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Two new species of cave-adapted pseudoscorpions (Pseudoscorpiones: Neobisiidae, Chthoniidae) from Guangxi, China

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Abstract. Two new troglomorphic pseudoscorpion species, *Bisetocreagris maomaotou* sp. nov. (Family Neobisiidae) and *Tyrannochthonius chixingi* sp. nov. (Family Chthoniidae) are described from one cave in the tower karst of northern Guangxi Province, China. This cave is located at close proximity to a village and an adjacent urban area. As with many caves in the South China Karst, this feature occurs at an elevation slightly above agriculture and rural activities; thus, we suggest it may be partially buffered from human activities in the lowland areas. We discuss the likelihood of narrow range endemism and provide research and conservation recommendations to guide future management of these two species.

Keywords: *Bisetocreagris*, *Tyrannochthonius*, troglobionts, cave conservation

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Southeast Asia is postulated to yield the highest diversity of troglomorphic animals among the well-sampled tropical regions of the globe (Clements et al. 2006). Yet despite research conducted over the past three decades, few areas in the region have been sufficiently investigated, and knowledge of cave biological diversity and ecological processes is limited (Deharveng & Bedo 2000). The expansive South China Karst represents one of these regions (Chen et al. 2001; Clarke 2006). Among the four administrative units in China where this formation occurs, Guangxi Zhuang Autonomous Region (Guangxi) is considered the most taxonomically well-studied region. At least 99 troglomorphic (cave-adapted) arthropods have been identified; with over half (or 58 species) considered single-cave endemic species (Wynne, unpublished data).

Our knowledge of cave-dwelling pseudoscorpions in this karst area is equally limited. To date, 19 troglomorphic pseudoscorpion species (including the two described here), representing three families (Chernetidae, Chthoniidae, and Neobisiidae), have been described (Schawaller 1995; Mahnert 2003, 2009; Mahnert & Li 2016; Gao et al. 2017; Table 1). All of these animals are known from southern China – occurring within the Guizhou, Hubei, Sichuan, and Yunnan Provinces, and the Chongqing Municipality.

In the paper, we describe two new species of troglomorphic pseudoscorpions (Families Chthoniidae and Neobisiidae) representing the first cave-adapted pseudoscorpions described from Guangxi. We also provide recommendations to guide future research and management efforts.

METHODS

Study area.—Located in southwest China, Guangxi encompasses ~236,400 km^2. Once an ancient shallow sea during the middle Cambrian to Late Triassic periods, this region is now largely characterized by a massive karst (limestone) stratum over 10,000 m thick (Cao et al. 2007) with steep-sided mountains called "tower karst" protruding skyward. As a result of the subtropical climate and rock stratum, Guangxi supports at least 600 dissolution caves.

We sampled four caves in the northeastern most extent of Guangxi within a 30 km radius of the city of Guilin, China. Caves were selected based upon two criteria – sufficient length to support deep zone conditions and the availability of a current cave map. Cave deep zones are defined as completely dark regions with relatively stable temperature, low to no airflow, and a near water-saturated atmosphere with a negligible evaporation rate (Howarth 1980, 1982). While we recognize other factors may contribute to the occurrence of cave deep zones (e.g., maze-like and/or constricted passageways, small or partially rock-fall obstructed entrances, and cave structure in general), we used these criteria because logistics prevented us from selecting study caves based upon site visit evaluations. None of these sites had been previously inventoried for cave-adapted arthropods.

Of the four caves sampled, only one yielded the two undescribed pseudoscorpion species described here (Figs. 1–6). All caves occurred at low elevations within tower karst formations. While extensive agriculture, and rural village and suburban habitation characterized the surrounding lowland plains, vegetation on the tower karst represented a marginally disturbed combination of native and introduced plant and tree species.

Field sampling.—We collected cave-dwelling arthropods at four caves from 15 to 18 November 2016. Approximately eight hours (2 observers at 4 hours per observer) per cave was spent conducting direct intuitive searches within estimated cave deep zones. Given the four caves varied in size and the diversity of arthropods encountered, the area sampled varied. We also opportunistically collected arthropods as encountered while transiting from entrance to estimated deep zones.

Analysis and preparation.—Specimens were collected and preserved in 75% ethanol and deposited in the Museum of Hebei University (MHBU), Baoding City, China. Photographs were taken using a Leica M205A stereomicroscope

Table 1.—Troglomorphic pseudoscorpions described from southern China. Family, genus and species, name of administrative province(s), number of caves (to suggest a level of potential endemism), and names of taxonomic authority are provided.

Family, genus, species	Province	# Caves	Authority
Family Chernetidae			
Megachernes glandulosus	Sichuan	1	Mahnert (2009)
Megachernes tuberosus	Sichuan	1	Mahnert (2009)
Nudochernes troglobius	Sichuan	2	Mahnert (2009)
Nudochernes lipase	Yunnan	1	Mahnert (2009)
Family Chthoniidae			
Tyrannochthonius akaleus	Sichuan	1	Mahnert (2009)
Tyrannochthonius ganshuanensis	Sichuan, Hubei	3	Mahnert (2009)
Tyrannochthonius antridraconis	Sichuan	3	Mahnert (2009)
Tyrannochthonius chixingi	Guangxi	1	this study
Family Neobisiidae			
Bisetocreagris baozinensis	Sichuan	1	Mahnert & Li (2016)
Bisetocreagris cavernarum	Chongqing	1	Mahnert & Li (2016)
Bisetocreagris chinacavernicola	Sichuan	2	Schawaller (1995)
Bisetocreagris chuanensis	Guizhou	2	Mahnert & Li (2016)
Bisetocreagris gracilenta	Guizhou	1	Schawaller (1995)
Bisetocreagris guangshanensis	Guizhou	1	Gao et al. (2017)
Bisetocreagris juanxuae	Sichuan	1	Mahnert & Li (2016)
Bisetocreagris maomaotou	Guangxi	1	this study
Bisetocreagris martii	Yunnan	1	Mahnert (2003)
Bisetocreagris scaurum	Yunnan	1	Mahnert (2003)
Bisetocreagris titanium	Yunnan	1	Mahnert (2003)

equipped with a Leica DFC550 camera and LAS software (Ver. 4.6). We used a Leica M205A stereomicroscope for drawings (with a drawing tube) and measurements. Detailed examination of characters was carried out using an Olympus BX53 general optical microscope. Temporary slide mounts were prepared in glycerol.

Cave locations.—We recognize standard practice for new species description is to provide ample locality information including georeference data to facilitate future collecting, interpretation and research. Because caves are sensitive resources, we provided general geographical information and offset the latitude and longitude coordinates by ~1 km. This level of detail provided is sufficient for future comparative studies, while protecting the precise location of the cave.

Terminology.—Cave ecosystems typically consist of four zonal environments (Howarth 1980, 1983): (1) *entrance zone* – combination of surface and cave environmental conditions; (2) *twilight zone* – both diminished light conditions and influence of

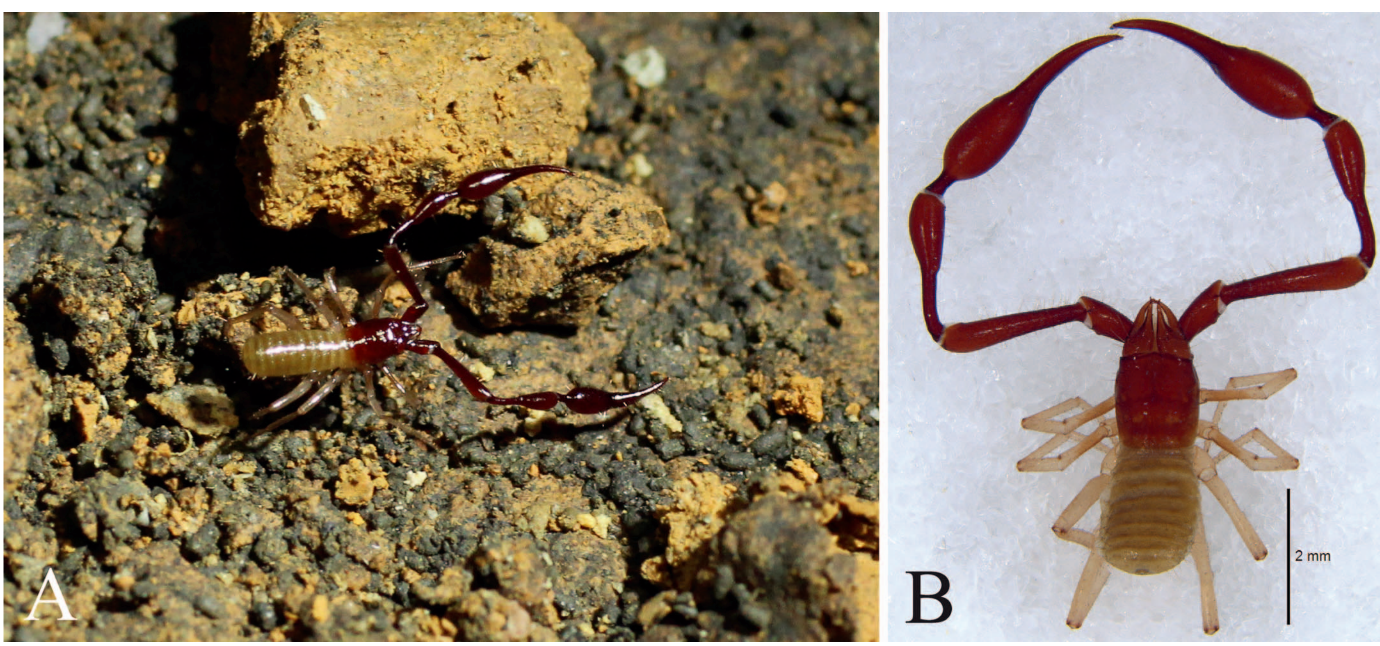

Figure 1.—*Bisetocreagris maomaotou,* sp. nov., A. Image of animal traversing cave floor. B. holotype female, dorsal view.

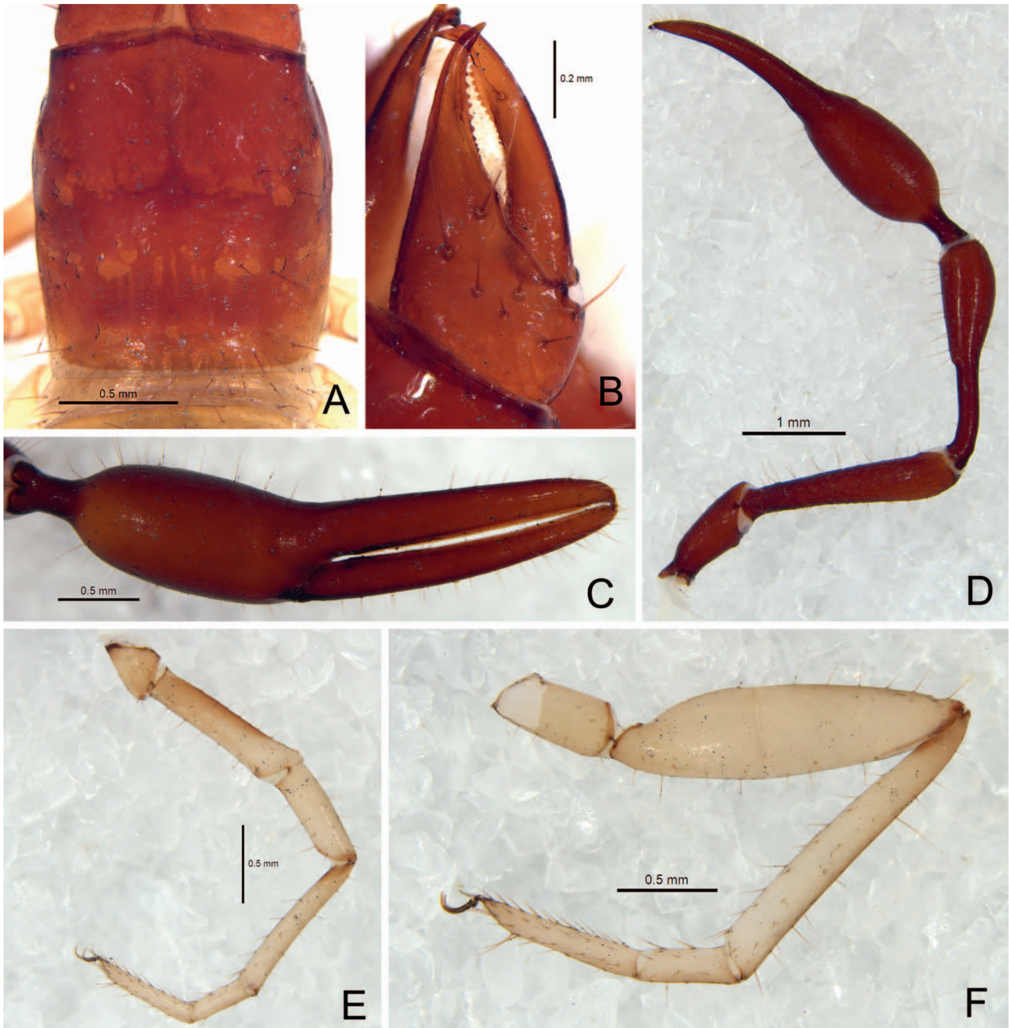

Figure 2.—*Bisetocreagris maomaotou* sp. nov., holotype female: A. Carapace (dorsal view); B. Right chelicerae (dorsal view); C. Chela (lateral view); D. Pedipalp (lateral view); E. Leg I (lateral view); F. Leg IV (lateral view). Scale bars: 0.20 mm (B); 0.50 mm (A, C, E–F); 1.00 mm (D).

surface environment; (3) *transition zone* – aphotic, yet barometric and diurnal shifts are observed at a significantly diminished rate approaching near stable climatic conditions; and, (4) *deep zone* – complete darkness, high environmental stability, constant temperature, and near water-saturated atmosphere with low to no airflow (typically occurs in the deepest portion of the cave). While there are four primary cave specific functional groups generally recognized, the specimens discussed are *troglomorphic* (cave-adapted) organisms known as *troglobionts*. These animals are obligate cave dwellers that require the stable environmental conditions of the deep zone to complete their life cycle and exhibit morphological characteristics indicative of cave adaptation. We also reference *troglophiles* (or *troglophilous* organisms) – non-troglomorphic animals that occur facultatively within caves and complete their life cycles there, but also exist in similar cave-like habitats on the surface.

Pseudoscorpion terminology and measurements largely follow Chamberlin (1931) with some minor modifications to the terminology of the trichobothria (Harvey 1992) and chelicera (Judson 2007). The chela and chelal hand are measured in dorsal (for Neobidiidae) and lateral (for Chthoniidae) view and all measurements are in millimeters (mm) unless noted otherwise.

The following abbreviations are used for the trichobothria: *b* = basal; *sb* = sub-basal; *st* = sub-terminal; *t* = terminal; *ib* = interior basal; *isb* = interior sub-basal; *ist* = interior sub-terminal; *it* = interior terminal; *eb* = exterior basal; *esb* = exterior sub-basal; *est* = exterior sub-terminal; *et* = exterior terminal.

TAXONOMY

Family Neobisiidae Chamberlin, 1930
Bisetocreagris Ćurčić, 1983
Bisetocreagris Ćurčić 1983: 25.
Chinacreagris Ćurčić 1983: 30–31.
Pedalocreagris Ćurčić, 1985: 349–350.

Type species.—*Bisetocreagris*: *Microcreagris annamensis* Beier, 1951, by original designation.

Chinacreagris: *Microcreagris chinensis* Beier, 1943, by original designation.

Pedalocreagris: *Pedalocreagris tethys* Ćurčić, 1985, by original designation.

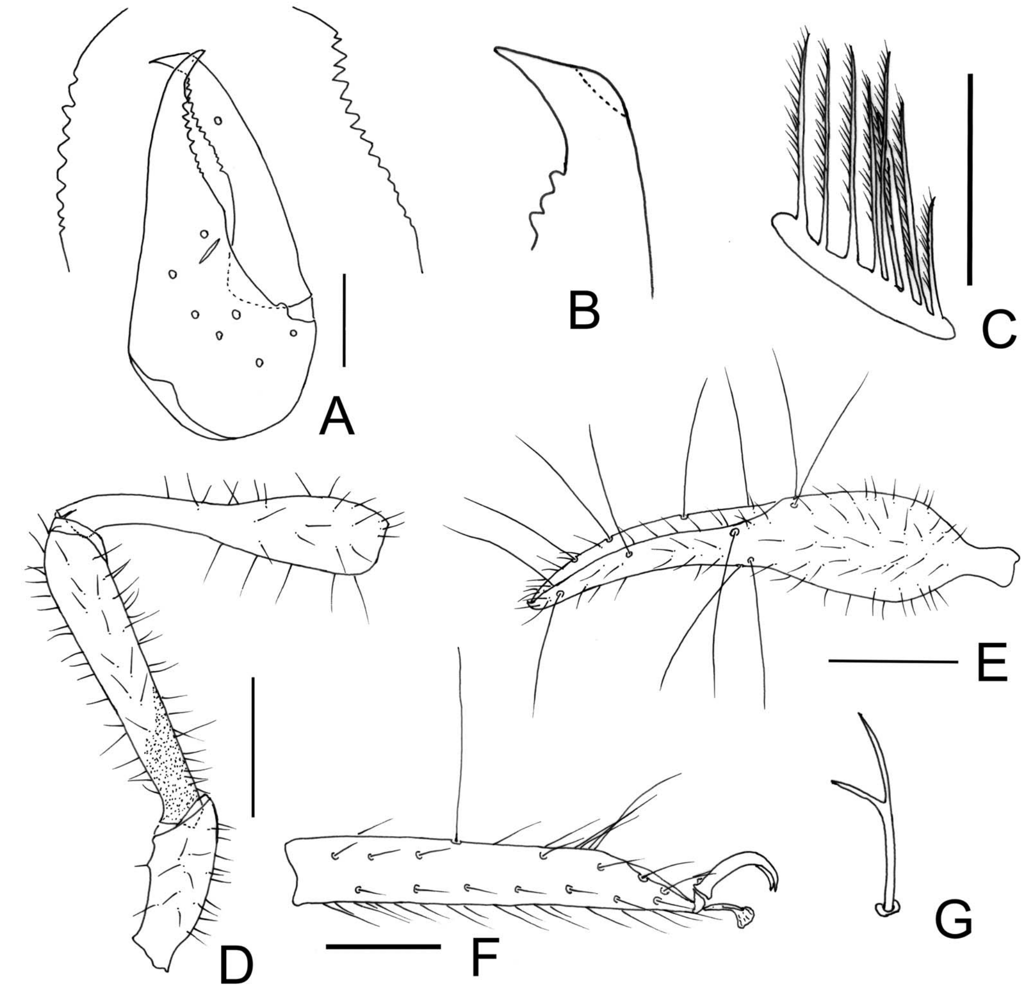

Figure 3.—*Bisetocreagris maomaotou* sp. nov., holotype female: A. Right chelicerae (dorsal view); B. Tip of movable finger of chelicerae (dorsal view); C. Rallum; D. Right pedipalp (minus chela, dorsal view); E. Right chela (lateral view); F. Telotarsus of leg IV (lateral view); G. Subterminal tarsal seta. Scale bars: 0.10 mm (C); 0.25 (A, F); 1.00 mm (D–E).

Remarks.—Species of *Bisetocreagris* can be identified by both the two small setae each on either side of the anteromedian groove of sternite III in the male (Jia et al. 2010) and the trichobothrial pattern: *et-it* near distal finger tip, *est* isolated in distal half of fixed finger, *ib-isb-ist* grouped closely together at the finger base, *eb-esb* on lateral distal side of hand; thus five trichobothria grouped basally (Mahnert & Li 2016).

Consisting of 34 species and one subspecies, *Bisetocreagris* is widely distributed across Asia and includes 21 species from China (including the species described below). Of these, ten species exhibit troglomorphic characters (Harvey 2013; Mahnert & Li 2016; Gao et al. 2017; this study) while one species is an unnamed troglophile (*Bisetocreagris* sp.; Mahnert & Li 2016).

Bisetocreagris maomaotou sp. nov.
http://zoobank.org/?lsid=urn:lsid:zoobank.org:act:516F187A-E76C-459C-8509-603AFD0422AA
(Figs. 1–3)

Type material.—*Holotype female:* **China:** *Guangxi Zhuang Autonomous Region:* Xiufeng District, Maomaotou cave, deep zone, [25°18′46.12″N, 110°16′12.64″E], alt. 225 m, 15 November 2016, J.J. Wynne (Ps.-MHBU-GX16121501).

Diagnosis.—Troglomorphic habitus; carapace without eyes or eyespots; epistome triangular and small; carapace with 8 setae on posterior margin; pedipalp smooth excepted for femur which is finely granular in basal part; pedipalp slender, both chelal fingers with 108–109 teeth; femur 5.20 times (length 2.29), patella 4.30 times (length 2.28) longer than broad, pedicel about half of total length of patella.

Description.—Female. Carapace, chelicerae and pedipalps reddish brown; abdomen and legs yellowish.

Carapace: Smooth, 1.16 times longer than broad, with a total of 34 setae, including 6 on anterior margin and 8 on posterior margin; without eyes or eyespots; epistome very small, triangular.

Chelicera: Hand with 7 setae, movable finger with one submedial seta; fixed finger with 10 teeth; movable finger with 14 teeth. Galea replaced by a small rounded transparent spinneret. Rallum with 8–9 pinnate setae, distal rallum without expanded base.

Pedipalps: Apex of coxa rounded, with 4 setae on each side. Femur with granulations basally, patella smooth, chelal hand

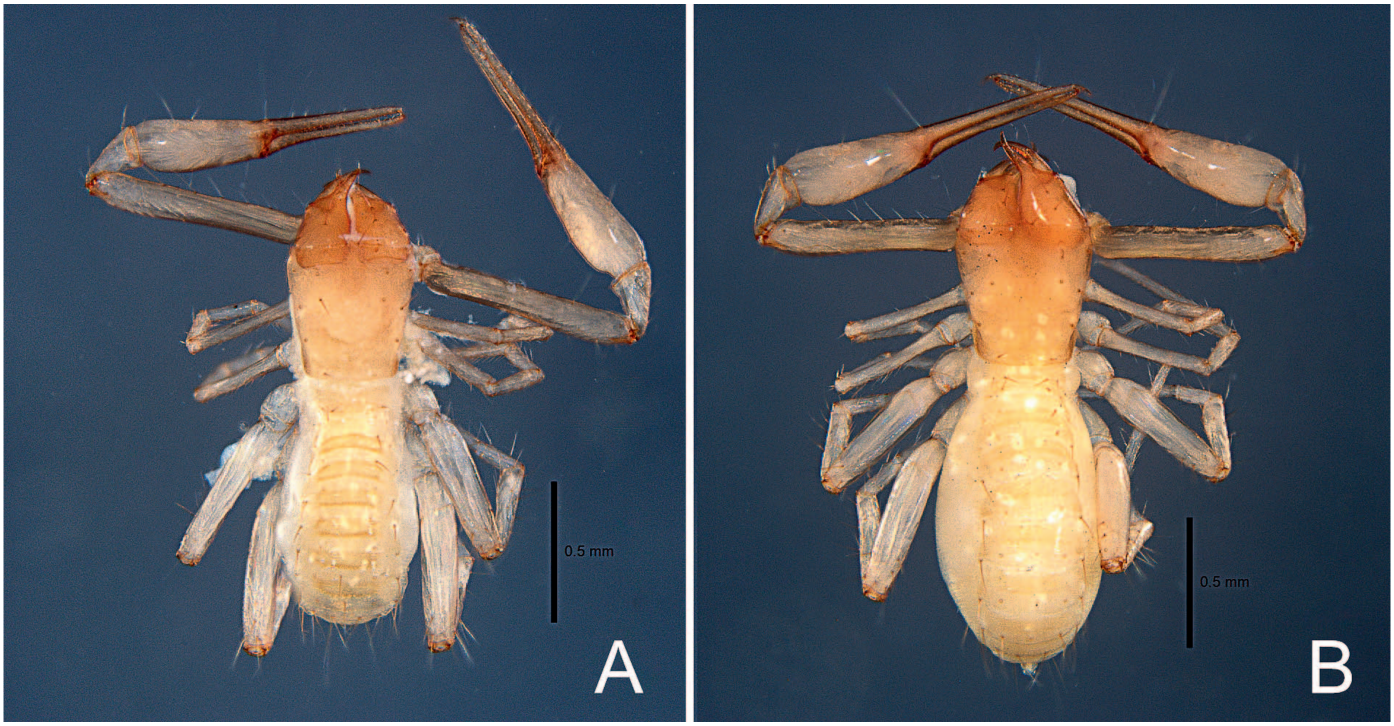

Figure 4.—*Tyrannochthonius chixingi* sp. nov., A. Male holotype, dorsal view; B. Female paratype, dorsal view.

with fine granulations on medial face. Trochanter 2.73, femur 5.20, patella 4.30, chela (with pedicel) 4.75, chela (without pedicel) 4.24 times longer than wide, movable finger 1.38 times longer than hand (without pedicel). Fixed chelal finger with 8 trichobothria, movable finger with 4, *eb* and *esb* on lateral margin of hand; *ib*, *isb* and *ist* on basal half, *et* and *it* on distal half, *est* almost on the middle of fixed finger; *t* and *st* on distal half, *sb* and *b* on basal half of movable finger. Venom apparatus present only in fixed chelal finger, venom duct short. Fixed chelal finger with 109 teeth, movable finger with 108 teeth.

Abdomen: Pleural membrane granulated. Tergal chaetotaxy (I–XI): 11: 11: 11: 11: 13: 12: 12: 13: 12: 15: 8; sternal chaetotaxy (IV–XI): 8: 15: 16: 14: 15: 14: 11: 7; stigmata with 5–6 setae around; anal cone with 2 dorsal and 2 ventral setae. Female genitalia: sternite II with 3–4 setae on each side and a row of 6 setae on the posterior margin; sternite III with a row of 8 setae on the posterior margin.

Legs: Leg I and Leg IV typical. Tibia IV with one submedial tactile seta (TS=0.43), basitarsus IV with one basal tactile seta (TS=0.14), telotarsus IV with one tactile seta (TS = 0.37). Subterminal tarsal seta bifurcate; arolium not divided, shorter than the slender and simple claws.

Measurements: (length/breadth or depth in mm; ratios for most characters in parentheses). Female. Body length 3.63. Carapace 1.16 (1.47/1.27). Pedipalpal trochanter 2.73 (1.23/0.45), femur 5.20 (2.29/0.44), patella 4.30 (2.28/0.53), chela (with pedicel) 4.75 (3.75/0.79), chela (without pedicel) 4.24 (3.35/0.79), hand length (without pedicel) 1.41, movable finger length 1.94 (1.38 times longer than hand without pedicel). Leg I: trochanter 1.41 (0.41/0.29), femur 3.93 (1.06/0.27), patella 3.27 (0.72/0.22), tibia 6.69 (1.07/0.16), basitarsus 3.38 (0.44/0.13), telotarsus 5.38 (0.70/0.13). Leg IV: trochanter 2.14 (0.62/0.29), femur + patella 3.91 (1.80/0.46), tibia 7.61 (1.75/0.23), basitarsus 2.83 (0.51/0.18), telotarsus 5.38 (0.86/0.16).

Remarks.—*Bisetocreagris maomaotou* is a cave-adapted member of the genus, whose pedipalpal pedicel on the patella is about half as long as patella (or about the same length as club). The new species resembles *B. chinacavernicola* but is distinguished by the complete lack of eyes or eyespots (*B. chinacavernicola* has a single small eyespot without lens on each side), epistome triangular (rounded in *B. chinacavernicola*) and the female pedipalpal femur 5.20 times longer than broad (5.7 times in *B. chinacavernicola*), patella 4.30 times longer than broad (4.75 times in *B. chinacavernicola*; Schawaller 1995).

Bisetocreagris maomaotou also resembles *B. cavernarum,* but once again, *B. maomaotou* lacks eyes or eyespots; *B. cavernarum* has four eyes and the anterior two have indistinct lenses, the posterior eyes reduced; *B. maomaotou* has a triangular and small epistome, while the epistome is absent in *B. cavernarum*; the new species may be further distinguished from *B. cavernarum* by the stouter pedipalpal femur (in *B. maomaotou*: femur 5.2, chela with pedicel 4.75 times longer than broad, in *B. cavernarum*: femur 5.80, chela with pedicel 5.3–5.4 times longer than broad; Mahnert & Li 2016).

Etymology.—The name, a noun in apposition, refers to Maomaotou cave – the type locality where this species occurs.

Family Chthoniidae Daday, 1888
Tyrannochthonius Chamberlin, 1929
Tyrannochthonius Chamberlin 1929:74.
Parachthonius Caporiacco 1949:317.
Paraliochthonius (Pholeochthonius) Beier 1976:209.

Type species.—*Tyrannochthonius*: *Chthonius terribilis* With, 1906, by original designation.

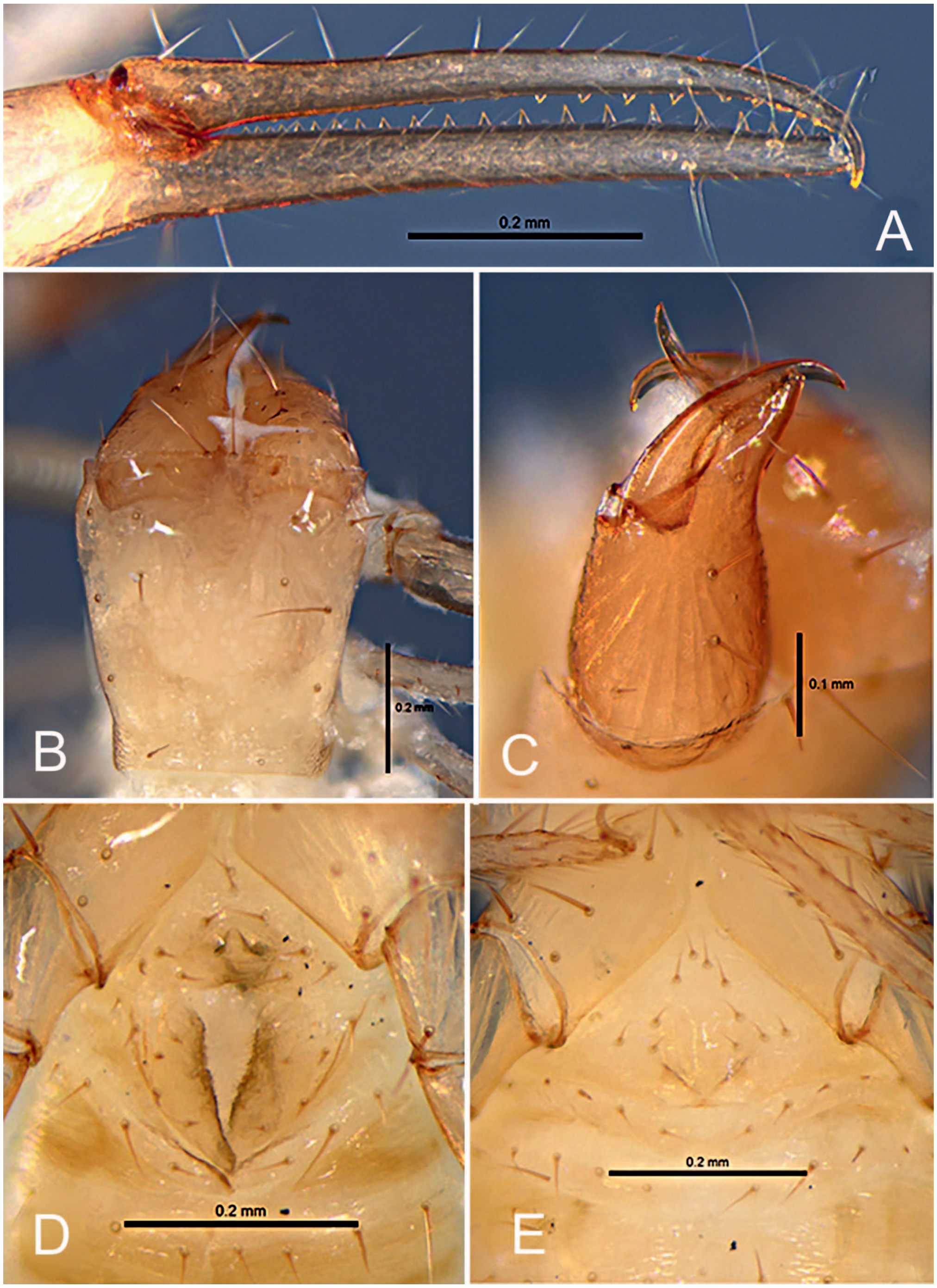

Figure 5.—*Tyrannochthonius chixingi* sp. nov., holotype male (A–D), female paratype (E): A. Chelal fingers (lateral view); B. Carapace (dorsal view); C. Left chelicerae (dorsal view); D. Male genital (ventral view); E. Female genital (ventral view).

Parachthonius: *Parachthonius meneghettii* Caporiacco, 1949, by monotypy.

Paraliochthonius (Pholeochthonius): *Paraliochthonius (Pholeochthonius) cavernicola* Beier, 1976, by original designation.

Remarks.—*Tyrannochthonius* is a globally distributed genus occurring primarily in tropical and subtropical regions. It represents one of the largest chthoniid genera with about 140 recognized species (Edward & Harvey 2008). Of these, seven species (including the one described below) and one subspecies are known from China including four troglomorphic species (Mahnert 2009; this study).

Tyrannochthonius chixingi sp. nov.
http://zoobank.org/?lsid=urn:lsid:zoobank.org:act:27F8FCC8-5F74-4AD0-8D81-6DA23309F55C
Figs. 4–6

Type material.—*Holotype male:* **China:** *Guangxi Zhuang Autonomous Region:* Xiufeng District, Maomaotou cave, deep

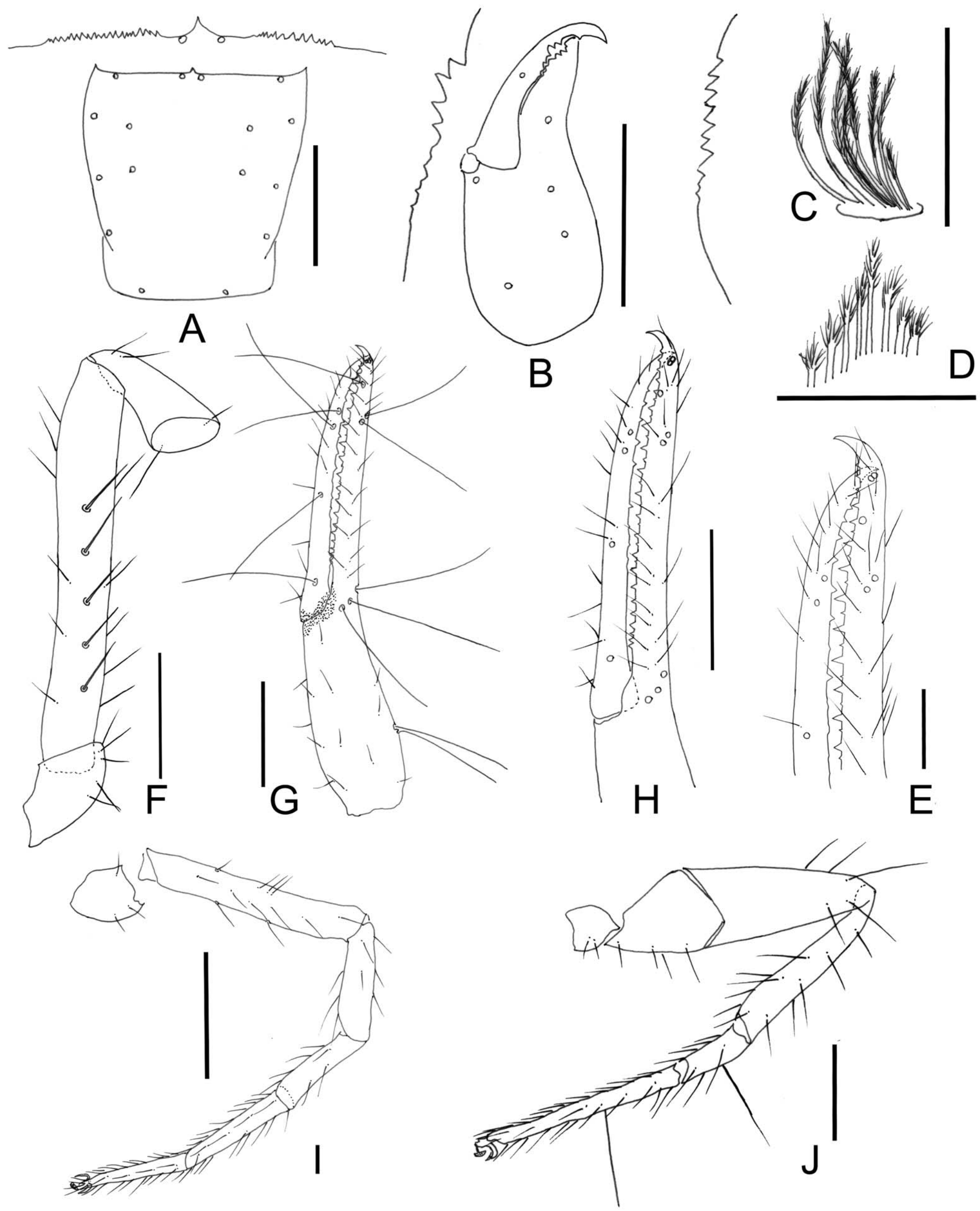

Figure 6.—*Tyrannochthonius chixingi* sp. nov., holotype male: A. Carapace (dorsal view); B. Left chelicerae (dorsal view); C. Rallum; D. Coxal spines on coxae II (ventral view); E. Finger tips of chela (lateral view); F. Left pedipalp (minus chela, dorsal view); G. Left chela (lateral view); H. Chelal fingers (lateral view, showing the teeth); I. Leg I (lateral view); J. Leg IV (lateral view). Scale bars: 0.10 mm (C–E); 0.25 mm (A–B, F–J).

zone, [25°18′46.12″, 110°16′12.64″], alt. 225 m, 15 November 2016, J.J. Wynne (Ps.-MHBU-GX16121502).

Paratypes: **China:** *Guangxi Zhuang Autonomous Region:* 1 ♂, 1 ♀, collected with holotype (Ps.-MHBU-GX16121503–GX16121504).

Diagnosis.—Moderately sized troglomorphic species; carapace without eyes or eyespots, anterior margin toothed, posterior margin with 2 setae, epistome very pointed and small; anterior tergites (I–II) with 4 setae; intercalary teeth only present on chelal fixed finger, movable finger with 6–7 teeth; lacking chemosensory setae on dorsum of chelal hand.

Description.—Adult male.

Colour: Generally pale yellow, chelicera and pedipalp slightly darker, soft parts pale.

Chelicera: Five setae on hand, all setae acuminate; movable finger with one medial seta; fixed finger and movable finger with nine teeth; galea represented by a very slight bump on movable finger; rallum consisting of 7–8 blades, the most anterior blade slightly denticulate, other blades long and well bipinnate.

Pedipalp: All setae acuminate; femur 5.54–6.15, patella 2.14–2.38, chela 5.55–5.74, hand 2.35–2.53 times longer than broad; movable finger 1.27–1.36 times longer than hand, without large basal apodeme (Fig. 6G), only slightly sclerotized section is present; Fig. 6H shows complete teeth.

Femur without tactile setae. Fixed chelal finger and hand with eight trichobothria, movable chelal finger with four trichobothria: *ib* and *isb* situated close together, medially on dorsum of chelal hand; *eb*, *esb* and *ist* forming a straight oblique row sublaterally at base of fixed chelal finger; *it* slightly distal to *est*, situated subdistally; *et* slightly near to tip of fixed finger, very close to chelal teeth; *xs* situated distal to *et*, each seta obviously smaller than those of other trichobothria; microsetae (chemosensory setae) absent on both pedipalpal fingers; trichobothrium *st* of movable finger situated close to the base; *sb* situated slightly closer to *b* than to *st*; *b* and *t* situated subdistally, *t* situated at same level as *it*; *b* situated basal to *est*. Sensilla and venom apparatus absent. Chelal teeth heterodentate: fixed finger with 22–23 large, erect, well-spaced teeth, plus 9 small intercalary teeth; movable finger with 6–7 middle sized well-spaced smooth teeth, without intercalary teeth.

Cephalothorax: Carapace 1.11–1.14 times longer than broad; anterior margin toothed; lateral margins constricted posteriorly; without any traces of eyes; epistome very pointed and small; with 16 setae arranged 4: 4: 4: 2: 2; without furrows. Chaetotaxy of coxae: 4: 4: 4: 5; manducatory process with two acuminate distal setae, anterior seta less than 1/2 length of medial seta; coxae II with seven terminally incised coxal spines on each side, set in oblique row; intercoxal tubercle absent; without sub-oral seta.

Abdomen: Pleural membrane papillostriate. Tergites and sternites undivided; setae uniseriate and acuminate. Tergal chaetotaxy (I–XI): 4: 4: 4: 4: 4: 4: 4: 5: 5: 4: 2. Sternal chaetotaxy V–XI: 6: 6: 6: 6: 8: 8:2.

Legs: Typical. Femur + patella of leg IV 3.14–3.35 times longer than broad; arolium slightly shorter than the claws, not divided; claws simple.

Measurements: (length/breadth or depth in mm, ratios for most characters provided in parentheses). Male holotype and paratype: Body length 1.24–1.30. Pedipalps: trochanter 1.62–1.92 (0.21–0.23/0.12–0.13), femur 5.54–6.15 (0.72–0.80/0.13), patella 2.14–2.38 (0.30–0.31/0.13–0.14), chela 5.55–5.74 (1.09–1.11/0.19–0.20), hand length 2.35–2.53 (0.47–0.48/0.19–0.20), movable finger length 0.61–0.64. Carapace 1.11–1.14 (0.49–0.50/0.43–0.45). Leg I: femur 7.00–7.50 (0.42–0.45/0.06), patella 4.00–4.50 (0.24–0.27/0.06), tibia 3.67–4.00 (0.20–0.22/0.05–0.06), tarsus 8.40–9.40 (0.42–0.47/0.05). Leg IV: femur + patella 3.14–3.35 (0.67–0.69/0.20–0.22), tibia 5.67 (0.51/0.09), basitarsus 3.33–3.83 (0.20–0.23/0.06), telotarsus 11.00–13.25 (0.53–0.55/0.04–0.05).

Female paratype: Body length 1.64. Pedipalps: trochanter 1.86 (0.26/0.14), femur 6.69 (0.87/0.13), patella 2.00 (0.34/0.17), chela 5.39 (1.24/0.23), hand length 2.26 (0.52/0.23), movable finger length 0.72. Carapace 1.04 (0.56/0.54). Leg I: femur 6.25 (0.50/0.08), patella 3.86 (0.27/0.07), tibia 4.00 (0.24/0.06), tarsus 11.00 (0.55/0.05). Leg IV: femur + patella 3.30 (0.76/0.23), tibia 6.33 (0.57/0.09), basitarsus 2.63 (0.21/0.08), telotarsus 11.40 (0.57/0.05).

Remarks.—All Chinese cave-dwelling *Tyrannochthonius* species lack eyes or eyespots (Mahnert 2009; this study). The new species resembles *T. ganshuanensis* but can be distinguished by the toothed anterior margin of carapace (not toothed in *T. ganshuanensis*); movable finger of pedipalp without intercalary teeth in the new species, while present in *T. ganshuanensis*; the tergal chaetotaxy on anterior tergites is also different (tergites I–III with four setae in the new species, while only two in *T. ganshuanensis*; Mahnert 2009).

Tyrannochthonius chixingi shares the character of anterior tergites with four marginal setae with *T. antridraconis* but is differentiated by the slightly wider pedipalps (e.g., femur 6.69 times vs. 7.3–7.8 times, patella 2.0 times vs. 2.20–2.60 times, chela 5.39 vs. 7.9–8.0 times longer than broad in males). This animal seems to be further distinguished from *T. antridraconis* by a smaller body size (*T. chixingi* males range from 1.24 to 1.30 and the female specimen is 1.64, while *T. antridraconis* is at least 1.80; Mahnert 2009).

Etymology.—This species name, *chixingi*, was derived from the Latinized Mandarin phrase for "toothed." *Chǐ xíng* (齿形) refers to the toothed anterior margin of the carapace.

DISCUSSION

The low number of cave-dwelling pseudoscorpions in southern China is potentially more reflective of limited biospeleological research rather than low diversity within this group. With the descriptions of the first known cave-adapted pseudoscorpions from Guangxi, we increase the total number of southern China cave-adapted pseudoscorpions to 19 species. Most of these species (14 of 19) were detected in only one cave (Table 1). Given our limited knowledge of regional cave biology (Chen et al. 2001; Clarke 2006; Whitten 2009) and that their type localities were either not sampled intensively or field sampling methodologies were not provided, we are unable to draw strong inference concerning whether any of these species may be reasonably considered single cave endemics.

While the Guangxi pseudoscorpions currently known only from their type locality may also occur in other regional caves, it is improbable they are wide-ranging species. In general, troglomorphic species are well documented as being either single endemics or having small distributional ranges (Christman et al. 2005; Deharveng et al. 2008; Latella & Chen 2008; Tian 2011; Borges et al. 2012; Harvey & Wynne 2014). Wynne (unpublished data) found that of the 99 known, cave-adapted arthropods for Guangxi, over half (or 58 species) were identified from one cave. Interestingly, in the eastern United States, Christman et al. (2005) found Pseudoscorpionida retained the highest rate of single-cave endemism (69%) across the arthropod groups examined.

Concerning other caves where these species may occur, there are at least seven caves within a 5 km radius of Maomaotou Cave (Y. Zhang, personal communication, 2017). Three of these caves occur within the same tower karst formation (Maomaotou Hill) but were not surveyed because they did not meet our study site selection criteria. We suggest these two new species likely occur throughout Maomaotou Hill within the subterranean network of interconnected fissures ranging in size from microcaverns (< 0.1 cm) to macrocaverns (> 20 cm; Howarth 1983), and thus may have once occurred within these three caves when habitat conditions were suitable.

Based upon extensive human activities in one cave and expert opinion describing environmental conditions of the other two caves, we deduced it is unlikely that troglomorphic organisms presently occur within these caves. Reed Flute Cave has been a popular tourist cave since the 1980s and has been significantly modified for tourism (E. Lynch, personal communication, 2017). Modifications include lighted and paved concrete walking pathways, colored lighting to illuminate speleothem formations, and excavation of a second entrance, which have likely altered airflow and relative humidity. Additionally, increased cave temperatures have been correlated with intensive human visitation (Pulido-Bosch et al. 1997; Song et al. 2000; Fernandez-Cortes et al. 2011).

The other two caves are relatively small through caves (i.e., tunnel caves; Zhu et al. 1988). One is located at the base of the hill approximately 0.5 km north by northeast of Maomaotou Cave, and is ~100 m in length with a small side passage (~80m in length). The second cave is ~300 m in length. Airflow has been observed in both of these caves (Y. Zhang, personal communication, 2017), and were excluded from survey because the climatic conditions seemed too variable to support deep zone conditions.

Maomaotou Hill is surrounded by human activities. It is likely that agricultural and rural activities in this region span millennia. Today, urban development sprawls to the south and east, and agriculture, suburban areas and rural village habitation occur to the north and west. Subsequently, these two new cave-adapted pseudoscorpion species may have been restricted to this limestone formation for thousands of years.

To obtain a better understanding of these species' distributional ranges, we recommend additional arthropod surveys be conducted at the seven regional caves within a 5 km radius of Maomaotou Cave. Such an effort will be required to help constrain whether these species are single-cave or regional endemics, as well as to obtain the information necessary to make science-based recommendations for conservation and management. However, because our two species are cave-adapted and thus endemic, we consider these species to be of management concern.

We have limited information regarding the cave-dwelling arthropod community within which these two species occur. Through better characterizing this community, researchers and managers may elucidate the pseudoscorpions' role in the community, as well as better define the distribution of these two species within Maomaotou Cave based upon the distributions of suitable habitat and potential prey species. As our sampling was temporally constrained (2 people at ~ 4 hours) during one site visit and employed a single technique, we suggest applying multiple techniques with multiple site visits conducted during the appropriate time of year to garner a more comprehensive picture of the cave arthropod community (Wynne & Voyles 2014; Wynne et al. 2018). If this is not possible, we minimally suggest the deep zone of Maomaotou Cave be intensively and systematically sampled using baits (Howarth et al. 2007), leaf-litter traps (Slaney & Weinstein 1996), and direct intuitive searches using a similar sampling protocol proposed by Wynne et al. (2014) and Wynne et al. (2018).

Conservation and management.—These two new pseudoscorpion species are presumed to have restricted distributional ranges and are subsequently sensitive to human disturbance. Presently, there are no cave management strategies in place to mitigate impacts associated with trampling by human visitation, surface contamination or other human activities. Although we did not observe a significant amount of litter within this cave, we did observe trampled areas associated with recent visitation. Additionally, this cave is well known as evidenced by the old Mandarin inscriptions believed to be at least 100 years old and contemporary graffiti along the cave walls, as well as garbage both around the entrance and along the trail leading to the cave. Given that future human activity will probably intensify rather than diminish, increased human visitation is anticipated to further challenge the persistence of these species, the arthropod community within which they occur, and the other sensitive cave biological resources occurring within this cave.

Regarding other human impacts, this cave is situated at a slightly higher elevation than human development, so it may be partially insulated from human activities including runoff associated with fertilizer and pesticide use, siltification from vegetation conversion and agriculture, and other related human activities.

Finally, an earlier attempt was made to restrict human access as evidenced from a now dilapidated cave gate. While gates can be effective in deterring some of the proximal effects of human activities (inadvertently trampling arthropod habitats, contamination including spray paint used for graffiti, etc.) and repairing the gate is advisable, an outreach program to educate both villagers and visitants regarding the sensitive biological resources within the cave should also be considered. The local karst research institute in Guilin could possibly host a meeting in the Yujiacun village (the village below the cave) to discuss these new discoveries and stress the sensitivities of cave-restricted animal populations to human disturbance. Additionally, we recommend establishing an educational display on the sensitivities of cave-adapted animals and the threats human activities pose at the Reed Flute Cave Visitor's Center. We further suggest posting signage within the village and at Maomaotou cave entrance describing the sensitivity of cave resources, the presence of sensitive endemic species, and cave etiquette protocols describing how to reduce human impacts. Through both additional research and the management recommendations elucidated here, we may be able to make strides towards evidence-based conservation and management including the protection of Chinese cave-adapted animal populations such as the Maomaotou pseudoscorpions.

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