reduction of eyes and unusually long appendages for the genus (Figure 10). This ant species is currently being formally described. Its colonies are established in rock cracks or muddy soil and sometimes under stones. This ant is rather common. It appears to be omnivorous and can hunt small invertebrates found in cave environments. If confirmed, it would be the second cave-ant of Southeast Asia, after *Leptogenys khammouanensis* Roncin & Deharveng, 2003 from a cave in Laos.

Figure 10. (**Left**) undescribed species of staphylinid beetle (Oxytelinae); a possible troglobiotic ant species *Brachyponera* sp. (**right**), photos by S. Jantarit.

(15) Coleoptera

At least two subterranean beetles have been reported from Tham Chiang Dao: *Bironium troglophilum* Löbl, 1990 and an undescribed species of staphylinid beetle (Oxytelinae) (Figure 10). *Bironium troglophilum* was collected by J. Sedlacek from Tham Chiang Dao. The type locality is Tham Hued in Mae Hong Son and the beetle is also known from another small cave in Mae Hong Son. Although it has only been recorded from caves, *B. troglophilum* has fully developed wings and does not exhibit any morphological adaptation [25]. Löbl does not give a date for the specimen collected in Tham Chiang Dao, but there is circumstantial evidence that this was in May 1974. The undescribed species of the staphylinid beetle (Oxytelinae) was found on the passage wall in Tham Lab Lae by the DMR in 2023.

(16) Diptera

Non-glowing larvae of a fungus gnat, *Chetoneura* sp., have been found in the cave. This predatory larva builds sticky threads to catch flying insects by hanging them down from the ceilings of the cave passages (Figure 11). The species is rather common throughout the cave, especially in wet habitats and/or near water pools. Its adult stage is still unknown, but there is a report of an epigean species, *Chetoneura oligoradiata*, from the Doi Chiang Dao nature trail [74]. We here place this fungus gnat as a possible troglobiotic species.

The troglobiotic mosquito *Culex harrisoni* Sirivanakorn, 1977 was reported from Tham Chiang Dao (Table 1), breeding in two rock pools of 38–45 cm in diameter and 8.5–10.0 cm in depth, located 300–400 m inside the cave. Most adult specimens came from rearing the larvae and only a few were collected on the wall of the cave near the breeding site. The adult biology is unknown [22]. This mosquito has also been found in Tham Borichinda in the Doi Inthanon National Park, Chiang Mai.

(17) Lepidoptera

Tineid moths are abundant on guano deposits in Tham Chiang Dao with three species identified: *Crypsithyris spelaea* Meyrick, 1908, *Tinea antricola*, and *Wegneria cerodelta* (Meyrick, 1911). Only *T. antricola* (Figure 11) is considered a troglobiont, the two other species being troglophilic. *Tinea antricola* was collected by the APS [43]. The larvae feed on guano and the species is common in caves in Southern Asia.

Figure 11. Non-glowing sticky worm, *Chetoneura* sp. (**A**) its sticky threads and (**B**) its larva, photos by R. Promdam with permission.

3.2.2. Aquatic Fauna

Only five species are stygobiotic, though many aquatic taxa were sampled and described from this cave.

(1) Nematoda

A species of the genus *Tobrilus* sp. was collected from the pool at the end of Tham Nam. Its ecological assignation is not possible.

(2) Annelida

The stygobiotic species, *Heterochaetella glandularis* (Yamaguchi, 1953) was reported in the pools at the end of Tham Nam and Tham Kaew [47,48]. An unidentified Enchytraeidae from the same section of the cave might be stygobiotic as well [47].

(3) Harpacticoida

A single stygobiotic copepod species *Elaphoidella namnaoensis* was found in Tham Chiang Dao in 2007–2011 by S. Watiroyram as part of a study into the cave Harpacticoida of northern Thailand. The samples were taken from individual pools on the floor of the caves, which were filled exclusively by percolation water. *E. namnaoensis* is rather common in the caves of northern and central Thailand, in both the unsaturated and saturated zones [53]. In addition, three stygophilic copepod species are also reported from water pools in this cave: *Tropocyclops prasinus* (Fischer, 1860), *Elaphoidella* cf. *grandidieri* (Guerne & Richard, 1893) [43], and *Epactophanes richardi* Mrázek, 1893 [35].

(4) Bathynellacea

The micro-stygobiotic species *Siambathynella janineana* was collected by the APS in July 1985 from muddy pools in Tham Maa, where hundreds of specimens were found, and one specimen from a sump in Tham Nam. The species was also found outside the cave in the

resurgence pool and in the hyporheic of the stream at −40 cm, about 25 m downstream of the resurgence [47,54].

The number of stygobiotic species recorded from Tham Chiang Dao is rather small. Ostracoda and Cyclopoidea have been collected, but remain unidentified [47]. Stygobiotic amphipods, decapods, and fish are known from tropical subterranean habitats, but have not been found in Tham Chiang Dao. Blind fish and shrimps have long been mentioned by local people to exist in Tham Chiang Dao, but attempts to find them have failed so far [14,27]. The shrimp *Macrobrachium yui* Holthuis, 1950, which is present in the permanent pools of Tham Nam, does not show adaptations to cave life [14]. Several specimens of the Cyprinidae fish *Neolissochilus stracheyi* (Day, 1871) were observed, but the species does not show any sign of cave adaption and is considered as a stygoxene.

3.2.3. Other Fauna

Surprisingly, the long-legged centipede (*Thereuopoda longicornis* (Fabricius, 1793)) and bent-toed geckos (*Cyrtodactylus* sp.) are not reported even though Tham Chiang Dao has long been zoologically investigated. These taxa are very common and widespread in the caves of Thailand [44]. No amphibians nor birds have been reported from Tham Chiang Dao, while only a single species of snake, the common and widespread cave racer *Elaphe taeniura*, has been found recently [14]. There are also no reports of rodents, especially *Rattus tanezumi* Temminck, 1844 and *Leopoldamys nielli* (Marshall, 1976), which are common visitors in Thai caves. However, footprints were seen on the floor of many passages suggesting that rodents may visit the cave.

Bats are common in Tham Chiang Dao, which is the type locality of *Hipposideros lylei*. Tham Chiang Dao is among the best caves in the region for bats, supporting large colonies and at least 10 species of bats (Table 1). All of them roost in the habitats where there is less impact from tourist visits or in the chambers where electric lights are absent. Many colonies exist even in the deep parts of the cave, near the end of the passages (>500 m from the entrance), suggesting that there are several small openings through which bats can enter and leave the cave.

Table 3. List of obligate cave species present in Tham Chiang Dao, Chiang Mai, Thailand.

#	TB/SB	Species	Taxonomic Classification	Notes	Reference(s)
1	SB	*Heterochaetella glandularis* (Yamaguchi, 1953)	Clitellata: Haplotaxida: Haplotaxidae	(TM)	[47]
2	SB?	Undetermined sp.	Clitellata: Enchytraeida: Enchytraeidae		[47]
3	TB	*Acmella* sp.	Gastropoda: Caenogastropoda: Assimineidae	TM?	[14]
4	TB	Undetermined sp.	Arachnida: Acari: Leeuwenhoekiidae (?)	TM	[14,43]
5	TB	*Systaria lannops* Jäger, 2018	Arachnida: Araneae: Clubionidae		[37]
6	TB	*Micythus anopsis* Deeleman-Reinhold, 2001	Arachnida: Araneae: Gnaphosidae	* TM	[50]
7	TB	*Spermophora* sp.	Arachnida: Araneae: Pholcidae	TM	[43]
8	TB	*Althepus tibiatus* Deeleman-Reinhold, 1985	Arachnida: Araneae: Psilodercidae	TL	[24,75]
9	TB	*Sinopoda ruam* Grall & Jäger, 2020	Arachnida: Araneae: Sparassidae	*	[34]
10	TB	*Paratakaoia* sp.	Arachnida: Opiliones: Epedanidae	TM	[43]
11	TB	*Eukoenenia thais* Condé, 1988	Arachnida: Palpigradi: Eukoeneniidae	* TM	[41,69]
12	TB	*Eukoenenia* sp. (*E.* cf. *lyrifer* Condé, 1992)	Arachnida: Palpigradi: Eukoeneniidae		[69]
13	TB	*Tyrannochthonius* sp.	Arachnida: Pseudoscorpiones: Chthoniidae	(TM)	[14,43]

Table 3. *Cont.*

#	TB/SB	Species	Taxonomic Classification	Notes	Reference(s)
14	TB?	Undetermined sp.	Arachnida: Schizomida: Hubbardiidae	G	[43]
15	TB	*Eutrichodesmus gremialis* Hoffman, 1982	Diplopoda: Polydesmida: Haplodesmidae	*	[26,76]
16	TB	Undetermined sp.	Diplopoda: Polydesmida: Opisotretidae		[14]
17	SB	*Elaphoidella namnaoensis* Brancelj, Watiroyram & Sanoamuang, 2010	Maxillopoda: Harpacticoida: Canthocamptidae		[47,53]
18	SB	*Siambathynella janineana* Camacho & Leclerc, 2022	Malacostraca: Bathynellacea: Parabathynellidae	*	[47,54]
19	TB	*Cubaris* sp.	Malacostraca: Isopoda: Armadillidae	(TM) G	[14,43]
20	TB	*Exalloniscus beroni* Taiti & Ferrara, 1988	Malacostraca: Isopoda: Oniscidae	* (TM)	[31]
21	TB?	Undetermined sp.	Malacostraca: Isopoda: Philosciidae	(TM)	[43]
22	TB	*Coecobrya guanophila* Deharveng, 1990	Collembola: Entomobryomorpha: Entomobryidae	* G	[28]
23	TB	*Pseudosinella chiangdaoensis* Deharveng, 1990	Collembola: Entomobryomorpha: Entomobryidae	* (TM)	[28]
24	TB	*Troglopedetes fredstonei* Deharveng 1988	Collembola: Entomobryomorpha: Paronellidae	* TM	[56]
25	TB	*Troglopedetes leclerci* Deharveng, 1990	Collembola: Entomobryomorpha: Paronellidae	* G	[28]
26	TB	*Acherontiella colotlipana* Palacios-Vargas & Thibaud, 1985	Collembola: Poduromorpha: Hypogastruridae	G	[57]
27	TB	*Arrhopalites chiangdaoensis* Nayrolles, 1990	Collembola: Symphypleona: Arrhopalitidae	*	[58]
28	TB?	Undetermined sp.	Insecta: Diplura: Japygidae	(TM)	[43]
29	TB	*Helmablatta* sp.	Insecta: Blattodea: Nocticolidae	TM	[14]
30	TB	*Spelaeoblatta* sp.	Insecta: Blattodea: Nocticolidae	TM	[14]
31	TB	*Myrmecophilus* sp.	Insecta: Orthoptera: Myrmecophilidae	TM	[14]
32	TB?	*Brachyponera* sp.	Insecta: Hymenoptera: Formicidae		[14]
33	TB	*Bironium troglophilum* Löbl, 1990	Insecta: Coleoptera: Scaphidiidae		[25]
34	TB?	Undetermined sp.	Insecta: Coleoptera: Staphylinidae: Oxytelinae	(TM)	[14,43]
35	TB	*Tinea antricola* Meyrick, 1924	Insecta: Lepidoptera: Tineidae	G	[43]
36	TB?	*Culex harrisoni* Sirivanakorn, 1977	Insecta: Diptera: Culicidae	TL	[22]
37	TB?	*Chetoneura* sp.	Insecta: Diptera: Keroplatidae		[14,23]

TB: troglobiont; TB?: probable troglobiont; SB: stygobionts; SB?: probable stygobiont; TL: type locality; *: type locality and only recorded locality; TM: troglomorphic; (TM): slightly troglomorphic; G: guanobiont or guanophile.

4. Cave Management and Conservation

Tham Chiang Dao is situated in a protected area under the Chiang Dao Wildlife Sanctuary, managed by the DNP, where all the fauna is protected by laws and regulations. In practice, the entrance to the cave is located in a Buddhist monastery and it is a very popular tourist attraction which is managed by a local cave management committee. There are two tours: (1) self-guided through electrically lit horizontal passages (Tham Phra Non) and (2) a longer guided tour through unlit passages with the guide using a kerosene storm lantern (Tham Lab Lae and Tham Maa).

Tham Phra Non is the main religious tourism attraction and contains lots of shrines, statues, images, and other sights of interest. Permanent infrastructure such as concrete paths, bridges, CCTV, and a 4G mobile telephone network has been built. Electric lights are all along the tourist cave passage for illumination, decoration, and the safety and comfort of visitors. The passage has been illuminated for many years and today the electric lights are switched on for at least 8 to 9 consecutive hours every day, which directly stimulates the growth of lampenflora, especially algae, mosses, and ferns ([77,78] and Figure 12A–C).

The proliferation of lampenflora has considerable impacts on cave formations and the cave environment as it creates habitats for various external opportunistic species that may compete with or prey on the original obligate cave species [79], though hard data are still very scarce. Lampenflora in Tham Chiang Dao supports the colonization of invasive species such as the yellow crazy ant *Anoplolepis gracilipes*. This ant species is one of the worst invasive alien species in the world and is today widespread in the tropics and subtropics. It can affect the population dynamics of obligate subterranean species, being rather aggressive and having been reported to prey on and attack mollusks, arachnids, myriapods, isopods, insects, and earthworms [80]. The species is, however, limited to the most disturbed areas or entrance zone in caves and preserving passages in their natural state should largely limit its impact. In any case, it is highly recommended that the lampenflora in Tham Chiang Dao is controlled or cleaned by non-chemical agents, that lights which do not heat the cave and with a low emission in the wavelengths that are not absorbed for growth by the lampenflora are installed, and that lights are switched off when visitors are absent by using automatic light sensors.

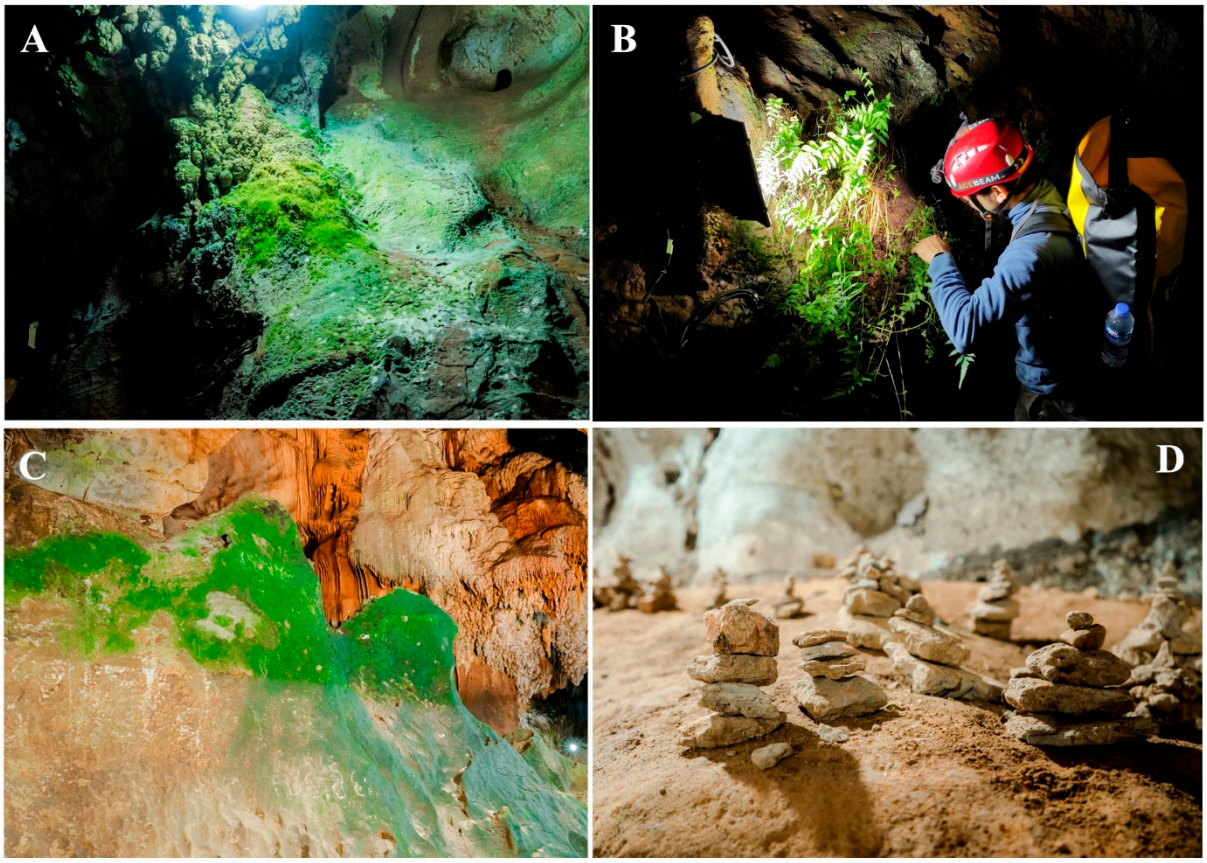

Figure 12. The proliferation of lampenflora (**A**–**C**) and little towers by piling up stones in Tham Chiang Dao (**D**), photos by P. Chananin with permission.

Tham Lab Lae and Tham Maa are frequently visited by tourists as these two interconnected passages are more adventurous with various kinds of cave formations through unlit passages. Local guides prefer to follow the tradition of using a kerosene storm lantern to illuminate the cave. This has caused serious problems not only to the cave ecosystem and its biodiversity, but also to the health of the guides and visitors. It has long been known that using kerosene is smelly and irritating to the eyes, skin, and respiratory system [81]. When used for lighting, the kerosene lanterns emit toxic and carcinogenic gases, such as carbon monoxide, nitric oxides, and sulfur dioxide, and fine particulates [82]. It has been shown [83] that these lamps emit significant amounts of black carbon, 20 times more than

previously thought, which directly affects the beauty of the cave formations, prevents the accumulation of calcite, and contributes to microclimate pollution. At least 70 people are working part-time or full-time as guides in the cave, mostly women. Replacing kerosene lamps with LED lamps is, therefore, recommended not only for the environment, but also for the health and welfare of the local guides and tourists.

In Tham Phra Non it has become common in the last 10 years for tourists to construct, for good luck, little towers by piling up stones (Figure 12D). Aside from creating unsightly artificial eyesores, this activity also poses a threat to the cave fauna as moving the stones disturbs their habitat. Tourists should be advised not to construct these piles and existing towers should be removed so that future visitors are not inspired to make their own.

The carbon dioxide in Tham Chiang Dao was measured in the wet season in July 1985 [84] and June 2023 [14] and in the dry season in January 2023 [14] (Figure 13). In the wet season, CO_2 reached the highest concentration (2.9%) at the end of the northern branch of Tham Nam near the water, a high level (1.3–2.2%) in Tham Kaew, and had the lowest concentration (0.1–0.5%) near the entrance. In the dry season, CO_2 levels were much lower in all passages, with the maximum level at the western end of Tham Kaew (0.46%). At the beginning of the wet season (June), the minimal levels of CO_2 were higher than in the dry season (January) and lower than later in the wet season (July) [14] (Figure 13). It is noteworthy that the cave sections which had the highest CO_2 level in the wet season seemed to be richer in troglobionts, in support of Howarth and Stone's observations of a positive impact of CO_2 on biodiversity in an Australian cave [85]. These parts of the caves should, therefore, be closed to tourist visits in order to keep habitats in their original state, aside from the fact that high peaks of CO_2 in the wet season may be uncomfortable or dangerous for visitors.

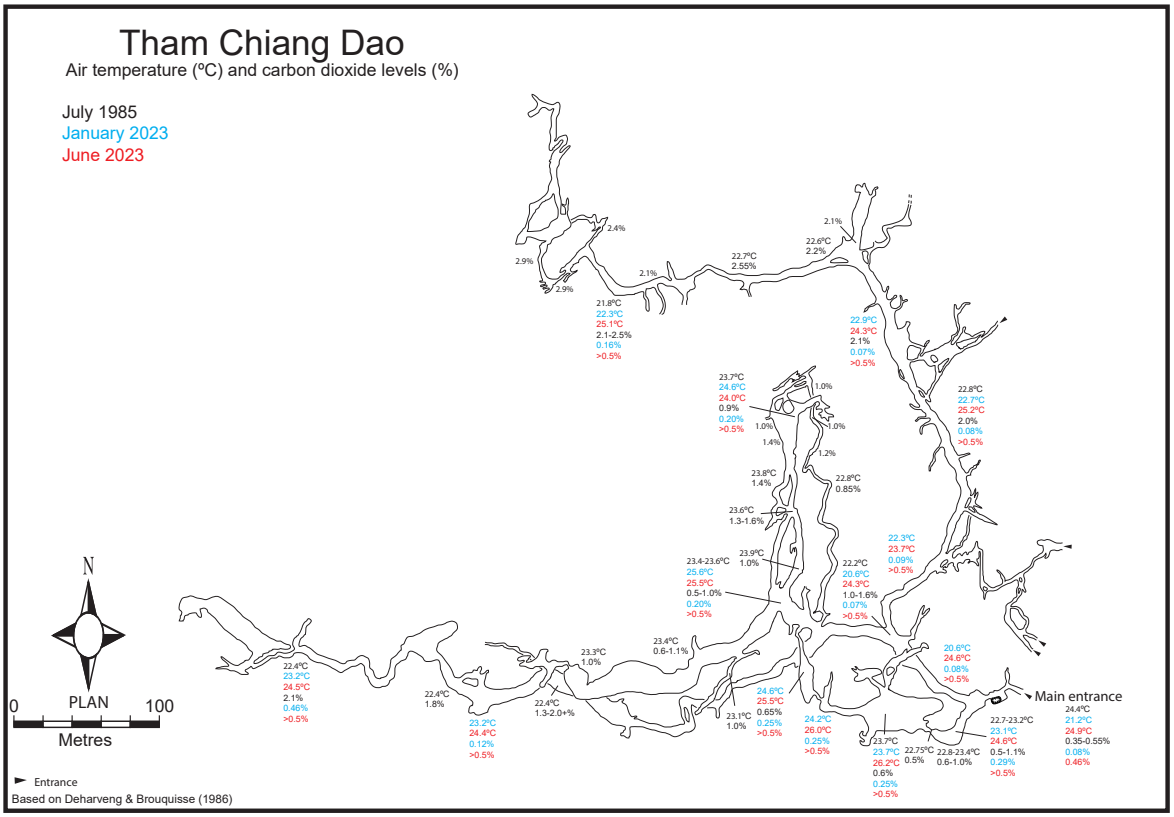

Figure 13. Temperature and carbon dioxide in Tham Chiang Dao. Black indicates measurements done in July 1985 [84], blue, those done in January 2023 [14], and red, those done in June 2023 [14].

The detailed zoological record extending back more than 40 years shows some indications of changes in the fauna, including the possible extirpation of some species. This needs

to be investigated in more detail before any conclusions can be drawn. Deharveng and Bedos [43] tabulated 92 taxa from Tham Chiang Dao while only 50 are listed in the recent survey of the DMR [14]. However, the former dataset was carried out over a much longer period than the later dataset, and the comparison is not conclusive. The slow, but continuous, increase in tourist frequentation, habitat disturbance, installation of infrastructure in the tourist section (concrete path, bridge, electric lights), as well as the use of kerosene storm lanterns, may directly and indirectly drive changes in cave animal population dynamics, as well as favoring the spread of invasive species. This is supported by the observation that the tourist passages with electric lighting contain a smaller number of cave-obligate species and more alien species than the natural passages [14]. Although Doi Chiang Dao became a UNESCO Biosphere Reserve in 2021, its cave fauna appears to have played no part in the designation. The present paper fills this gap and shows the biological importance of the Tham Chiang Dao cave fauna, especially its endemic species, in this Biosphere Reserve. It might also serve as a basic reference for the bodies in charge of the management of the Chiang Dao Wildlife Sanctuary, i.e., the local cave management committee, the NCMPC, and the DMR, and in a larger scope will be a tool for conservation purposes in the future.

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