

# Scleractinian corals (Fungiidae, Agariciidae and Euphylliidae) of Pulau Layang-Layang, Spratly Islands, with a note on *Pavona maldivensis* (Gardiner, 1905)

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## Abstract

Layang-Layang is a small island part of an oceanic atoll in the Spratly Islands off Sabah, Malaysia. As the reef coral fauna in this part of the South China Sea is poorly known, a survey was carried out in 2013 to study the species composition of the scleractinian coral families Fungiidae, Agariciidae and Euphylliidae. A total of 56 species was recorded. The addition of three previously reported coral species brings the total to 59, consisting of 32 Fungiidae, 22 Agariciidae, and five Euphylliidae. Of these, 32 species are new records for Layang-Layang, which include five rarely reported species, i.e., the fungiids *Lithophyllon ranjithi*, *Podabacia sinai*, *Sandalolitha boucheti*, and the agariciids *Leptoseris kalayaanensis* and *L. troglodyta*. The coral fauna of Layang-Layang is poor compared to other areas in Sabah, which may be related to its recovery from a crown-of-thorns seastar outbreak in 2010, and its low habitat diversity, which is dominated by reef slopes consisting of steep outer walls. Based on integrative molecular and morphological analyses, a *Pavona* variety with small and extremely thin coralla was revealed as *P. maldivensis*. Since specimens from Sabah previously identified as *P. maldivensis* were found to belong to *P. explanulata*, the affinities and distinctions of *P. maldivensis* and *P. explanulata* are discussed.

**Keywords**

Scleractinia, South China Sea, Malaysia, atoll, distribution ranges, new records, species richness

**Introduction**

Pulau [island] Layang-Layang is a small island standing 2 m high on the southeast rim of a reef known as Swallow Reef (Hancox and Prescott 1995). The reef is an atoll situated at the southern edge of the Spratly Islands in the South China Sea, approximately 300 km northwest of Kota Kinabalu, Sabah, Malaysia. Layang-Layang was reported to have one of the best reefs in East Malaysia in terms of coral cover and diversity and fish life (Ismail et al. 1998; Pilcher and Cabanban 2000).

Being remote, the reef was regarded to be in pristine condition (Pilcher et al. 1999; Pilcher and Cabanban 2000; Zainuddin et al. 2000), although it had experienced disturbances in the past years. In the 1980s, reclamation work was carried out to accommodate a military base, and in the 1990s the island was further extended to construct an airstrip, a resort and a seawall. For the latter developments, coral and sand were mined from the lagoon for building material. A comparative study in 1993 and 1998 showed that the impact of the development on the reef was most evident in the lagoon, with a reduction on live coral cover from 29% to 10% (Mohamed et al. 1994; Zakariah et al. 2007). The outer reefs were not affected by the construction development, except at sites immediate to the island. Here the coral cover averaged 48% at 5 m and 34% at 10 m depth in 1993 (Mohamed et al. 1994). At subsequent independent surveys from 1996 to 1999 in four outer reef sites, mean live coral cover was 73% at 5 m and 58% at 10 m depth (Pilcher and Cabanban 2000).

A massive coral bleaching event during the 1997–98 El Niño event had also affected the reefs of Layang-Layang. Up to 40% of the coral colonies at less than 10 m depth and 25% at 10–20 m depth were bleached at 55 monitoring sites, but by 1999 the corals had recovered or were overgrown with zoantharians and soft corals (Pilcher and Cabanban 2000).

A recent calamity to confront the reefs was an outbreak of the crown-of-thorns (COT) seastar, *Acanthaster planci* (Linnaeus, 1758), in July 2010. During a 3-day survey, densities of 1,011 COTs were counted in a 7,000 m<sup>2</sup> reef area over eight sites, which corresponds to over 1,400 individuals per ha with dominant size class of 21–30 cm (Nasrulkhikim et al. 2010). During the time of the survey, reefs in the southwest of the atoll were badly damaged and had dead corals covered by algae. Although damage to the reefs was not quantified, it was noted that COT had started to infest the reefs in the northwest of the atoll and coral mortality was not as extensive as compared to the reefs in the southwest (Nasrulkhikim et al. 2010).

While several short research expeditions and surveys have been carried out to collect baseline information on the marine biodiversity of Pulau Layang-Layang (Zakariah et al. 2007), only one checklist of hard coral species is available as reference, with over 140 species reported by Ridzuan et al. (n.d.) cited in Pilcher and Cabanban (2000) (pp

46–47, Suppl. material VI). In the present study, we aim to update the species list of the hard coral families *Fungiidae*, *Agariciidae* and *Euphylliidae* in Layang-Layang, as similarly done for the reefs of Sabah, Malaysia (Waheed and Hoeksema 2013, 2014). These families, together consisting of ~100 species, were selected as a proxy for scleractinian reef coral diversity, as they can be found in a variety of reef habitats and in a wide geographical range within the Indo-Pacific (Veron 2000). At the time of the survey, small, thin and encrusting corals thought to belong to an unknown *Pavona* species were encountered. Several specimens that were collected for closer inspection of corallite morphology appeared to match with *Pavona maldivensis* (Gardiner, 1905) despite the unusual growth form of the corallum. For verification, a comparison was made between these *P. maldivensis* specimens and those collected from other localities including its type locality in the Maldives. Samples of *P. explanulata* (Lamarck, 1816) closely resembling *P. maldivensis* were also examined in order to better define the boundaries between these two species.

## Methods

### Physical setting

Pulau Layang-Layang (7°22'20"N, 113°50'30"E) measures approximately 1,500 m × 200 m (Google Earth 2013). The only infrastructures on the island are buildings of the Royal Malaysian Navy base, the Marine Research Station Layang-Layang (MARSAL) of the Fisheries Department and the Avillion Layang-Layang Resort. An airstrip runs alongside these establishments. The atoll is somewhat oval in shape situated in a SW-NE axis and measures approximately 7 km long and 2 km wide. Its rim is formed by a ring of 13 shallow reefs, which covers an area of over 4 km<sup>2</sup> (Musa et al. 2006). The reef circumference is almost 17 km with a sandy cove at the western end and it encloses a shallow lagoon with a maximum depth of 20 m (Pilcher et al. 1999, Sahari et al. 2004, Svrucula 2008). The reefs rise to sea level from around 1,500 m depth forming steep outer reef walls (see Hutchison and Vijayan 2010). The north and northeast reef slopes have a more gradual profile to depths of 20–25 m before plunging down steeply, as compared to the reefs in the south and southwest where the reefs form vertical walls.

Water parameters were measured at 10 m depth of each survey site (Suppl. material 1). The water temperature ranged 28.4–30.0 °C, with a salinity range of 30.1–31.2 ppt. Temperature and salinity measurements were slightly higher in July 2002 (see Ku Yaacob and Ibrahim 2004) in comparison to our readings in March 2013.

Layang-Layang in the South China Sea is influenced by the monsoon system (see Wyrтки 1961). The northeast monsoon dominates between November to March and the southwest monsoon prevails from May to September (Saadon et al. 1999, Morton and Blackmore 2001, Ku Yaacob and Ibrahim 2004, Akhir 2012) while the transitional periods are in April and October (Saadon et al. 1999). The surface current patterns are characterised by the monsoonal system (Akhir 2012). The northeast monsoon causes an anticlockwise circulation pattern in the South China Sea, creating a southwesterly

current from the northern rim of the sea, which either departs via the Karimata Straits or turns northeasterly along the west coast of Borneo (East Malaysia) and Palawan, whereas the southwest monsoon reverses the current direction, driving a northward current in the central South China Sea while creating a clockwise gyre above the Spratly Islands (Wyrтки 1961, Morton and Blackmore 2001). The rainy season occurs during the northeast monsoon and due to unpredictable weather Layang-Layang is not accessible for diving. The diving season lasts from March to September annually.

### Field sampling

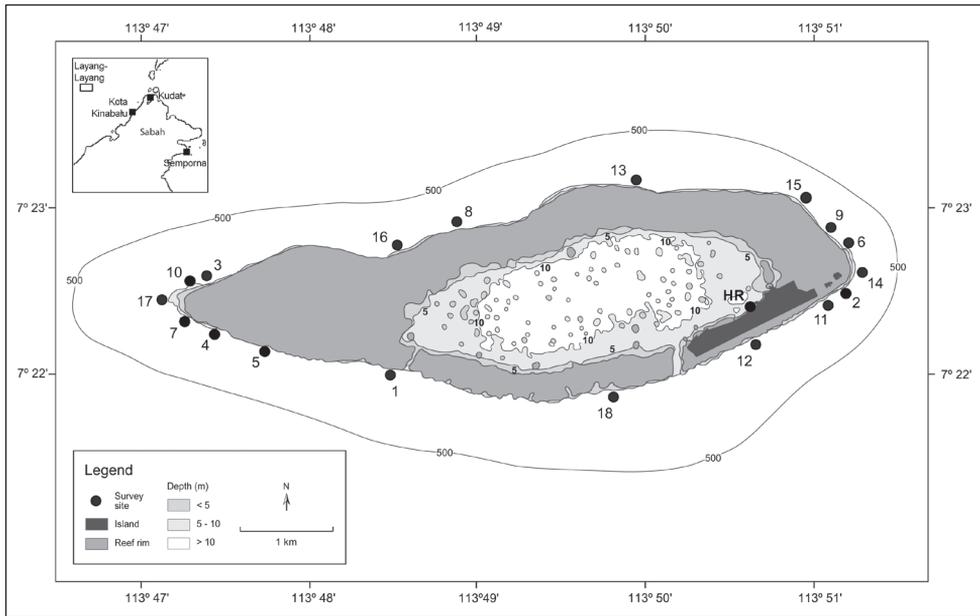
Fieldwork was carried out 24–30 March 2013 on the reefs of Layang-Layang. Due to safety issues, surveys were confined to dive sites designated for tourism around the atoll. A total of 18 sites was surveyed on the outer slope of the reef wall from a maximum depth of 40 m to the shallow reef crest of 1 m using the roving diver technique (Schmitt et al. 2002) (Figure 1, Table 1). An additional dive was made at the House Reef (10 m maximum depth) off the resort jetty (7°22'23"N, 113°50'37"E). A checklist of the coral families Fungiidae (sensu Gittenberger et al. 2011, Benzoni et al. 2012a), Agariciidae and Euphylliidae (sensu Veron 2000) was made for each site with photo documentation of each species. Specimens that could not be identified *in situ* were collected for further examination and are kept at the Borneo Marine Research Institute reference collection, Universiti Malaysia Sabah (UMS) in Kota Kinabalu.

Coral specimens were identified by referring to taxonomic literature (Dinesen 1980, Veron and Pichon 1980, Hoeksema 1989, 2012a, 2012b, 2014, Veron 2000, Ditlev 2003, Licuanan and Aliño 2009, Gittenberger et al. 2011, Benzoni et al. 2012a). Recent molecular studies have led to taxonomic revisions of many scleractinian corals, including the families Agariciidae and Euphylliidae (sensu Veron 2000). The genera *Coeloseris*, *Pachyseris*, *Catalaphyllia*, *Nemenezophyllia*, *Physogyra* and *Plerogyra* are now classified *incertae sedis* (Fukami et al. 2008, Kitahara et al. 2010, Benzoni et al. 2014). Nevertheless, these genera were included in the checklist for comparison with similar studies previously conducted around Sabah (Waheed and Hoeksema 2013, 2014, Waheed et al. *subm.*).

Specimens of a thin morph of *P. maldivensis* were collected and small fragments were preserved in 95% absolute ethanol for molecular analyses. The specimens were bleached with sodium hypochlorite, rinsed, air-dried and small fragments were taken for morphological examination. The remaining coralla of these specimens are kept in the dry reference collection of the Borneo Marine Research Institute, UMS.

### Further examination of *Pavona* corals

Seven samples of *P. maldivensis* corals collected from Layang-Layang and samples from Banggi, North Sabah (n=1), Ternate, Indonesia (n=1), New Caledonia (n=2) and the



**Figure 1.** Research area at Pulau Layang-Layang, Spratly Islands. Survey sites are numbered 1-18, and HR for the House Reef. Depth contours are indicated in metres (smaller font). For a complete georeferenced list of localities and depths of survey sites, see Table 1.

**Table 1.** Locality data of survey sites at Pulau Layang-Layang, Spratly Islands.

Site	Site name	Latitude (N)	Longitude (E)	Date	Max. depth (m)
1	Snapper Ledge	07°22.048	113°48.467	24/03/2013	31.8
2	Dogtooth Lair	07°22.470	113°51.100	24/03/2013	30.7
3	Wrasse Strip	07°22.557	113°47.397	25/03/2013	30.3
4	Shark Cave 1	07°22.279	113°47.457	25/03/2013	32.6
5	D'Wall	07°22.191	113°47.701	25/03/2013	33.8
6	Gorgonian Forest	07°22.710	113°51.218	26/03/2013	37.9
7	Shark Cave 2	07°22.323	113°47.321	26/03/2013	27.9
8	Crack Reef	07°22.876	113°48.910	26/03/2013	29.3
9	Coral Café	07°22.773	113°51.144	27/03/2013	38.5
10	Wrasse Strip 2	07°22.555	113°47.371	27/03/2013	33.5
11	Wreck Point	07°22.407	113°51.032	27/03/2013	33.3
12	Wreck Point 2	07°22.197	113°50.649	28/03/2013	40.4
13	Navigator Lane	07°23.110	113°49.979	28/03/2013	36.8
14	The Point	07°22.573	113°51.254	28/03/2013	34.2
15	Coral Café 2	07°23.013	113°50.912	29/03/2013	36.7
16	Mid Reef	07°22.725	113°48.539	29/03/2013	37.7
17	The Valley	07°22.447	113°47.180	29/03/2013	34.8
18	Runway	07°21.902	113°49.778	30/03/2013	40.3

Maldives (n=2) were used for further molecular and morphological analyses. Samples of *P. explanulata* collected from Banggi, North Sabah (n=1), Ternate, Indonesia (n=2) and Redang, Peninsular Malaysia (n=1) closely resembling *P. maldivensis* were also included. In total, 17 samples were used in the analyses (Suppl. material 2).

## Molecular analyses

Coral samples were sequenced for two markers, namely the mitochondrial intergenic spacer between CO1 and 16S-rRna (IGR for short; Terraneo et al. 2014) and the nuclear internal transcribed spacers 1 and 2 including the 5.8S region (ITS for short; White et al. 1990, Takabayashi et al. 1998). DNA extraction was performed using the DNeasy Blood and Tissue Kit (QIAGEN) following the manufacturer's protocol for animal tissue. The samples were left to incubate overnight. The extracts had concentrations of between 1 to 3 ng/μl for the PCR, quantified using a NanoDrop ND-1000 Spectrophotometer. The PCR mixture was composed of 2.5 μl CoralLoad Buffer (containing 15 mM MgCl<sub>2</sub>), 1.0 μl of each primer (10 pmol), 0.5 μl dNTPs (2.5 mM), 0.5 μl Taq polymerase (15 units/ μl), 18.5 μl of extra pure water and 1.0 μl DNA extract. The primer sequences and PCR amplification details are provided in Table 2. The PCR cycles consisted of an initial denaturation step of 95 °C for 2 min, followed by 39 cycles of 95 °C for 30 s, annealing temperature for 1 min, extension step of 72 °C for 1 min and a final elongation step of 72 °C for 5 min. The PCR products were run on a 1% agarose gel electrophoresis, stained with ethidium bromide and visualized on a Red™ Personal Imaging System. Successfully amplified samples were sent to Macrogen Europe for bidirectional sequencing on an ABI Automated Sequencer 3730xl. The sequences were edited and assembled with Sequencher 4.10.1 and the consensus sequences were blasted against GenBank to check for specific amplification or contamination.

Sequences were aligned on the GUIDANCE server using PRANK algorithm (Penn et al. 2010a, b) and pruned in BioEdit 7.2.5 (Hall 1999). Gaps were treated as missing data. Pairwise genetic differences were calculated as uncorrected p-distance in MEGA 6.06 (Tamura et al. 2013). The most appropriate model of nucleotide substitution based on the Akaike Information Criterion (AIC) as determined in jModelTest 2.1.6 (Darriba et al. 2012) was a three-parameter model a proportion of invariant sites (TPM3uf+I) for IGR and a Kimura two-parameter model with a proportion of invariant sites and gamma distributed rates (K80+I+G) for ITS. Phylogenies were reconstructed separately for each marker and for the concatenated dataset partitioned by genes based on three optimality criteria.

Maximum Likelihood (ML) analyses were carried out in Garli 2.0 (Zwickl 2006) with the default configuration settings. Separate runs were made for searching the ML tree (100 replicates of random addition) and bootstrapping (1000 replicates). The bootstrap consensus tree was visualised with SumTrees 3.3.1 of the DendroPy 3.12.0 package (Sukumaran and Holder 2010) with a majority rule consensus that includes

**Table 2.** Primer pairs, gene region, fragment size, annealing temperature and references of the molecular markers used in this study.

Name	Primer	Gene region	Fragment size	Annealing temp.	Reference
AGAH	GCT TGA CAG GGT TTC CAA GA	COI-1-rRNA intron	~1200	54 °C	Terraneo et al. (2014)
AGAL	CGC ATT GAA ACA CGA GCT TA	COI-1-rRNA intron	~1200	54 °C	Terraneo et al. (2014)
ITS4	CCT CCG CTT ATT GAT ATG C	ITS1-5.8S-ITS2	~700	55 °C	White et al. (1990)
A18S	GAT CGA ACG GTT TAG TGA GG	ITS1-5.8S-ITS2	~700	55 °C	Takabayashi et al. (1998)

branch length information. Maximum Parsimony (MP) analyses were conducted in PAUP\* 4.0a136 (Swofford 2002) using heuristic searches with 100 replicates of random addition with a Tree Bisection and Reconnection (TBR) branch swapping method. Branch support was obtained with 1000 bootstrap replicates to produce a majority rule consensus tree. Bayesian Inferences (BI) were made in MrBayes 3.2.2 (Huelsenbeck and Ronquist 2001, Ronquist and Huelsenbeck 2003, Ronquist et al. 2012), whereby four Markov Chain Monte Carlo (MCMC) of 10 million generations were applied in two runs, saving one tree every 100 generations and discarding the initial 25% of the total trees as burnin. The average standard deviation of split frequencies after 10 million generations was 0.001615 for IGR, 0.001679 for ITS and 0.001840 for the concatenated dataset in the Bayesian analyses. For the mtDNA phylogeny, sequences of *P. maldivensis* and *P. explanulata* available on GenBank (Luck et al. 2013) were included in the analyses. In order to root the trees, the closely related species *Leptoseris foliosa* was selected as outgroup (Benzoni et al. 2012b, Terraneo et al. 2014). Novel sequences were submitted to GenBank (accession numbers KR706116–KR706143).

### Morphological analyses

A subset of the *Pavona* corals was examined under a Leica MZ16 microscope and analysed using scanning electron microscope (SEM). Coral fragments were mounted on SEM stubs using blu-tack and coated with Pd/Au for 8 minutes. Images were taken with a JEOL JSM6490LV scanning electron microscope. Distinguishing characters for species identification include macromorphological features of the corallum and calices as well as micromorphological features of the septocostae, columella and radial elements (terminology according to Dinesen 1980, Budd et al. 2012, Benzoni et al. 2012b). Original species descriptions of *P. maldivensis* and *P. explanulata* as well as descriptions by Wells (1954), Pillai and Scheer (1976), Scheer and Pillai (1983), Veron and Pichon (1980) were used as references.

## Results

### Coral checklist

The number of scleractinian corals recorded in the study area is 56 species with 31 Fungiidae, 22 Agariciidae and three Euphylliidae (Table 3, Figures 2–8, Suppl. material 3). Thirty-two species were not documented from Layang-Layang before and are considered new records (17 Fungiidae, 14 Agariciidae, and one Euphylliidae). Most coral colonies were small in size, making identification difficult for some specimens. Specimens that could not be identified to species level *in situ* include corals of three *Leptoseris* spp. (Figure 9). All were encountered once, except *Leptoseris* sp. 1 at two sites. The House Reef within the lagoon was species-poor in terms of Scleractinia and only one fungiid species, *Danafungia horrida*, was encountered.

Other coral species recorded at Layang-Layang during earlier studies, but not encountered during the present survey are the fungiids *Heliofungia actiniformis* (Quoy & Gaimard, 1833) and *Podabacia crustacea* (Pallas, 1766), the agariciids *Pavona cactus* (Forskål, 1775) and *P. decussata* (Dana, 1846), and the euphylliids *Euphyllia ancora* Veron & Pichon, 1980 and *Plerogyra sinuosa* (Dana, 1846) (Pilcher et al. 1999, Pilcher and Cabanban 2000). The presence of *H. actiniformis* and both euphylliids was verified by images in Pilcher et al. (1999), thus bringing the total species count to 59 (Table 4).

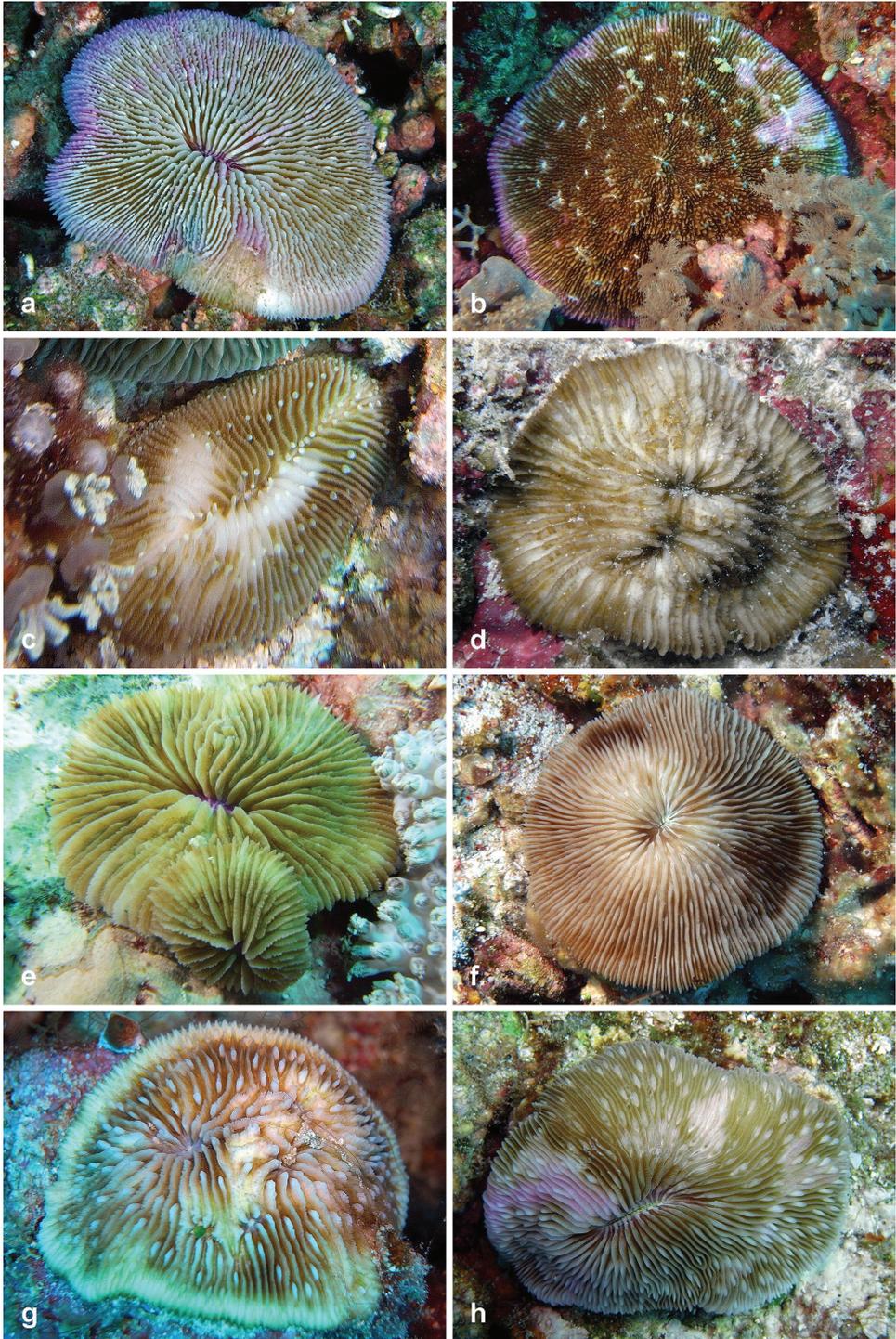
**Table 3.** Checklist of hard coral families Fungiidae, Agariciidae and Euphylliidae from 18 sites at Layang-Layang. Species marked with an asterisk (\*) are now considered *incertae sedis*. The number of sites indicate the species occurrence frequencies. The figure number corresponds with photos in Figures 2 to 8, while a dash (-) denotes no available photo from the surveys. Previous records are indicated as follows: a = Pilcher and Cabanban (2000), b = Abdullah (2005), dash (-) = species not reported before, therefore are considered new records for Layang-Layang.

Family	No.	Species	No. of sites	Figure no.	Previous records
Fungiidae	1	<i>Ctenactis albitentaculata</i> Hoeksema, 1989	1	2a	b
	2	<i>Ctenactis crassa</i> (Dana, 1846)	15	-	b
	3	<i>Ctenactis echinata</i> (Pallas, 1766)	12	-	a
	4	<i>Cycloseris boschmai</i> Hoeksema, 2014	6	2b	-
	5	<i>Cycloseris costulata</i> (Ortmann, 1889)	12	2c	-
	6	<i>Cycloseris cyclolites</i> (Lamarck, 1815)	1	-	-
	7	<i>Cycloseris explanulata</i> (Van der Horst, 1922)	2	2d	-
	8	<i>Cycloseris mokai</i> (Hoeksema, 1989)	6	2e	-
	9	<i>Cycloseris sinensis</i> Milne Edwards & Haime, 1851	1	-	-
	10	<i>Cycloseris tenuis</i> (Dana, 1846)	11	2f	-
	11	<i>Danafungia horrida</i> (Dana, 1846)	13	2g	a
	12	<i>Danafungia scruposa</i> (Klunzinger, 1879)	13	2h	a
	13	<i>Fungia fungites</i> (Linnaeus, 1758)	15	3a	a, b
	14	<i>Halomitra pileus</i> (Linnaeus, 1758)	5	3b	a

Family	No.	Species	No. of sites	Figure no.	Previous records
	15	<i>Herpolitha limax</i> (Esper, 1797)	15	3c	a, b
	16	<i>Lithophyllon concinna</i> (Verrill, 1864)	13	-	-
	17	<i>Lithophyllon ranjithi</i> Ditlev, 2003	7	3d	-
	18	<i>Lithophyllon repanda</i> (Dana, 1846)	17	3e	b
	19	<i>Lithophyllon scabra</i> (Döderlein, 1901)	12	3f	-
	20	<i>Lithophyllon undulatum</i> Rehberg, 1892	4	3g	a
	21	<i>Lobactis scutaria</i> (Lamarck, 1801)	15	3h	b
	22	<i>Pleuractis granulosa</i> (Klunzinger, 1879)	12	4a	-
	23	<i>Pleuractis gravis</i> (Nemenzo, 1955)	5	4b	-
	24	<i>Pleuractis moluccensis</i> (Van der Horst, 1919)	6	4c	a
	25	<i>Pleuractis paumotensis</i> (Stutchbury, 1833)	16	-	-
	26	<i>Podabacia motuporensis</i> Veron, 1990	1	-	-
	27	<i>Podabacia sinai</i> Veron, 2000	1	4d	-
	28	<i>Polyphyllia talpina</i> (Lamarck, 1801)	1	4e	a, b
	29	<i>Sandalolitha boucheti</i> Hoeksema, 2012	2	4f	-
	30	<i>Sandalolitha dentata</i> Quelch, 1884	12	4g	-
	31	<i>Sandalolitha robusta</i> (Quelch, 1886)	9	4h	a, b
	32	<i>Coeloseris mayeri</i> Vaughan, 1918*	3	5a	-
	33	<i>Gardineroseris planulata</i> (Dana, 1846)	7	5b	a
	34	<i>Leptoseris foliosa</i> Dinesen, 1980	5	5c	-
	35	<i>Leptoseris glabra</i> Dinesen, 1980	17	5d	-
	36	<i>Leptoseris hawaiiensis</i> Vaughan, 1907	12	5e	-
	37	<i>Leptoseris incrustans</i> (Quelch, 1886)	9	5f	-
	38	<i>Leptoseris kalayaanensis</i> Licuanan and Aliño, 2009	13	5g	-
	39	<i>Leptoseris mycetoseroides</i> Wells, 1954	18	5h	a
	40	<i>Leptoseris scabra</i> Vaughan, 1907	12	6a	-
	41	<i>Leptoseris solida</i> (Quelch, 1886)	6	6b	-
Agariciidae	42	<i>Leptoseris troglodyta</i> Hoeksema, 2012	1	6c	-
	43	<i>Leptoseris yabei</i> (Pillai and Sheer, 1976)	1	6d	-
	44	<i>Pachyseris rugosa</i> (Lamarck, 1801)*	8	6e	a
	45	<i>Pachyseris speciosa</i> (Dana, 1846)*	6	6f	a
	46	<i>Pavona bipartita</i> Nemenzo, 1980	3	6g	-
	47	<i>Pavona clavus</i> (Dana, 1846)	3	6h	a
	48	<i>Pavona duerdeni</i> Vaughan, 1907	5	7a	-
	49	<i>Pavona explanulata</i> (Lamarck, 1816)	6	7b	a
	50	<i>Pavona maldivensis</i> (Gardiner, 1905)	4	7c	-
	51	<i>Pavona minuta</i> Wells, 1954	6	7d	a
	52	<i>Pavona varians</i> Verrill, 1864	14	7e	a
	53	<i>Pavona venosa</i> (Ehrenberg, 1834)	9	7f	-
Euphylliidae	54	<i>Euphyllia glabrescens</i> (Chamisso & Eysenhardt, 1821)	1	8a	a
	55	<i>Euphyllia paraancora</i> Veron, 1990	1	8b	-
	56	<i>Physogyra lichtensteini</i> Milne Edwards & Haime, 1851*	1	8c	a



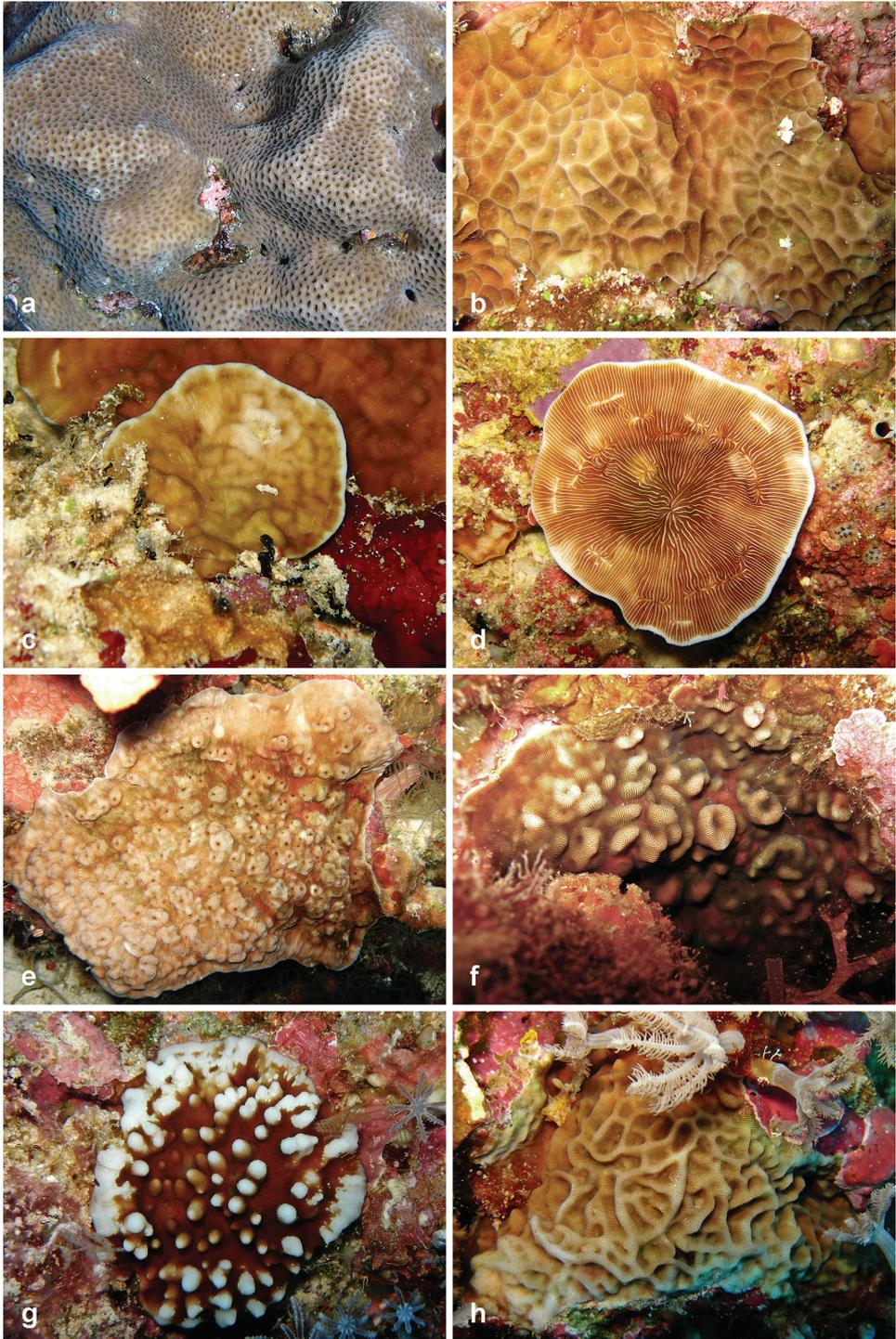
**Figure 2.** Fungiidae recorded at Pulau Layang-Layang in this study. **a** *Ctenactis albitentaculata* **b** *Cycloseris boschmai* **c** *C. costulata* **d** *C. explanulata* **e** *C. mokai* **f** *C. tenuis* **g** *Danafungia horrida* **h** *D. scruposa*.



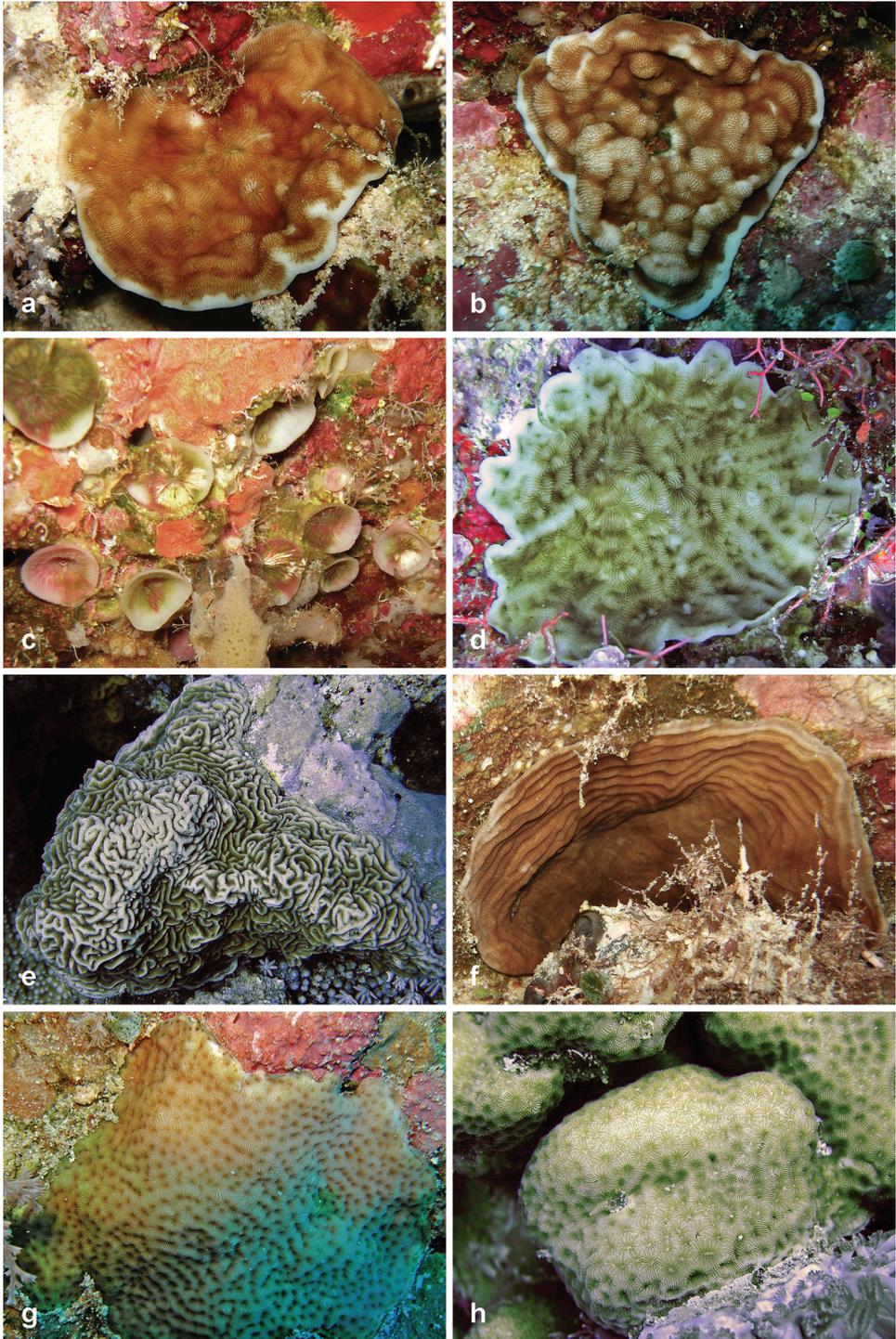
**Figure 3.** Fungiidae recorded at Pulau Layang-Layang in this study. **a** *Fungia fungites* **b** *Halomitra pileus* **c** *Herpolitha limax* **d** *Lithophyllon ranjithi* **e** *L. repanda* **f** *L. scabra* **g** *L. undulatum* **h** *Lobactis scutaria*.



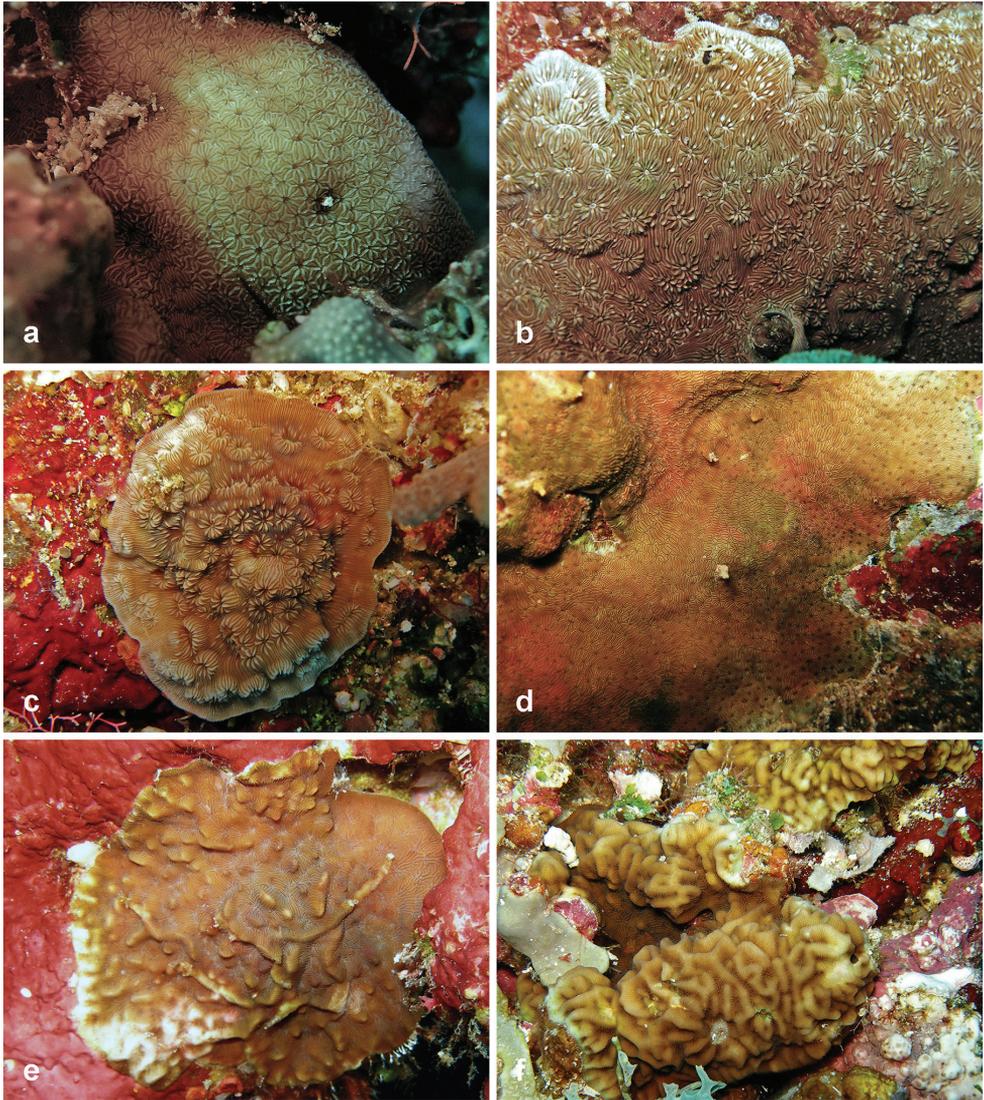
**Figure 4.** Fungiidae recorded at Pulau Layang-Layang in this study. **a** *Pleuractis granulosa* **b** *P. gravis* **c** *P. moluccensis* **d** *Podabacia sinai* **e** *Polyphyllia talpina* **f** *Sandalolitha boucheti* **g** *S. dentata* **h** *S. robusta*.



**Figure 5.** Agariciidae recorded at Pulau Layang-Layang in this study. **a** *Coelosera mayeri* **b** *Gardinerosera planulata* **c** *Leptosera foliosa* **d** *L. glabra* **e** *L. hawaiiensis* **f** *L. incrustans* **g** *L. kalayaanensis* **h** *L. mycetoseroides*.



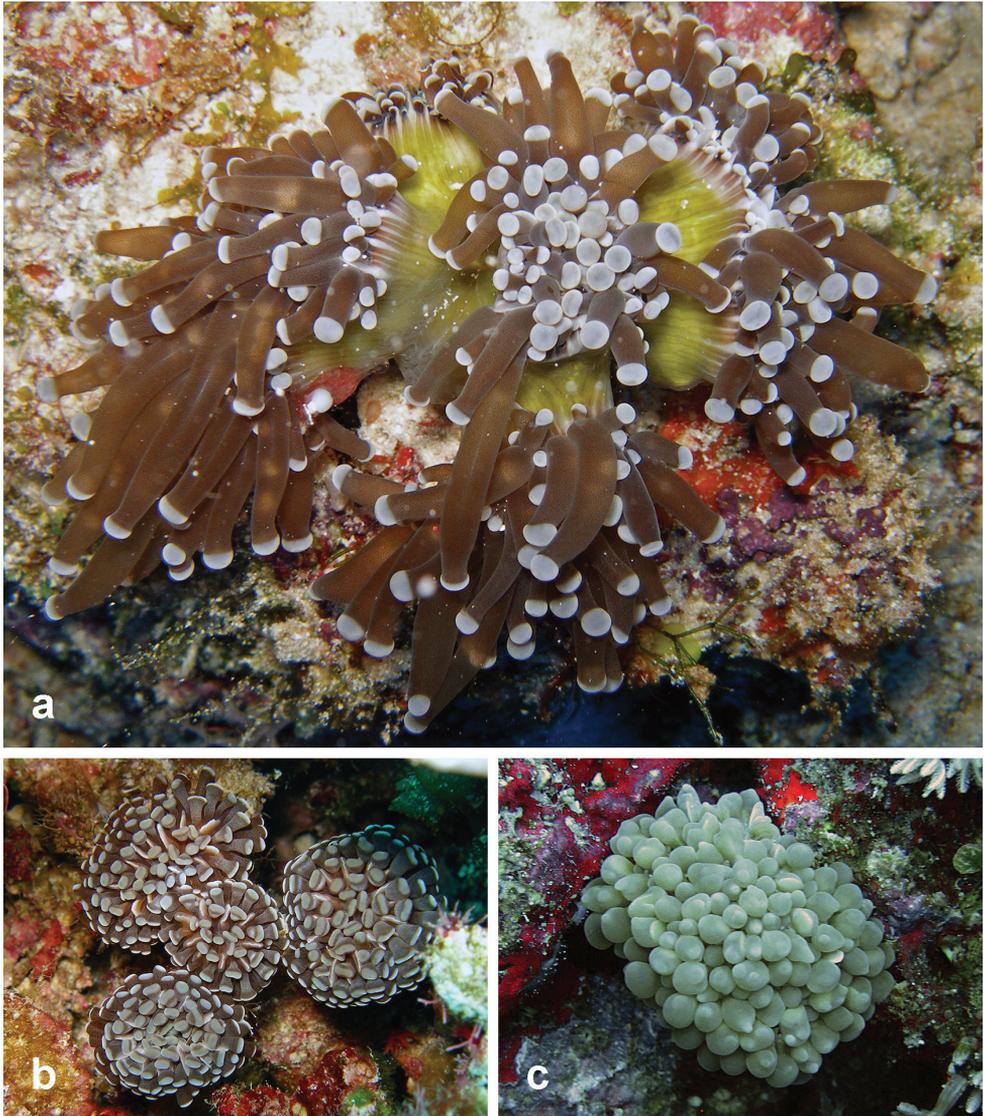
**Figure 6.** Agariciidae recorded at Pulau Layang-Layang in this study. **a** *Leptoseris scabra* **b** *L. solida* **c** *L. troglodyta* **d** *L. yabei* **e** *Pachyseris rugosa* **f** *P. speciosa* **g** *Pavona bipartita* **h** *P. clavus*.



**Figure 7.** Agariciidae recorded at Pulau Layang-Layang in this study. **a** *Pavona duerdeni* **b** *P. explanulata* **c** *P. maldivensis* (registration no. IPMB-C 13.00007) **d** *P. minuta* **e** *P. varians* **f** *P. venosa*.

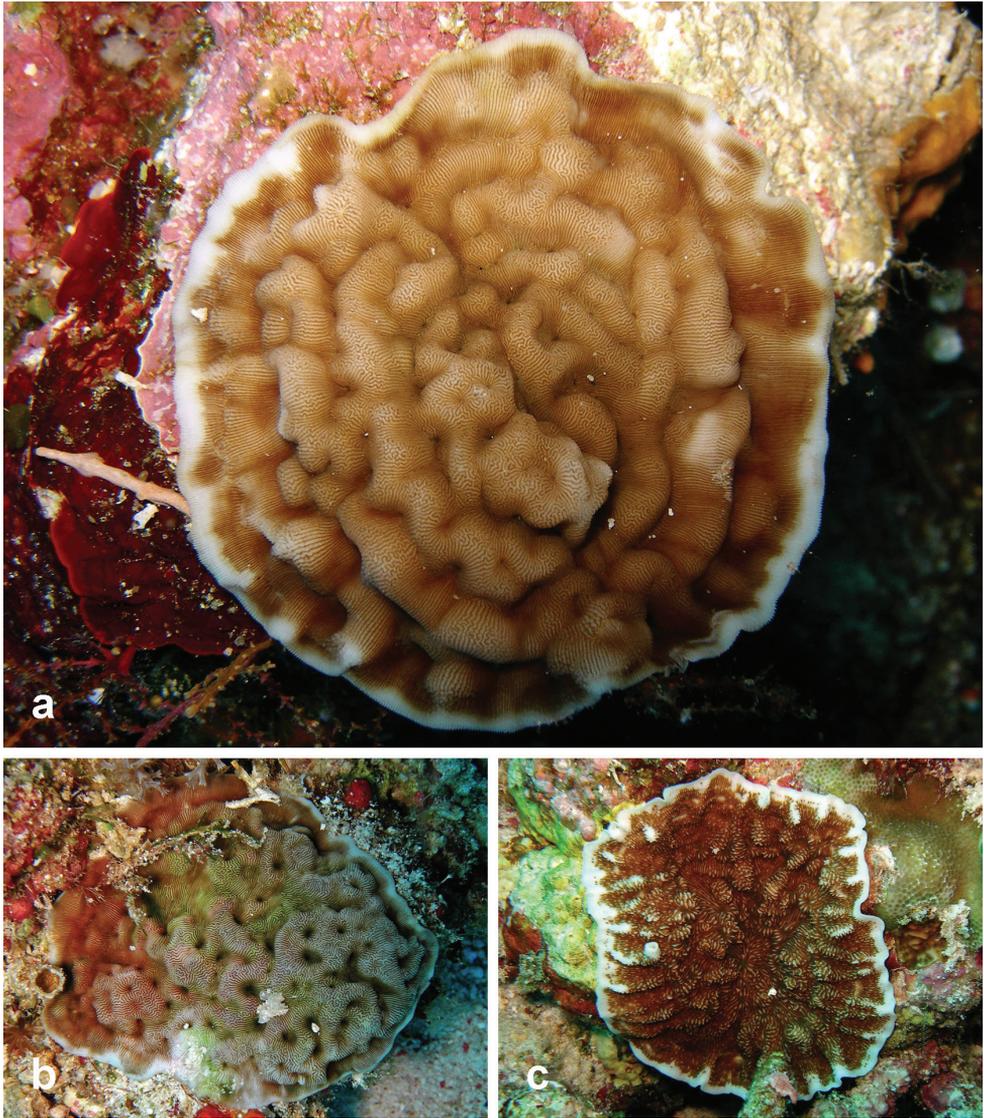
### *Pavona* corals – molecular perspective

Sequences were obtained from 11 and 17 *Pavona* samples for the IGR and ITS markers, respectively. Amplification success for the IGR marker was rather low and the length of the sequences ranged between 432 and 887 bp, shorter than the expected length of ~1200 bp (Terraneo et al. 2014). Tree topologies obtained from the ML, MP and BI analyses for each gene and the concatenated dataset were comparable so only the ML phylogram is shown. There were some differences in the topology between



**Figure 8.** Euphylliaidae recorded at Pulau Layang-Layang in this study. **a** *Euphyllia glabrescens* **b** *E. paraancora* **c** *Physogyra lichtensteini*.

the IGR and ITS phylogeny trees, but the ITS tree was less resolved and has lower support values (Suppl. material 4). The topology of the IGR tree is almost similar with the concatenated sequences tree and has well-supported basal clades, hence we focus on the latter. The final alignment of the concatenated sequences consisted of 1360 characters with 1243 constant, 35 variable and 82 parsimony informative characters. The phylogram consists of four clades (Figure 10). Samples of the *Pavona maldivensis* from Layang-Layang (samples with LAC labels) clustered with those of *P. maldivensis*



**Figure 9.** Undetermined *Leptoseris* coral species recorded at Pulau Layang-Layang in this study **a** *Leptoseris* sp. 1 (registration no. IPMB-C 13.00009) **b** *Leptoseris* sp. 2 **c** *Leptoseris* sp. 3.

from other areas (clade I). Clade II consists of a single specimen of *Pavona* cf. *explanulata* from Hawaii (Luck et al. 2013). Samples BAN02 from Banggi, North Borneo and TER28 from Ternate, Indonesia, initially identified as *P. maldivensis* during in situ observations from previous studies clustered together with *P. explanulata* samples (clade III). *Pavona* cf. *explanulata* from Redang, Peninsular Malaysia formed clade IV. The pairwise genetic difference between clades, although considerably low, were highest between clade II and clade IV ( $0.073 \pm 0.011$ ), followed by clade II and clade III

( $0.066 \pm 0.011$ ) and clade I and clade IV ( $0.047 \pm 0.005$ ). The intraspecific genetic distance within the clades was also very low:  $0.004 \pm 0.001$  for clade I and  $0.008 \pm 0.002$  for clade III.

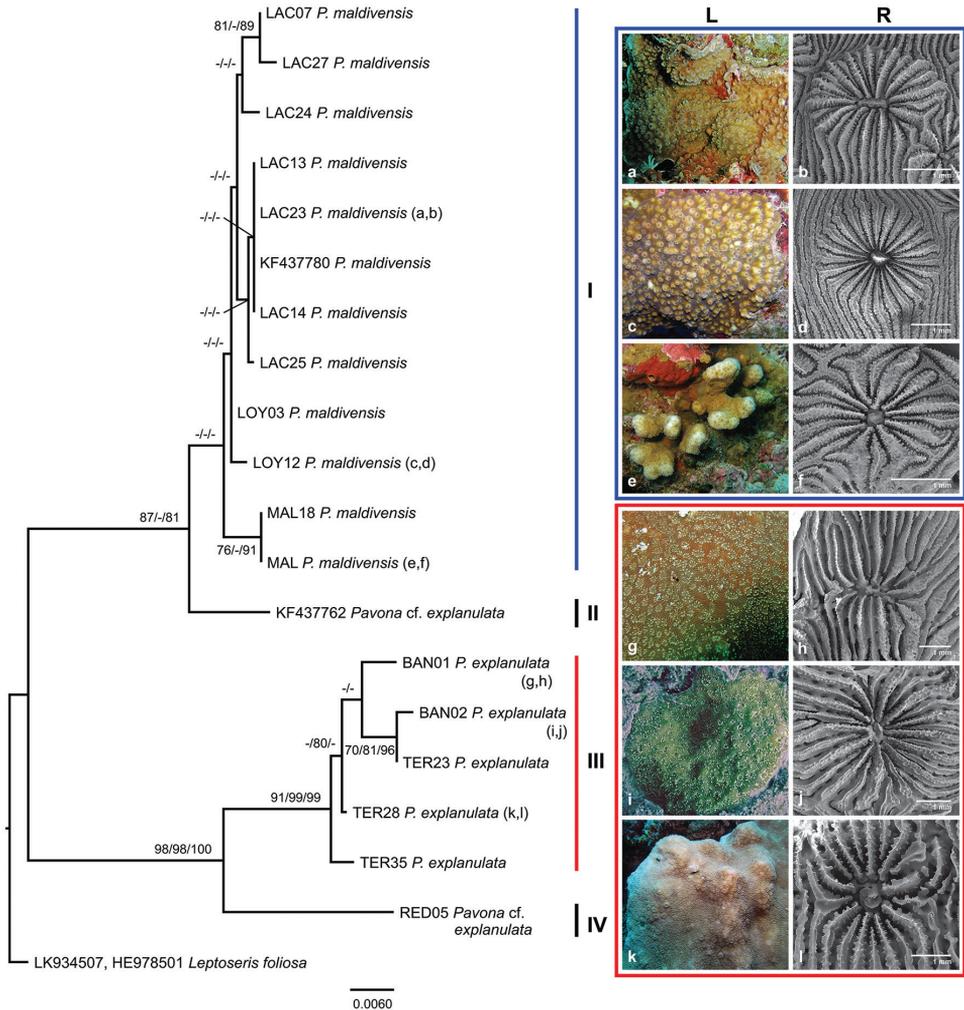
**Table 4.** Hard coral species that were not encountered in the present study. Species marked with an asterisk (\*) is now considered *incertae sedis*. Previous records are indicated as follows: a = Pilcher et al. (1999), b = Pilcher and Cabanban (2000). The presence of *Heliofungia actiniformis*, *Euphyllia ancora* and *Plerogyra sinuosa* are verified by images in Pilcher et al. (1999).

Family	No.	Species	Previous records	Status
Fungiidae	1	<i>Heliofungia actiniformis</i> (Quoy & Gaimard, 1833)	a, b	Verified
	2	<i>Podabacia crustacea</i> (Pallas, 1766)	b	Unverified
Agariciidae	3	<i>Pavona cactus</i> (Forskål, 1775)	b	Unverified
	4	<i>Pavona decussata</i> (Dana, 1846)	b	Unverified
Euphylliidae	5	<i>Euphyllia ancora</i> Veron & Pichon, 1980	a, b	Verified
	6	<i>Plerogyra sinuosa</i> (Dana, 1846)*	a, b	Verified

### *Pavona* corals – morphology

Macro- and micromorphology features of the *Pavona* corals support the clades of the molecular analyses (Figure 10a–l, Suppl. material 5). In general, the *P. maldivensis* specimens from Layang-Layang were small in size, the largest measured 11 cm × 8 cm while the smallest was 3.5 cm × 3 cm. All *P. maldivensis* specimens from Layang-Layang had paper-thin coralla ( $\leq 1$  mm) and were found encrusting the reef wall (e.g. Figure 7c). Several specimens had knobs or rounded columns protruding from the corallum (Figure 10a). The specimen from the Maldives has a columnar or club-shaped growth form (Figure 10e). The corallite morphology is variable within the same specimen, largely depending on the position of the corallites in the corallum. Calices at the top of the knobs or columns are small and compact and become larger and widely spaced towards the base or on horizontal plates (see Gardiner 1905). Calices vary from circular, distinctly raised edges (plocoid) (Figure 10d) to broad, flattened edges particularly at the base of the colony (Figure 10f), or a combination of both features (Figure 10b) when inclined towards the margin. Calices with raised walls protrude up to 2–4 mm. The columella is well-developed in the form of a peg (Figure 10b) or a single, rounded or twisted rod (Figure 10d, f).

Specimens of *P. explanulata* were either encrusting (Figure 10g, i), submassive (Figure 10k) or a combination of submassive with plate margins. Corallites may have irregular arrangements and shapes and mostly lack any form of wall (theca), giving the corallum a smooth surface appearance. Veron and Pichon (1980) described the thecae as “synapticulothecate”, if present, which is defined as rod- or bar-like structures extending between the septa (Budd et al. 2012). In plate colonies, the corallites are



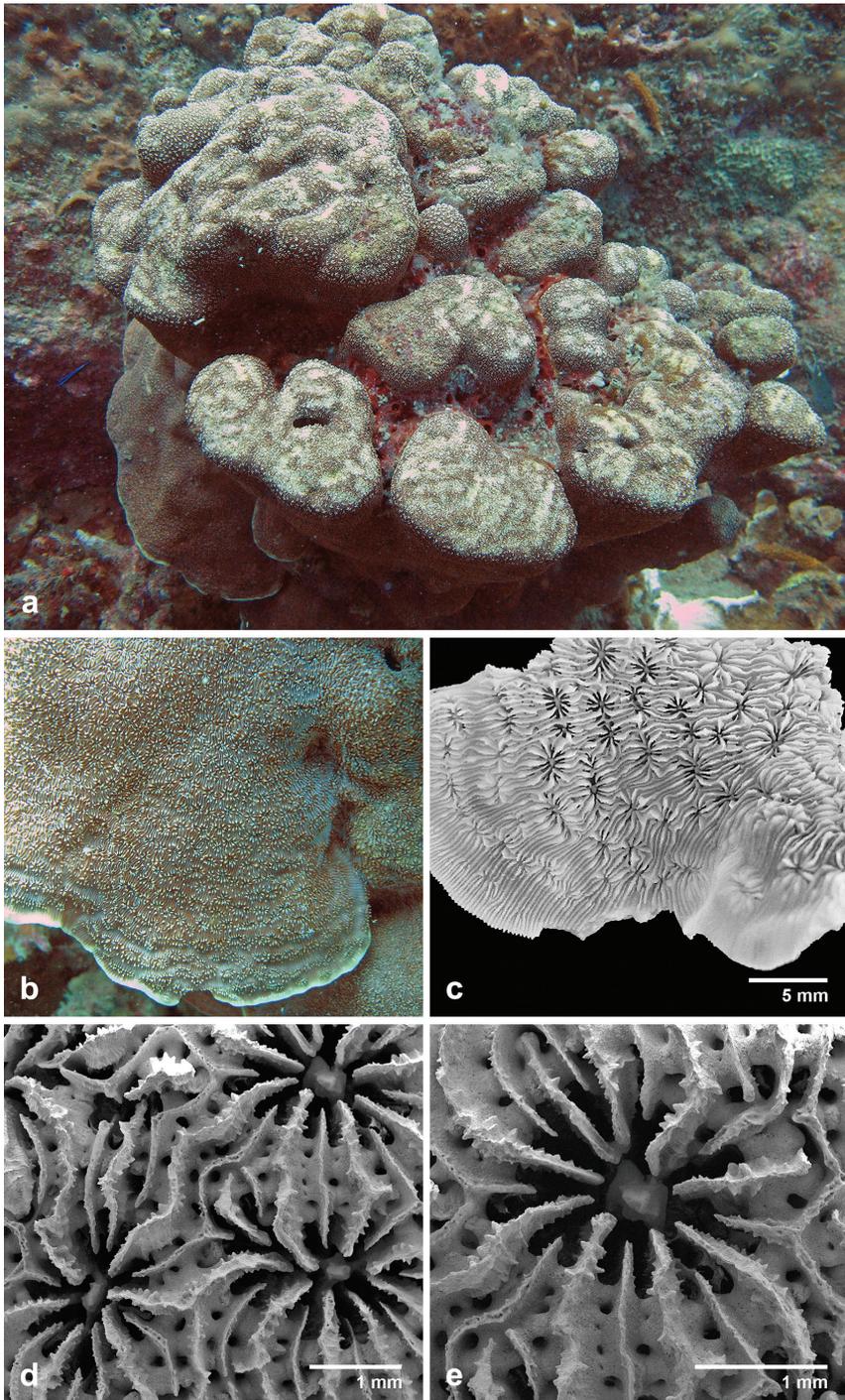
**Figure 10.** Maximum likelihood phylogram of *Pavona maldivensis* and *P. explanulata* based on combined mitochondrial intergenic spacer between CO1 and 16S-rRna and nuclear marker ITS1-5.8S-ITS2 sequences. Support values for maximum likelihood, maximum parsimony (>70) and bayesian posterior probabilities (>80) are given at the nodes. Dashes (-) indicate nodes without statistical support. Letters in parentheses correspond to images a–l in rows L and R. L: coral colonies *in situ*, R: SEM images of calices. Locality for the coral samples are: LAC = Layang-Layang, LOY = Loyalty Islands, MAL = the Maldives, BAN = Banggi, East Malaysia, TER = Ternate, Indonesia, RED = Redang, Peninsular Malaysia. **a–b** *P. maldivensis* from Layang-Layang **c–d** *P. maldivensis* from Loyalty Islands **e–f** *P. maldivensis* from the Maldives **g–h** *P. explanulata* from Banggi, Sabah **i–j** *P. explanulata* from Banggi, Sabah **k–l** *P. explanulata* from Ternate, Indonesia. Additional samples KF437780 *Pavona maldivensis* and KF437762 *Pavona cf. explanulata* are from Pearl and Hermes Atoll, the northwest Hawaiian Islands and O’ahu, Hawaii, respectively (Luck et al. 2013). Outgroup LK934507, HE978501 *Leptoseris foliosa* is from Prony Bay, New Caledonia (Benzoni et al. 2012b, Terraneo et al. 2014).

inclined towards the margin and usually in parallel rows. The columella consists of several fused processes that extend from the radial elements into the fossa (Figure 10h) or a single process, which appears as a twisted rod (Figure 10j, l). Synapticular rings may be visible in this species (Figure 10j, l). The specimen from Redang, Peninsular Malaysia looks superficially like *P. explanulata*, but the morphology differs from the rest of the *P. explanulata* specimens by the deeply seated columella and the widely spaced septa (Figure 11). This specimen resembles *Pavona* cf. *explanulata* in Veron and Pichon (1980: Fig. 31).

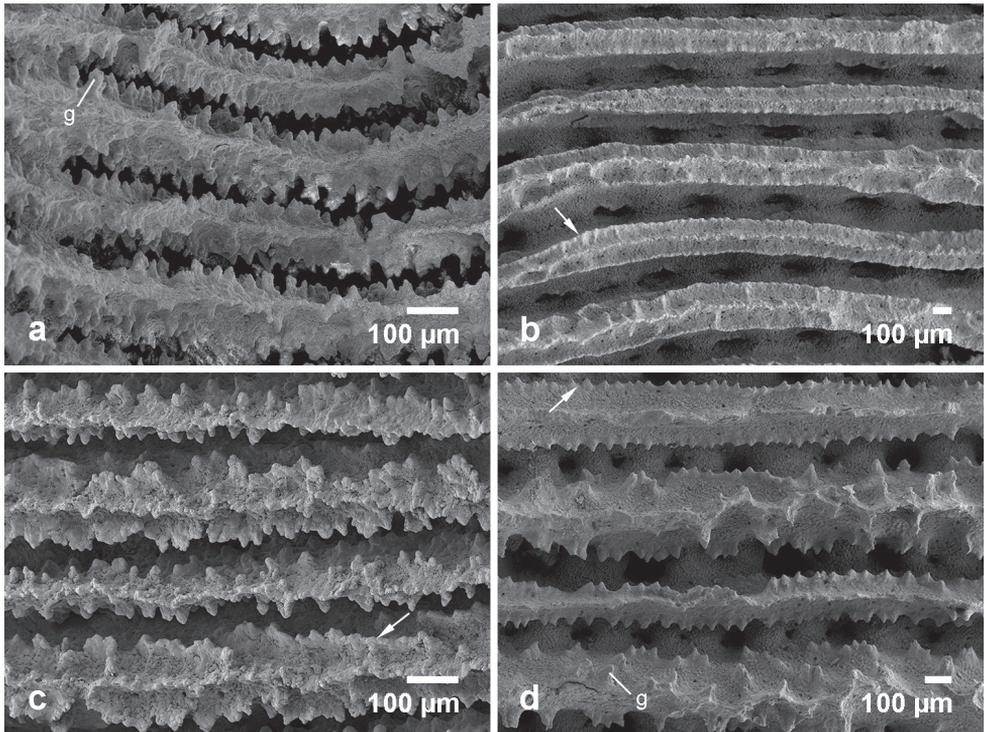
Septocostae of both *Pavona* species are closely compacted, but in *P. maldivensis* they have denser granulated sides (Figure 12). In *P. explanulata*, the order of septa may alternate between thin with rows of fine granules and thick with prominent spines. The upper margin of the septa (forming radial elements) consist of beaded granules in *P. maldivensis*, and in *P. explanulata* it appears to taper into a somewhat straight ridge. The side walls or lateral faces of the septa are covered with granules either in rows or scattered on the surface (e.g. Figure 12a, d). Aligned granulations alongside the lateral faces also known as menianae (Kitahara et al. 2010, Benzoni et al. 2012b, Terraneo et al. 2014), or menianes (Kitahara et al. 2012, Hoeksema 2012b), are more obvious in *P. explanulata* (Figure 12b, d) as compared with *P. maldivensis*, which has short series of menianae, if formed (Figure 12c). Radial elements of *P. explanulata* can have almost smooth margins (e.g. Figure 12b), and this has been described by Veron and Pichon (1980) for the second order septa of this species. A summary of the variation in morphological characters between *P. maldivensis* and *P. explanulata* is given in Table 5.

**Table 5.** Summary of variation in morphological characters between *Pavona maldivensis* and *P. explanulata*.

Morphological characters	<i>Pavona maldivensis</i>	<i>Pavona explanulata</i>
Growth form	Encrusting; paper-thin coralla, club-shaped (specimen from the Maldives)	Encrusting, submassive; may have plate margins
Corallite (arrangement)	Small and compact (top of the colony), widely spaced (base of the colony)	Irregular spacing and arrangement, in parallel rows towards the margin
Corallite (shape)	Circular, plocoid, flattened edges when inclined towards the margin	Irregular shape, but may be somewhat circular
Theca	Distinct; plocoid	Mostly lacking, synapticulothecate if present
Columella	Well-developed; peg-like, single, rounded or twisted rod	Several fused processes
Septo-costae	Compact, dense granulated sides	Compact, septa alternate between thin with fine granules and thick with spines
Radial elements	Beaded granules	Tapers into straight ridge, may have smooth margins
Lateral faces	Granules in rows or scattered on the surface, may form short series of menianae	With granules and menianae



**Figure 11.** Specimen RED05 *Pavona* cf. *explanulata* from Pulau Redang, Peninsular Malaysia. **a** coral colony *in situ* at 13 m depth **b** corallites detail at the plate margin **c** coral fragment preserved in ethanol **d, e** SEM images showing calices.



**Figure 12.** Variation of radial elements in *Pavona maldivensis* (**a, c**) and *P. explanulata* (**b, d**). **a** specimen LAC23 from Layang-Layang, **b** specimen BAN02 from Banggi, North Borneo, **c** specimen LOY12 from Loyalty Islands, and **d** specimen TER28 from Ternate, Indonesia. Lateral faces of septa are covered with granules (g) as indicated in **a** and **d**. Aligned granulations along the lateral faces of septa (menianae) are indicated by white arrows in **b, c, d**.

## Discussion

### Species occurrence

The total number of coral species noted at Layang-Layang is lower than that of other localities in Sabah where similar surveys have been conducted. Nevertheless, the overall species diversity is considered high even for fungiid corals, despite the fact that steep reef walls are hostile environments for free-living mushroom corals, as they can get dislodged from these drop-offs (Hoeksema and Moka 1989). In contrast, agariciid corals of the genus *Leptoseris* are known to flourish at greater depths (Kahng and Maragos 2006, Rooney et al. 2010, Dinesen et al. 2012, Luck et al. 2013). Based on the three target coral families, there is a decrease in the number of species from the east to the west coast of Sabah, from Semporna (90 species: 44 Fungiidae, 31 Agariciidae, 15 Euphylliidae; Waheed and Hoeksema 2013) to Kudat (84 species: 39 Fungiidae, 30 Agariciidae, 15 Euphylliidae; unpublished data), then Kota Kinabalu (72 species: 35 Fungiidae, 26 Agariciidae, 11 Euphylliidae; Waheed and Hoeksema 2014), and finally

offshore Layang-Layang (59 species: 32 *Fungiidae*, 22 *Agariciidae*, 5 *Euphylliidae*) (see inset of Figure 1). This is concordant with the general pattern of decreasing diversity away from the designated centre of maximum marine biodiversity (Briggs 1974, Hoeksema 2007, 2013, 2015, Bellwood and Meyer 2009), also known as the Coral Triangle, with its present western border at the Sulu Sea (Veron et al. 2009, 2011). However, Huang et al. (2015) demonstrated that there is no significant structure in species diversity on a larger scale from the eastern to the western reefs of the South China Sea, and suggested that local dynamics are at play in driving the species richness and distribution patterns in the area. Based on their coral species composition, the Spratly Islands clustered together with southern Vietnam rather than closer continental localities such as Sabah, Brunei or Palawan, the Philippines (Huang et al. 2015), which implies that the former two localities may have similar reef attributes. For oceanic Layang-Layang with its steep reefs walls, an additional factor for its lower species richness as compared to nearby continental reef areas such as Kota Kinabalu and Kudat could be the lack of habitat heterogeneity, which would be important for supporting species diversity (Done 1982, Best et al. 1989; Cornell and Karlson 1996, 2000, Karlson and Cornell 1998, Hoeksema 2007, 2012c).

Among the new coral records for Layang-Layang are five rarely documented species, i.e., *Lithophyllon ranjithi* (Figure 3d), *Podabacia sinai* (Figure 4d), *Sandalolitha boucheti* (Figure 4f), *Leptoseris kalayaanensis* (Figure 5g) and *L. troglodyta* (Figure 6c). *Lithophyllon ranjithi*, a mushroom coral previously thought to be endemic to northeast Borneo was encountered at seven sites. The first mention of this species from the South China Sea was from Brunei (Turak and DeVantier 2011), although this record could not be confirmed in a later review (Hoeksema and Lane 2014). This species is usually found on nearshore or coastal reefs (Waheed and Hoeksema 2013) so it was surprising to find it at an offshore and oceanic locality. Conversely, *L. kalayaanensis* was anticipated to be present in Layang-Layang. In fact, its type locality, the Kalayaan Islands in the Philippines is located ~ 350 km northeast from the atoll and this species has been reported from three other localities in the South China Sea, two with rather similar reef conditions (Licuanan and Aliño 2009) and one from the coastal area of Nha Trang, Vietnam (Hoeksema et al. 2010). Specimens of *L. kalayaanensis* were found at 13 sites along steep reef walls and considered rather common in Layang-Layang. *Leptoseris troglodyta*, a cavernicolous and azooxanthellate species was encountered only once during the dives. A cluster of about 12 small calices was found on the ceiling of a small cave in a reef wall at 30 m depth (Site 1). This species is widely distributed in the West Pacific (Hoeksema 2012b) and this account is the first record for the South China Sea. *Podabacia sinai* was previously recorded from the Red Sea (Veron 2000) but meanwhile it has also been found in various other Indo-Pacific localities (Hoeksema unpubl.). *Sandalolitha boucheti* has been observed in Vanuatu (Hoeksema 2012a) and Semporna, East Sabah (Waheed and Hoeksema 2013). This species was represented on the Layang-Layang reefs by two specimens. The largest of these ( $\varnothing$  ~ 6 cm; Figure 4f) was still attached by a very wide stalk while the other was free-living and showed a large detachment scar. It is abnormal for free-living mushroom corals to

maintain a long-lasting fixed growth form (Hoeksema and Yeemin 2011), which may hinder their identification.

Corals of three *Leptoseris* spp. could not be identified to species level. Two specimens of encrusting *Leptoseris* sp. 1 had free margins and small corallites ( $\leq 1.5$  mm in size). One of these corals (Figure 9a) has calices in rows somewhat concentric and parallel with the margin and a central corallite can be discerned. Corallites appear sunken because of the high and continuous carinae. This specimen measures  $\varnothing 5$  cm, and it is possibly a juvenile *L. mycetoseroides*. Further examination of these specimens is required for certainty. Unfortunately, specimens of *Leptoseris* sp. 2 and 3 were not collected; nevertheless photos have been included for visual record (Figure 9b, c).

Three coral species that have been reported from Layang-Layang but were not observed in the present study are the fungiid *Podabacia crustacea* and the agariciids *Pavona cactus* and *P. decussata* (Pilcher and Cabanban 2000). Since there is no photographic evidence or other supporting information to support the presence of these species on the atoll, they have not been included in the current species list. Still, it is very likely that these three species are present on the reef as they are common Indo-Pacific species and their distribution ranges certainly cover across the South China Sea, including the Spratly Islands (see Huang et al. 2015). As a note, *P. cactus* is usually found in turbid and sheltered reef conditions (Veron and Pichon 1980, Veron 2000). However, *P. cactus* and *P. decussata* can also be found in shallow reef environments such as upper reef slopes and lagoons. It is possible that these species are present in the lagoon reefs, which were underexplored in our study, as surveys were only possible around the reef walls of the atoll.

Many coral colonies in Layang-Layang appeared small in size, and most were juveniles. This was consistent across the reef sites for most coral families including those targeted in our study. For example, the largest collected *L. kalayaanensis* specimen measured 7.5 cm  $\times$  5 cm while the smallest was 4 cm  $\times$  3 cm. Also, the initial uncertainty in identifying *P. maldivensis* most likely stemmed from the fact that the specimens were very small in size (collected colonies were between 11 cm  $\times$  8 cm and 3.5 cm  $\times$  3 cm). This puzzling find can be explained by the fact that corals in the study area are recolonizing after the outbreak of the corallivorous crown-of-thorns (COT) seastar. Surveys during the COT outbreak in July 2010 were conducted down to 10 m depth only (Nasrullahakim et al. 2010), but the damage extends deeper based on our surveys ( $\sim 20$  m depth). Preceding this event there was also a COT outbreak on the nearby reefs of Brunei in April-May 2010, and at the same time a report of large numbers of COT at the reefs of the Tunku Abdul Rahman Park in Kota Kinabalu, Sabah on the northwest coast of Borneo (Lane 2012). Following this outbreak, Brunei and Kota Kinabalu reported to have thermally induced bleaching episodes in June-July 2010 (Lane 2011, Aw and Muhammad Ali 2012). There is no account on whether the reefs of Layang-Layang were also affected by this bleaching event, and based on our observations, we are unable to determine if a bleaching episode did occur.

There is no information on the extent of damage caused to the reefs and the rate of recovery from the COT outbreak in 2010, as the reefs of Layang-Layang are not

monitored regularly. Many studies have reported the effects of COTs to reefs in terms of coral cover loss and changes in coral assemblage (e.g. Lourey et al. 2000, Pratchett 2010, Lane 2011, 2012, Baird et al. 2013, Bos et al. 2013, Osborne et al. 2011, Saponari et al. 2014). While COTs are known to have a feeding preference for *Acropora* (De'ath and Moran 1998, Pratchett 2007), they have also been found to feed on many different coral taxa (Glynn 1974, Ormond et al. 1976, Colgan 1987, De'ath and Moran 1998, Pratchett 2007, Pratchett et al. 2009), which includes fungiids (De'ath and Moran 1998, Pratchett 2007, 2010, Pratchett et al. 2009, Scott et al. 2015) and agariciids (Colgan 1987, Pratchett 2007, 2009, 2010) particularly during an outbreak or when food becomes scarce (Moran 1986). Similarly for Layang-Layang, it appears that the COT outbreak resulted in high coral mortality (E Foo, J Bell, R Wahab, Avillon Layang-Layang Resort, pers. comm.). Our study was carried out almost three years after the outbreak and from our observations, the high frequency of coral recruits and small-sized colonies indicate an ongoing recovery of corals. We question whether all coral species (as prior to the outbreak) have re-established on the reefs as coral species such as *Euphyllia ancora* and *Plerogyra sinuosa*, both reported as common from previous surveys (NJ Pilcher, pers. comm.), were not observed during the present study. We are unable to draw a conclusion that the absence of certain species previously reported for Layang-Layang is caused by the 2010 COT event. While some baseline data is available for comparison (e.g. Pilcher et al. 1999, Pilcher and Cabanban 2000), there is no specific locality data of species occurrences to refer to. As far as we know, the reefs of Layang-Layang were monitored between 1996 and 1999 (see Pilcher et al. 1999, Pilcher and Cabanban 2000) and since then and prior to that, reef surveys were conducted intermittently. As several studies have impressed upon the importance of utilising long-term monitoring data in order to assess changes to the coral communities (e.g. Brown et al. 2002, Somerfield et al. 2008), there is a need to establish a coral reef monitoring plan for Layang-Layang. With a monitoring plan in place, any changes or disturbance can be detected at the onset so that mitigation measures can be taken if necessary.

### ***Pavona* species boundaries**

The IGR marker has proven to be successful in resolving species boundaries in the family Agariciidae and the genus *Pachyseris* (Terraneo et al. 2014). In our small dataset, the IGR marker gave better resolution than the ITS marker in resolving species-level relationships for two *Pavona* species. Both the IGR and the concatenated gene tree supported two main groups, one of *P. maldivensis*, including specimens from Layang-Layang, and the other of *P. explanulata*.

For all specimens in the *P. maldivensis* clade, the calice size is smaller, the calice walls are raised and distinct, the septocostae spacing is more compact and there is more surface ornamentation on the radial elements as compared to *P. explanulata*. They share some similar features in colony growth form, but *P. explanulata* does not form

club-shaped branches. *Pavona explanulata* specimens also tend to have a smooth surface appearance due to the absent calice wall, but exceptions do occur. The columella is well-developed as a single, rounded or twisted rod for both species, peg-like for *P. maldivensis* and as fused processes in *P. explanulata*. Lastly, synapticular rings are obvious in *P. explanulata* but not so in *P. maldivensis*, though Veron and Pichon (1980) have described them to be obvious on the branch ends.

Upon re-examining the morphological characters of the *Pavona* specimens identified as *P. maldivensis* in our previous studies (Waheed and Hoeksema 2013, 2014), it was clear that the specimens were more similar to *P. explanulata* instead. However, these specimens have calices with somewhat distinct walls, a feature that is more typical of *P. maldivensis*. This is most likely one of the factors that prompted the misidentification of these specimens. Adding to this, *P. maldivensis* has a wide distribution range in the Indo-Pacific (e.g. Veron and Pichon 1980, Scheer and Pillai 1983, Maragos and Jokiel 1986, Dai and Lin 1992, Nishihira and Veron 1995, Glynn et al. 2007, Pichon 2007, Pichon and Benzoni 2007), and has been reported from the Bodgaya and Sipadan islands in Semporna, Sabah (Wood and Tan 1987); hence, we had expected to find this species in our previous study areas (i.e. Semporna and Kota Kinabalu).

Although *P. maldivensis* and *P. explanulata* may not be considered the most problematic species within *Pavona*, specimens that closely resemble these species have been collected and analysed. For example, sample KF437762 *Pavona* cf. *explanulata* (Luck et al. 2013) clusters basally to *P. maldivensis* rather than with its conspecifics, while sample RED05 *Pavona* cf. *explanulata* from Redang clusters basally to the other samples of *P. explanulata*. For the latter, the macro- and micromorphology of this specimen was noticeably different from the rest of the *P. explanulata* samples. These cases indicate that the identity of *P. explanulata* should be carefully re-examined in the future through a larger morpho-molecular study including several specimens from various localities.

### **Implication of misidentified *Pavona maldivensis***

Based on the findings of this study, the “true” *P. maldivensis* has only been found in Layang-Layang out of the other localities previously visited in Sabah, Malaysia, i.e. Semporna and Kota Kinabalu (Waheed and Hoeksema 2013, 2014), and the status of this species in those localities remains ambiguous until future data is available. It is highly likely that the misidentified specimens from those previous studies are *P. explanulata*, as was discovered for specimens from Banggi and Ternate utilised in this study, or a variety closely resembling it.

The name *Pavona explanulata*, like *P. maldivensis*, has been mistakenly used in the past (examples given by Veron and Pichon 1980: 17–36). Furthermore, the type specimen of *P. explanulata* appears to be missing and the original species description is rather vague, so taxonomic literature of this species since when it was first described needs to be re-examined in order to better define its species boundaries.

## Conclusions

The coral species list for the families Fungiidae, Agariciidae and Euphylliidae in the present study added 32 new records for Layang-Layang and includes rarely recorded species such as *Leptoseris kalayaanensis*, which is thus far a South China Sea endemic. The mushroom coral *Lithophyllon ranjithi* has a wider distribution range than previously thought and can no longer be considered endemic to northeastern Borneo. This is the first record of this species from an oceanic and offshore reef habitat, in contrast to its previously reported habitat preference for coastal and sheltered reef conditions.

An integrative molecular and morphological approach was utilised to determine that specimens identified as *P. maldivensis* from previous surveys are in fact *P. explanulata*. The combination of both techniques have proven to be powerful in addressing species complexes in scleractinians (e.g. Benzoni et al. 2007, 2011, 2014, Kitahara et al. 2012, Arrigoni et al. 2014a, b, c, Kitano et al. 2014), particularly if type specimens and coral samples from the type locality are included in the analyses (Huang et al. 2014), and taxonomic descriptions are consolidated (Benzoni et al. 2010). While the species boundaries between *P. maldivensis* and *P. explanulata* may already be distinct based on morphological descriptions and images in current taxonomic literature, the present study has included SEM images of calices and radial elements of specimens of both species for the first time to further illustrate the previous descriptions. In addition, a specimen closely resembling but dissimilar from *P. explanulata* is also shown. As such, this finding may serve as a stepping stone for further investigations of *Pavona*.

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## References

- Abdullah MP (2005) Marine Research Station Layang-Layang Malaysia (MARSAL) 2004 & 2005 highlights. Department of Fisheries Malaysia and Ministry of Agriculture and Agro-based Industry, 52 pp. <http://www.fri.gov.my/marsal/publications.html>
- Akhir MFM (2012) Surface circulation and temperature distribution of southern South China Sea from Global Ocean Model (OCCAM). *Sains Malaysiana* 41: 701–714.
- Arrigoni R, Terraneo TI, Galli P, Benzoni F (2014a) Lobophylliidae (Cnidaria, Scleractinia) reshuffled: Pervasive non-monophyly at genus level. *Molecular Phylogenetics and Evolution* 73: 60–64. doi: 10.1016/j.ympev.2014.01.010
- Arrigoni R, Kitano YF, Stolarski J, Hoeksema BW, Fukami H, Stefani F, Galli P, Montano S, Castoldi E, Benzoni F (2014b) A phylogeny reconstruction of the Dendrophylliidae (Cnidaria, Scleractinia) based on molecular and micromorphological criteria, and its ecological implications. *Zoologica Scripta* 43: 661–688. doi: 10.1111/zsc.12072
- Arrigoni R, Richards ZT, Chen CA, Baird AH, Benzoni F (2014c) Taxonomy and phylogenetic relationships of the coral genera *Australomussa* and *Parascolymia* (Scleractinia, Lobophylliidae). *Contributions to Zoology* 83: 195–215.
- Aw SL, Muhammad Ali SY (2012) Coral bleaching event in Kota Kinabalu, Sabah, Malaysia. In: International Seminar on Marine Science and Aquaculture, 11–13 March 2012. Universiti Malaysia Sabah, Kota Kinabalu, 80.
- Baird AH, Pratchett MS, Hoey AS, Herdiana Y, Campbell SJ (2013) *Acanthaster planci* is a major cause of coral mortality in Indonesia. *Coral Reefs* 32: 803–812. doi: 10.1007/s00338-013-1025-1
- Bellwood DR, Meyer CP (2009) Searching for heat in a marine biodiversity hotspot. *Journal of Biogeography* 36: 569–576. doi: 10.1111/j.1365-2699.2008.02029.x
- Benzoni F, Stefani F, Stolarski J, Pichon M, Mitta G, Galli P (2007) Debating phylogenetic relationships of the scleractinian *Psammocora*: molecular and morphological evidences. *Contributions to Zoology* 76: 35–54.
- Benzoni F, Stefani F, Pichon M, Galli P (2010) The name game: morpho-molecular species boundaries in the genus *Psammocora* (Cnidaria, Scleractinia). *Zoological Journal of the Linnean Society* 160: 421–456. doi: 10.1111/j.1096-3642.2010.00622.x
- Benzoni F, Arrigoni R, Stefani F, Pichon M (2011) Phylogeny of the coral genus *Plesiastrea* (Cnidaria, Scleractinia). *Contributions to Zoology* 80: 231–249.
- Benzoni F, Arrigoni R, Stefani F, Reijnen BT, Montano S, Hoeksema BW (2012a) Phylogenetic position and taxonomy of *Cycloseris explanulata* and *C. wellsii* (Scleractinia: Fungiidae): lost mushroom corals find their way home. *Contributions to Zoology* 81: 125–146.
- Benzoni F, Arrigoni R, Stefani F, Stolarski J (2012b) Systematics of the coral genus *Craterastrea* (Cnidaria, Anthozoa, Scleractinia) and description of a new family through combined morphological and molecular analyses. *Systematic and Biodiversity* 10: 417–433. doi: 10.1080/14772000.2012.744369
- Benzoni F, Arrigoni R, Waheed Z, Stefani F, Hoeksema BW (2014) Phylogenetic relationships and revision of the genus *Blastomussa* (Cnidaria: Anthozoa: Scleractinia) with description of a new species. *Raffles Bulletin of Zoology* 62: 358–378.

- Best MB, Hoeksema BW, Moka W, Moll H, Sutarna IN (1989) Recent scleractinian coral species collected during the Snellius-II Expedition in eastern Indonesia. *Netherlands Journal of Sea Research* 23: 107–115. doi: 10.1016/0077-7579(89)90005-7
- Bos AR, Gumanao GS, Mueller B, Saceda-Cardoza MM (2013) Management of crown-of-thorns sea star (*Acanthaster planci* L.) outbreaks: removal success depends on reef topography and timing within the reproduction cycle. *Ocean and Coastal Management* 71: 116–122. doi: 10.1016/j.ocecoaman.2012.09.011
- Briggs JC (1974) *Marine Zoogeography*. McGraw-Hill, New York, 475 pp.
- Brown BE, Clarke KR, Warwick RM (2002) Serial patterns of biodiversity change in corals across shallow reef flats in Ko Phuket, Thailand, due to the effects of local (sedimentation) and regional (climatic) perturbations. *Marine Biology* 141: 24–29. doi: 10.1007/s00227-002-0810-0
- Budd AF, Fukami H, Smith ND, Knowlton N (2012) Taxonomic classification of the reef coral family Mussidae (Cnidaria: Anthozoa: Scleractinia). *Zoological Journal of the Linnean Society* 166: 465–529. doi: 10.1111/j.1096-3642.2012.00855.x
- Colgan MW (1987) Coral reef recovery on Guam (Micronesia) after catastrophic predation by *Acanthaster planci*. *Ecology* 68: 1592–1605. doi: 10.2307/1939851
- Cornell HV, Karlson RH (1996) Species richness of reef-building corals determined by local and regional processes. *Journal of Animal Ecology* 65: 233–241. doi: 10.2307/5726
- Cornell HV, Karlson RH (2000) Coral species richness: ecological versus biogeographical influences. *Coral Reefs* 19: 37–49. doi: 10.1007/s003380050224
- Dai CF, Lin CH (1992) Scleractinia of Taiwan. Part III. Family Agariciidae. *Acta Oceanographica Taiwanica* 28: 80–101.
- Darriba D, Taboada GL, Doallo R, Posada D (2012) jModelTest 2: more models, new heuristics and parallel computing. *Nature Methods* 9: 772. doi: 10.1038/nmeth.2109
- De'ath G, Moran PJ (1998) Factors affecting the behaviour of crown of-thorns starfish (*Acanthaster planci* L.) on the Great Barrier Reef: 2: Feeding preferences. *Journal of Experimental Marine Biology and Ecology* 220: 107–126. doi: 10.1016/S0022-0981(97)00100-7
- Dinesen ZD (1980) A revision of the coral genus *Leptoseris* (Scleractinia: Fungina: Agariciidae). *Memoirs of the Queensland Museum* 20: 182–235.
- Dinesen ZD, Bridge TCL, Luck DG, Kahng SE, Bongaerts P (2012) Importance of the coral genus *Leptoseris* to mesophotic coral communities in the Indo-Pacific. Poster 12th International Coral Reef Symposium, Cairns, 2012: P101. <http://www.icrs2012.com/eposters/P101.pdf>
- Ditlev H (2003) New scleractinian corals (Cnidaria: Anthozoa) from Sabah, North Borneo. Description of one new genus and eight new species, with notes on their taxonomy and ecology. *Zoologische Mededelingen Leiden* 77: 193–219.
- Done TJ (1982) Patterns in the distribution of coral communities across the Central Great Barrier Reef. *Coral Reefs* 1: 95–107. doi: 10.1007/BF00301691
- Fukami H, Chen CA, Budd AF, Collins A, Wallace C, Chuang YY, Chen C, Dai CF, Iwao K, Sheppard C, Knowlton N (2008) Mitochondrial and nuclear genes suggest that stony corals are monophyletic but most families of stony corals are not (order Scleractinia, class Anthozoa, phylum Cnidaria). *PLoS ONE* 3(9): e3222. doi: 10.1371/journal.pone.0003222

- Gardiner JS (1905) Madreporaria III. Fungida IV. Turbinolidae. In: Fauna and geography of the Maldives and Laccadives Archipelagoes, Cambridge 2: 933–957, pls. 89–93.
- Gittenberger A, Reijnen BT, Hoeksema BW (2011) A molecularly based phylogeny reconstruction of mushroom corals (Scleractinia: Fungiidae) with taxonomic consequences and evolutionary implications for life history traits. *Contributions to Zoology* 80: 107–132.
- Glynn PW (1974) The impact of *Acanthaster* on corals and coral reefs in the Eastern Pacific. *Environmental Conservation* 1: 295–303. doi: 10.1017/S037689290000494X
- Glynn PW, Wellington GM, Riegl B, Olson DB, Borneman E, Wieters EA (2007) Diversity and biogeography of the scleractinian coral fauna of Easter Island (Rapa Nui). *Pacific Science* 61: 67–90. doi: 10.1353/psc.2007.0005
- Google Earth (2013) Version 7.1.2.2014. <https://www.google.com/earth/>
- Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucleic Acids Symposium Series* 41: 95–98.
- Hancox D, Prescott V (1995) A geographical description of the Spratly Islands and an account of hydrographic surveys amongst those islands. *Maritime Briefing*, Volume 1 Number 6. International Boundaries Research Unit, Department of Geography, University of Durham, Durham, UK, 88 pp.
- Hoeksema BW (1989) Taxonomy, phylogeny and biogeography of mushroom corals (Scleractinia: Fungiidae). *Zoologische Verhandelingen, Leiden* 254: 1–295.
- Hoeksema BW (2007) Delineation of the Indo-Malayan centre of maximum marine biodiversity. In: Renema W (Ed.) *Biogeography, Time, and Place: Distributions, Barriers, and Islands*. Springer, Leiden, 117–178. doi: 10.1007/978-1-4020-6374-9\_5
- Hoeksema BW (2012a) Mushroom corals (Scleractinia, Fungiidae) of Espiritu Santo (Vanuatu, West Pacific), with the description of a new species. *Zoosystema* 34(2): 429–443. doi: 10.5252/z2012n2a14
- Hoeksema B (2012b) Forever in the dark: the cave-dwelling azooxanthellate reef coral *Leptoseris troglodyta* sp. n. (Scleractinia, Agariciidae). *ZooKeys* 228: 21–37. doi: 10.3897/zookeys.228.3798
- Hoeksema BW (2012c) Distribution patterns of mushroom corals (Scleractinia: Fungiidae) across the Spermonde Shelf, South Sulawesi. *Raffles Bulletin of Zoology* 60: 183–212.
- Hoeksema BW (2013) In search of the Asian-Pacific centre of maximum marine biodiversity: explanations from the past and present. *Galaxea, Journal of Coral Reef Studies* 15 (Supplement): 1–8.
- Hoeksema BW (2014) The “*Fungia patella* group” (Scleractinia, Fungiidae) revisited with a description of the mini mushroom coral *Cycloseris boschmai* sp. n. *ZooKeys* 371: 57–84. doi: 10.3897/zookeys.371.6677
- Hoeksema BW (2015) Latitudinal species diversity gradient of mushroom corals off eastern Australia: a baseline from the 1970s. *Estuarine, Coastal and Shelf Science*. doi: 10.1016/j.ecss.2015.05.015
- Hoeksema BW, Lane DJW (2014) The mushroom coral fauna (Scleractinia: Fungiidae) of Brunei Darussalam (South China Sea) and its relation to the Coral Triangle. *Raffles Bulletin of Zoology* 62: 566–580.
- Hoeksema BW, Moka W (1989) Species assemblages and ecomorph variation of mushroom corals (Scleractinia: Fungiidae) related to reef habitats in the Flores Sea. *Netherlands Journal of Sea Research* 23:149–160. doi: 10.1016/0077-7579(89)90009-4

- Hoeksema BW, Yeemin T (2011) Late detachment conceals serial budding by the free-living coral *Fungia fungites* in the Inner Gulf of Thailand. *Coral Reefs* 30: 975. doi: 10.1007/s00338-011-0784-9
- Hoeksema BW, Dautova TN, Savinkin OV, Vo ST, Hoang XB, Phan KH, Hoang TD (2010) The westernmost record of the coral *Leptoseris kalayaanensis* in the South China Sea. *Zoological Studies* 49: 325.
- Huang D, Benzoni F, Arrigoni R, Baird AH, Berumen ML, Bouwmeester J, Chou LM, Fukami H, Licuanan WY, Lovell ER, Meier R, Todd PA, Budd AF (2014) Towards a phylogenetic classification of reef corals: the Indo-Pacific genera *Merulina*, *Goniastrea* and *Scapophyllia* (Scleractinia, Merulinidae). *Zoologica Scripta* 43: 531–548. doi: 10.1111/zsc.12061
- Huang D, Licuanan WY, Hoeksema BW, Chen CA, Ang PO, Huang H, Lane DJW, Vo ST, Waheed Z, Affendi YA, Yeemin T, Chou LM (2015) Extraordinary diversity of reef corals in the South China Sea. *Marine Biodiversity* 45: 157–168. doi: 10.1007/s12526-014-0236-1
- Huelsenbeck JP, Ronquist F (2001) MRBAYES: Bayesian inference of phylogeny. *Bioinformatics* 17: 754–755. doi: 10.1093/bioinformatics/17.8.754
- Hutchison CS, Vijayan VR (2010) What are the Spratly Islands? *Journal of Asian Earth Sciences* 39: 371–385. doi: 10.1016/j.jseas.2010.04.013
- Ismail G, Shizuri Y, Oakley S, Pilcher N, Miyachi S (1998) Evaluation of marine communities: Their potential as bioresources. In: Proceedings of The Tokyo International Forum on Conservation and Sustainable Use of Tropical Bioresources, Tokyo, Japan, 9-10 November 1998. New Energy and Industrial Technology Development Organization (NEDO) and Japan Bioindustry Association (JBA), Japan, 84–110.
- Kahng SE, Maragos JE (2006) The deepest, zooxanthellate scleractinian corals in the world? *Coral Reefs* 25: 254. doi: 10.1007/s00338-006-0098-5
- Karlson RH, Cornell HV (1998) Scale-dependent variation in local vs. regional effects on coral species richness. *Ecological Monographs* 68: 259–274. doi: 10.1890/0012-9615(1998)068[0259:SDVILV]2.0.CO;2
- Kitahara MV, Cairns SD, Stolarski J, Blair D, Miller DJ (2010) A comprehensive phylogenetic analysis of the Scleractinia (Cnidaria, Anthozoa) based on mitochondrial CO1 sequence data. *PLoS ONE* 5(7): e11490. doi: 10.1371/journal.pone.0011490
- Kitahara MV, Stolarski J, Miller DJ, Benzoni F, Stake J, Cairns SD (2012) The first modern solitary Agariciidae (Anthozoa, Scleractinia) revealed by molecular and microstructural analysis. *Invertebrate Systematics* 26: 303–315. doi: 10.1071/IS11053
- Kitano YF, Benzoni F, Arrigoni R, Shirayama Y, Wallace CC, Fukami H (2014) A phylogeny of the family Poritidae (Cnidaria, Scleractinia) based on molecular and morphological analyses. *PLoS ONE* 9(5): e98406. doi: 10.1371/journal.pone.0098406
- Ku Yaacob KK, Ibrahim M (2004) Temperature, salinity and density properties of the south-eastern South China Sea: Pulau Layang Layang area. In: Abdullah MP (Ed.) *Marine Biodiversity of Pulau Layang-Layang Malaysia*, Fisheries Research Institute, Department of Fisheries Malaysia, 89–102. <http://www.fri.gov.my/marsal/penerbitan/temperature1.pdf>
- Lamarck JBP (1816) Histoire naturelle des Animaux sans Vertèbres, présentant les caractères généraux et particuliers de ces animaux, leur distribution, leurs classes, leurs familles, leurs genres, et la cita-

- tion des principales espèces qui s’y rapportent; précédée d’une Introduction offrant la Détermination des caractères essentiels de l’Animal, sa distinction du Végétal et des autres corps naturels, enfin, l’exposition des principes fondamentaux de la Zoologie. Déterville & Verdière, Paris.
- Lane DJW (2011) Bleaching and predation episodes on Bruneian coral reefs. *Scientia Bruneiana* 12: 51–58.
- Lane DJW (2012) *Acanthaster planci* impact on coral communities at permanent transect sites on Bruneian reefs, with a regional overview and a critique on outbreak causes. *Journal of the Marine Biological Association of the United Kingdom* 92: 803–809. doi: 10.1017/S0025315411000890
- Licuanan WY, Aliño PM (2009) *Leptoseris kalayaanensis* (Scleractinia: Agariciidae), a new coral species from the Philippines. *Raffles Bulletin of Zoology* 57: 1–4.
- Lourey MK, Ryan DAJ, Miller IR (2000) Rates of decline and recovery of coral cover on reefs impacted by, recovering from and unaffected by crown-of-thorns starfish *Acanthaster planci*: a regional perspective on the Great Barrier Reef. *Marine Ecology Progress Series* 196: 179–186. doi: 10.3354/meps196179
- Luck DG, Forsman ZH, Toonen RJ, Leicht SJ, Kahng SE (2013) Polyphyly and hidden species among Hawai‘i’s dominant mesophotic coral genera, *Leptoseris* and *Pavona* (Scleractinia: Agariciidae). *PeerJ* 1: e132. doi: 10.7717/peerj.132
- Maragos J, Jokiel P (1986) Reef corals of Johnston Atoll: one of the world’s most isolated reefs. *Coral Reefs* 4: 141–150. doi: 10.1007/BF00427935
- Mohamed MIH, Rahman RA, Abdullah MP (1994) Impact of development on Pulau Layang-Layang coral reefs. In: Sudara S, Wilkinson CR, Chou LM (Eds) *Proceedings, Third ASEAN-Australia Symposium on Living Coastal Resources, Volume 2 Research Papers, May 1994*. Chulalongkorn University, Bangkok, 35–40.
- Moran PJ (1986) The *Acanthaster* phenomenon. *Oceanography and Marine Biology, An Annual Review* 24: 379–480.
- Morton B, Blackmore G (2001) South China Sea. *Marine Pollution Bulletin* 42: 1236–1263. doi: 10.1016/S0025-326X(01)00240-5
- Musa G, Kadir SLSA, Lee L (2006) Layang Layang: an empirical study on SCUBA divers’ satisfaction. *Tourism in Marine Environments* 2(2): 89–102.
- Nasrulhakim M, Daud A, Mushidi H (2010) Study of population, distribution and proposed method to control Crown-of-thorns (COT) starfish species outbreak in the waters of Layang-Layang Island, Malaysia. Unpublished report, 15 pp.
- Nishihira M, Veron JEN (1995) *Corals of Japan*. Kaiyusha Publishers, Tokyo.
- Ormond RFG, Hanscomb NJ, Beach DH (1976) Food selection and learning in the crown-of-thorns starfish *Acanthaster planci* (L). *Marine Behaviour and Physiology* 4: 93–105. doi: 10.1080/10236247609386944
- Osborne K, Dolman AM, Burgess SC, Johns KA (2011) Disturbance and the dynamics of coral cover on the Great Barrier Reef (1995–2009). *PLoS ONE* 6(3): e17516 doi: 10.1371/journal.pone.0017516
- Penn O, Privman E, Ashkenazy H, Landan G, Graur D, Pupko T (2010a) GUIDANCE: a web server for assessing alignment confidence scores. *Nucleic Acids Research* 38: W23–W28. doi: 10.1093/nar/gkq443

- Penn O, Privman E, Landan G, Graur D, Pupko T (2010b) An alignment confidence score capturing robustness to guide-tree uncertainty. *Molecular Biology and Evolution* 27: 1759–1767. doi: 10.1093/molbev/msq06
- Pichon M (2007) Scleractinia of New Caledonia: check list of reef dwelling species. In: Payri C, Richer De Forges B (Eds) *Compendium of marine species of New Caledonia*. Documents Scientifiques et Techniques IRD, Nouméa 117(2): 149–157.
- Pichon M, Benzoni F (2007) Taxonomic re-appraisal of zooxanthellate scleractinian corals in the Maldive Archipelago. *Zootaxa* 1441: 21–33. doi: 10.1353/psc.2007.0011
- Pilcher N, Cabanban AS (2000) The status of coral reefs in eastern Malaysia. Global Coral Reef Monitoring Network (GCRMN) Report. Australia Institute of Marine Science, Townsville, 63 pp.
- Pilcher N, Oakley S, Ismail G (1999) *Layang Layang a drop in the ocean*. Natural History Publications, Kota Kinabalu, 126 pp.
- Pillai CSG, Scheer G (1976) Report on the stony corals from the Maldive Archipelago. *Zoologica, Stuttgart* 126: 1–83, Pl. 1–32.
- Pratchett MS (2007) Feeding preferences of *Acanthaster planci* (Echinodermata: Asteroidea) under controlled conditions of food availability. *Pacific Science* 61: 113–120.
- Pratchett MS (2010) Changes in coral assemblages during an outbreak of *Acanthaster planci* at Lizard Island, northern Great Barrier Reef (1995–1999). *Coral Reefs* 29: 717–725. doi: 10.1007/s00338-010-0602-9
- Pratchett MS, Shenk TJ, Baine M, Syms C, Baird AH (2009) Selective coral mortality associated with outbreaks of *Acanthaster planci* L. in Bootless Bay, Papua New Guinea. *Marine Environmental Research* 67: 230–236. doi: 10.1016/j.marenvres.2009.03.001
- Ronquist F, Huelsenbeck JP (2003) MRBAYES 3: Bayesian phylogenetic inference under mixed models. *Bioinformatics* 19: 1572–1574. doi: 10.1093/bioinformatics/btg180
- Ronquist F, Teslenko M, van der Mark P, Ayres DL, Darling A, Höhna S, Larget B, Liu L, Suchard MA, Huelsenbeck JP (2012) MrBayes 3.2: efficient Bayesian phylogenetic inference and model choice across a large model space. *Systematic Biology* 61: 539–542. doi: 10.1093/sysbio/sys029
- Rooney J, Donham E, Montgomery A, Spalding H, Parrish F, Boland R, Fenner D, Gove J, Vetter O (2010) Mesophotic coral ecosystems in the Hawaiian Archipelago. *Coral Reefs* 29: 36–367. doi: 10.1007/s00338-010-0596-3
- Saadon N, Lim PK, Snidvong A, Rojana-Anawat P (1999) Physical characteristics of watermass in the South China Sea, area II: Sarawak, Sabah and Brunei Darussalam waters. In: *Proceedings of the second technical seminar on marine fishery resources survey in the South China Sea Area II: Sarawak, Sabah and Brunei Darussalam waters*, Kuala Lumpur, Malaysia, 14–15 December 1998. Southeast Asian Fisheries Development Center, Samutprakan, Thailand, 1–22.
- Sahari A, Ilias Z, Sulong N, Ibrahim K (2004) Giant clam species and distribution at Pulau Layang-Layang, Sabah. In: Abdullah MP (Ed.) *Marine Biodiversity of Pulau Layang-Layang Malaysia*, Fisheries Research Institute, Department of Fisheries Malaysia, 25–28. <http://www.fri.gov.my/marsal/penerbitan/giantclam1.pdf>
- Saponari L, Montano S, Seveso D, Galli P (2014) The occurrence of an *Acanthaster planci* outbreak in Ari Atoll, Maldives. *Marine Biodiversity*. doi: 10.1007/s12526-014-0276-6

- Scheer G, Pillai CSG (1983) Report on the stony corals from the Red Sea. *Zoologica*, Stuttgart 133: 1–198, pls. 1–41.
- Schmitt EF, Sluka RD, Sullivan-Sealey KM (2002) Evaluating the use of roving diver and transect surveys to assess the coral reef fish assemblage of southeastern Hispaniola. *Coral Reefs* 21: 216–223. doi: 10.1007/s00338-002-0216-y
- Scott CM, Mehrotra R, Urgell P (2015) Spawning observation of *Acanthaster planci* in the Gulf of Thailand. *Marine Biodiversity* (in press). doi: 10.1007/s12526-014-0300-x
- Somerfield PJ, Jaap WC, Clarke KR, Callahan M, Hackett K, Porter J, Lybolt M, Tsokos C, Yanev G (2008) Changes in coral reef communities among the Florida Keys, 1996–2003. *Coral Reefs* 27: 951–965. doi: 10.1007/s00338-008-0390-7
- Sukumaran J, Holder MT (2010) DendroPy: A Python library for phylogenetic computing. *Bioinformatics* 26: 1569–1571. doi: 10.1093/bioinformatics/btq228
- Svrcula K (2008) Layang Layang diving Malaysia's last frontier. Marshall Cavendish Editions, Malaysia, 168 pp.
- Swofford DL (2002) PAUP\*. Phylogenetic Analysis Using Parsimony (\*and Other Methods), Version 4.0. Sinauer Associates, Sunderland, Massachusetts.
- Takabayashi M, Carter D, Loh W, Hoegh-Guldberg O (1998) A coral-specific primer for PCR amplification of the internal transcribed spacer region in ribosomal DNA. *Molecular Ecology* 7: 928–930.
- Tamura K, Stecher G, Peterson D, Filipksi A, Kumar S (2013) MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. *Molecular Biology and Evolution* 30: 2725–2729. doi: 10.1093/molbev/mst197
- Terraneo TI, Berumen ML, Arrigoni R, Waheed Z, Bouwmeester J, Caragnano A, Stefani F, Benzoni F (2014) *Pachyseris inattesa* sp. n. (Cnidaria, Anthozoa, Scleractinia): a new reef coral species from the Red Sea and its phylogenetic relationships. *ZooKeys* 433: 1–30. doi: 10.3897/zookeys.433.8036
- Turak E, DeVantier L (2011) Field guide to the reef-building corals of Brunei Darussalam. Fisheries Department, Ministry of Industry and Primary Resources, Government of Brunei Darussalam, Brunei Darussalam, 256 pp.
- Veron JEN (2000) Corals of the world. Australian Institute of Marine Science, Townsville.
- Veron JEN, Pichon M (1980) Scleractinia of Eastern Australia III. Families Agariciidae, Siderastreidae, Fungiidae, Oculinidae, Merulinidae, Mussidae, Pectiniidae, Caryophylliidae, Dendrophylliidae. Australian Institute of Marine Science Monograph Series 4: 1–422. doi: 10.5962/bhl.title.60646
- Veron JEN, DeVantier LM, Turak E, Green AL, Kininmonth S, Stafford-Smith MG, Peterson N (2009) Delineating the Coral Triangle. *Galaxea* 11: 91–100. doi: 10.3755/galaxea.11.91
- Veron JEN, DeVantier LM, Turak E, Green AL, Kininmonth S, Stafford-Smith MG, Peterson N (2011) The Coral Triangle. In: Dubinsky Z, Stambler N (Eds) *Coral reefs: an ecosystem in transition*. Springer, Dordrecht, 47–55. doi: 10.1007/978-94-007-0114-4\_5
- Waheed Z, Hoeksema BW (2013) A tale of two winds: species richness patterns of reef corals around the Semporna peninsula, Malaysia. *Marine Biodiversity* 43: 37–51. doi: 10.1007/s12526-012-0130-7

- Waheed Z, Hoeksema BW (2014) Diversity patterns of scleractinian corals at Kota Kinabalu, Malaysia, in relation to exposure and depth. *Raffles Bulletin of Zoology* 62: 66–82.
- Waheed Z, Ahad BG, Jumin R, Hussein MAS, Hoeksema BW (subm) Corals at the northernmost tip of Borneo: An assessment of species richness patterns and reef benthic assemblages.
- Wells JW (1954) Recent corals of the Marshall Islands. United States Geological Survey, Professional Paper 260-I: 385–486.
- White TJ, Bruns T, Lee S, Taylor J (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (Eds) *PCR protocols. A guide to methods and application*. Academic Press Inc., San Diego, 315–322. doi: 10.1016/b978-0-12-372180-8.50042-1
- Wood EM, Tan BS (1987) Hard Coral. In: *The corals reefs of the Bodgaya Islands (Sabah: Malaysia) and Pulau Sipadan*. *Malayan Nature Journal* 40: 189–224.
- Wyrski K (1961) *Physical Oceanography of the Southeast Asian Waters*. NAGA Report Volume 2: Scientific Results of Marine Investigations of the South China Sea and the Gulf of Thailand, 1959–1961. University of California, La Jolla, USA, 195 pp.
- Zainuddin I, Pauzi MA, Abdul Razak L, Yazid MY (2000) Preliminary study on the diversity and distribution of sponges at Pulau Layang-layang, Sabah, Malaysia. *Malayan Nature Journal* 54: 77–86.
- Zakariah ZM, Ahmad AR, Tan KH, Basiron MN, Yusoff NA (2007) National report on coral reefs in the coastal waters of the South China Sea – Malaysia. In: *National reports on coral reefs in the coastal waters of the South China Sea*. UNEP/GEF/SCS Technical Publication 11: 37–54. [http://www.unepscs.org/components/com\\_repository\\_files/downloads/National-Report-Coral-Reefs-Malaysia.pdf](http://www.unepscs.org/components/com_repository_files/downloads/National-Report-Coral-Reefs-Malaysia.pdf)
- Zwickl DJ (2006) Genetic algorithm approaches for the phylogenetic analysis of large biological sequence datasets under the maximum likelihood criterion. PhD dissertation, The University of Texas, Austin.

## **Supplementary material 1**

### **Table S1**

Authors: Zarinah Waheed, Francesca Benzoni, Sancia E.T. van der Meij, Tullia I. Terraneo, Bert W. Hoeksema

Data type: measurement

Explanation note: Physical properties of seawater at Pulau Layang-Layang.

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## **Supplementary material 2**

### **Table S2**

Authors: Zarinah Waheed, Francesca Benzoni, Sancia E.T. van der Meij, Tullia I. Terraneo, Bert W. Hoeksema

Data type: specimens data

Explanation note: Coral samples included in the molecular analyses with supporting collection and locality data.

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## **Supplementary material 3**

### **Table S3**

Authors: Zarinah Waheed, Francesca Benzoni, Sancia E.T. van der Meij, Tullia I. Terraneo, Bert W. Hoeksema

Data type: specimens data

Explanation note: Species occurrence of hard coral families Fungiidae, Agariciidae and Euphylliidae at Pulau Layang-Layang.

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## Supplementary material 4

### Figure S1

Authors: Zarinah Waheed, Francesca Benzoni, Sancia E.T. van der Meij, Tullia I. Terraneo, Bert W. Hoeksema

Data type: molecular data

Explanation note: Maximum likelihood phylogram of *Pavona maldivensis* and *P. explanulata*. **a** mitochondrial intergenic spacer between CO1 and 16S-rRna. The sequence alignment consisted of 680 characters with 593 constant, 23 variable and 64 parsimony informative characters, **b** nuclear marker ITS1-5.8S-ITS2, with 680 characters of 649 constant, 14 variable and 17 parsimony informative characters. Support values for maximum likelihood, maximum parsimony (>70) and bayesian posterior probabilities (>80) are given at the nodes. Dashes (-) indicate nodes without statistical support.

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## Supplementary material 5

### Figure S2

Authors: Zarinah Waheed, Francesca Benzoni, Sancia E.T. van der Meij, Tullia I. Terraneo, Bert W. Hoeksema

Data type: specimens data

Explanation note: Variation of corallite form and structure in *Pavona maldivensis* (**a**, **c**, **e**), and *P. explanulata* (**b**, **d**, **f**). **a** specimen LAC23 from Layang-Layang, **b** specimen BAN01 from Banggi, North Borneo, **c** specimen LOY12 from Loyalty Islands, **d** specimen BAN02 from Banggi, North Borneo, **e** specimen MAL from the Maldives, and **f** specimen TER28 from Ternate, Indonesia.

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# A new member of troglobitic Carychiidae, *Koreozospeum nodongense* gen. et sp. n. (Gastropoda, Eupulmonata, Ellobioidea) is described from Korea

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**Citation:** Jochum A, Prozorova L, Sharyi-ool M, Páll-Gergely B (2015) A new member of troglobitic Carychiidae, *Koreozospeum nodongense* gen. et sp. n. (Gastropoda, Eupulmonata, Ellobioidea) is described from Korea. ZooKeys 517: 39–57. doi: 10.3897/zookeys.517.10154

## Abstract

A new genus of troglobitic Carychiidae Jeffreys, 1830 is designated from Nodong Cave, North Chungcheong Province, Danyang, South Korea. This remarkable find represents a great range extension and thus, a highly distant distribution of troglobitic Carychiidae in Asia. The *Zospeum*-like, carychiid snails were recently included, without a formal description, in records documenting Korean malacofauna. The present paper describes *Koreozospeum* Jochum & Prozorova, **gen. n.** and illustrates the type species, *K. nodongense* Lee, Prozorova & Jochum, **sp. n.** using novel Nano-CT images, including a video, internal shell morphology, SEM and SEM-EDX elemental compositional analysis of the shell.

## 발췌

Carychiidae Jeffreys, 1830 (양귀비고동/동굴거주생명체, 제프리 1830) 의 새로운 속은 한국 충청북도 단양의 노동동굴에서 지정되었다. 이 놀라운 발견은 이 동굴거주생물의 아시아지역까지의 광대한 확장과 상당히 분리된 분포를 나타낸다. “*Zospeum*-like” (유럽에서 발견된 달팽이종), carychiid snails 은 최근에 공식적인 명칭없이 한국의 연체동물문서목록에 포함되었다. 본 논문은 *Koreozospeum* Jochum & Prozorova, **gen. n.** 을 설명하고 껍질내부 X-ray촬영, SEM과 SEM-EDX 껍질 기본 구성분석등을 나타내는 영상을 포함, 첨단 나노-CT 이미지를 이용하며 신종 *K. nodongense* Lee, Prozorova & Jochum, **sp. n.** 을 묘사한다.

## Keywords

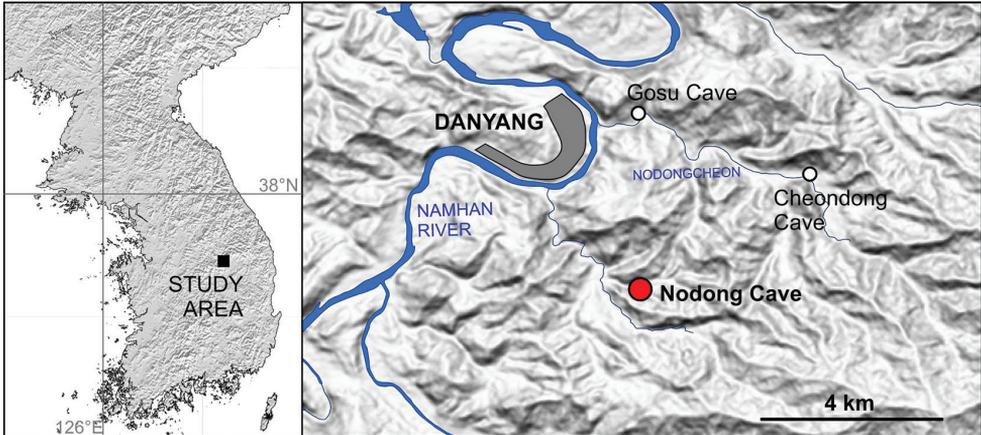
Cave-dwelling species, subterranean snail, energy-dispersive X-ray spectrometry, microgastropoda, ecology, conservation

## Introduction

It is estimated that the Korean peninsula harbors more than 1,000 caves within its Cambro-Ordovician limestone geology (Kashima et al. 1978, Woo et al. 2001). Of these caves, only one, Nodong-donggul (Nodong cave, 36°57.186'N, 128°22.938'E) in North Chungcheong Province, South Korea (Fig. 1) is so far known to contain finds of “*Zospeum*-like” carychiid microgastropods (Kwon et al. 2001, Lee and Min 2002, Min et al. 2004). The shell shape and microsculpture of these tiny snails most closely resemble the troglobitic genus *Zospeum* Bourguignat, 1856 (Ellobioidea, Carychiidae) rather than epigeal *Carychium* O. F. Müller, 1774 (Prozorova et al. 2010, 2011). Cave-dwelling species are not known from nearby Japan, which was recently found to contain the highest lineage diversity for Carychiidae Jeffreys, 1830 (Weigand et al. 2013a). The present material comprises the first account of troglobitic Carychiidae in Asia. Up to now, subterranean taxa included only members of the genus *Zospeum*, exclusively known to inhabit karst caves of southern Alpine Europe (Jochum et al. 2015). (The North American species, *Carychium stygium* Call, 1897 is no longer considered an exclusively troglobitic species (Weigand et al. 2011, 2013b)). The taxon described here represents an extreme range extension to Asia for subterranean ellobioid snails (Fig. 2).

Open to the public as a tourist attraction, Nodong cave extends approximately 800 m in length and drops 300 m in vertical depth. Geographically, it is located near the Nodongcheon, a branch of the Namhan River (Lee 2012) and near the city of Danyang, a resort town at the base of the extensive Sobaeksan National Park. Other known caves and potential habitats for troglobitic carychiid snails in the immediate vicinity include the public caves, Gosu and Cheondong.

When material, such as the shells of troglobitic carychiids, is particularly limited and rare, contemporary non-destructive techniques for taxonomic assessment are essential. Applied in taxonomy, contemporary methods used primarily in medicine and industry can provide new opportunities for understanding global and local biodiversity. They can also act as catalysts for igniting dire conservation strategies regarding rare populations and for extracting valuable information sequestered in their organic forms. In this work, one of six known Korean carychiid shells has been examined using Nano-CT imaging to assess and compare the internal shell morphology of *Koreozospeum nodongense* sp. n. with its supposed closest relative, the European genus *Zospeum*. In addition, available shell fragments of *K. nodongense* sp. n. material were examined via scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectrometry (EDX) to investigate the internal morphology



**Figure 1.** Map indicating location of Nodong cave (locus typicus), Danyang, North Chungcheong Province, South Korea. Red dot, *K. nodongense* sp. n.; White dots indicate potential *K. nodongense* sp. n. habitats in Gosu and Cheondong caves in the vicinity of Nodong cave.



**Figure 2.** Map indicating the extreme distant distribution of subterranean Carychiidae represented by *K. nodongense* sp. n. (Nodong cave, South Korea, locus typicus) in conjunction with the known subterranean distribution of European *Zospeum* Bourguignat, 1856 in Northern Spain, the Southern Alps and the Dinaric Alps. Red colour indicates *Zospeum*, and green indicates *Koreozospeum*.

of the shell and to determine the elemental composition of the shell matrix. In addition, and as a secondary consideration, limited information is available regarding the specific geology and ecology of Nodong cave and adjacent, potentially contiguous caves (i.e. Gosu cave and Cheongong cave) of North Chungcheong Province. SEM-EDX elemental compositional analysis opens windows for inference about the subterranean ecology of *K. nodongense* sp. n. and likely the ecology of adjacent caves for future investigation.

In this work, a new subterranean taxon is described from Korea based on characters significantly differentiating from European *Zospeum* morphotypes. SEM and Nano-CT images of the intact shell of the new species and SEM-EDX graphic images of the elemental composition of selected sections of shell fragments are presented.

## Material and methods

Similar to conditions known for *Zospeum* (see Jochum et al. 2015), carychiid snails were collected live on muddy walls in January 2000 by J.-S. Lee in the dark zone of Nodong cave (Prozorova et al. 2010, 2011).

One shell (Holotype NMBE 534197/1) available for examination outside of Vladivostok and Korea (99 lost, see below) and six paratypes located in Vladivostok were measured according to Jochum et al. (2015, fig. 1). The number of whorls was counted according to the method described in Kerney and Cameron (1979). For the species description, shell measurements are expressed as: shell height (SH); shell width (SW); height of the last whorl (HLWH); peristome height (PH); peristome diameter (PD); spire Angle (SA); number of whorls (W); widest diameter (WD) (distance from top to bottom). Spire angle (SA) is given in degrees. Other measurements are in mm. Measurements of the holotype (NMBE 534197/1) were taken from images obtained using a Leica DFC420 digital camera attached to a Leica M165c stereo microscope, supported by Leica LAS V4.4 software. Measurements of the paratypes (ZIN RAS 1) were taken using the LOMO MBS-10 stereo microscope (Lytkarino, Ru.). Qualitative aspects of shell morphology including peristome shape; whorl profile (whorl convexity); protoconch and teleoconch sculpture; description of the lamella on the parieto-columellar region of the aperture; configuration of the columellar lamella and the independent configuration of the columella are documented.

Since the individuals reported by Prozorova et al. (2011), which were housed in the Min Molluscan Research Institute in Seoul, South Korea have become regrettably lost to science, as much information as possible was extracted from the holotype (NMBE 534197/1), one paratype (IBSS FEB RAS 7787) and some fragments (paratype NMBE 534361/2) using Nano-CT imaging (whole shell), SEM and SEM-EDX energy-dispersive X-ray spectrometry (fragments). No individuals were preserved in ethanol, precluding molecular analyses and anatomical examination.

## Image acquisition

SEM: *Koreozospeum nodongense* sp. n. (IBSS FEB RAS 7787 paratype) (now damaged) was coated with carbon and imaged (Prozorova et al. 2011) at the Centers of Collective Use in IBSS and the Institute of Marine Biology FEB RAS using the Zeiss EVO -40 scanning electron microscope (Jena, Germany) implementing the Variable Pressure (VP) mode.

SEM-EDX: Morphological (SEM) and elemental composition (EDX) of *Koreozospeum nodongense* sp. n. paratype (NMBE 534361/2) fragments were assessed using the FEI-Aspex Explorer scanning electron microscope system (Hillsboro, OR, USA), implementing a BE detector for image generation. Non-coated shell material was placed on a cellulose membrane and mounted on a computer-controlled stage for scanning. Elemental composition was detected (i.e. each element shows a multiple-peak pattern in the spectrum) by using an emission current of 29 mA, an electron beam acceleration voltage of 20 kV under sample pressure of 0.15 Torr and a working distance of 22.9 mm at RJL Micro & Analytic GmbH, Karlsdorf-Neuthard, Germany. In our analyses, some peaks overlap, whereby the elemental letters also overlap. Peak height represents the intensity of the element and this is proportional to the mass percentage present in the assessed shell region.

Micro-CT: *Koreozospeum nodongense* sp. n. (NMBE 534197/1) was imaged using a nano-computed tomography system (Nano-CT), manufactured and developed by Bruker-Micro-CT/SkyScan (SkyScan 1172, Kontich, Belgium). The video of *K. nodongense* sp. n. was created using a SkyScan 1172 scanner at RJL Micro & Analytic GmbH, Karlsdorf-Neuthard, Germany. The scanner is equipped with a sealed micro focus X-ray source and a 11 Mpx CCD detector. The specimen was scanned with 4 µm voxel size in rotation steps of 0.6° at 59 kV tube voltage and 167 µA tube current. Reconstruction with cross sectional images was performed using a modified Feldkamp cone-beam reconstruction algorithm. Image resolution of the cross sectional images was 4 µm isotropic voxel side length with a grey scale resolution of 8 bit. The animated video was generated using a direct volume rendering method implemented in the software CTvox.

Digital images: *Koreozospeum nodongense* sp. n. (holotype NMBE 534197/1) and fragments of the ultimate whorl (paratype NMBE 534361/2) were photographed using a Leica DFC 425 multilayered photography system. All measurements are in mm.

## Abbreviations

<b>ANSP</b>	Academy of Natural Sciences, Philadelphia, Pa., USA
<b>IBSS FEB RAS</b>	Institute of Biology and Soil Science, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, Russia
<b>MHNG</b>	Museum d'Histoire Naturelle de Genève, Geneva, Switzerland
<b>MMRI</b>	Min Molluscan Research Institute, Seoul, South Korea
<b>MNCN</b>	Museo Nacional de Ciencias Naturales, Madrid, Spain
<b>NHMUK</b>	Natural History Museum, London, UK
<b>NHMW</b>	Naturhistorisches Museum, Wien, Austria
<b>NMBE</b>	Naturhistorisches Museum der Burgergemeinde Bern, Switzerland
<b>ZIN RAS</b>	Zoological Institute of the Russian Academy of Sciences, St. Petersburg, Russia
<b>ZUPV/EHU</b>	Colección de Fauna Cavernícola (Departamento de Zoología) de la Universidad del País Vasco-Euskal Herriko Unibertsitate, Bilbao, Spain

## Taxonomy

### Family Carychiidae Jeffreys, 1830

#### Genus *Koreozospeum* Jochum & Prozorova, gen. n.

<http://zoobank.org/FDA3DA2E-7FEE-4C65-ACFF-D8C953E1A2CA>

Figures 3–11

**Type species.** *Koreozospeum nodongense* sp. n.

**Diagnosis.** Shell thin, ovate-conic, fine spiral rows of interconnected pits constant throughout teleoconch, peristome oblique auriform, conspicuous plicate lip (side view).

**Differential diagnosis.** Differs from *Carychium* by its squat ovate-conic form, absence of major apertural dentition and its singularly troglobitic ecology; from *Zospeum* by the oblong, slightly detached, oblique, auriform peristome, shallow suture, minimally convex whorls, interrupted low lamella on roof of interior penultimate whorl forming annular lamella, and the conspicuously pleated lip folded back onto the body whorl and not rolled into the body whorl as in *Zospeum*.

**Derivatio nominis.** The name derives from Korea, the land of the type locality and the similarity to European *Zospeum*.

**Distribution.** Only known from Nodong cave.

#### *Koreozospeum nodongense* Lee, Prozorova & Jochum, sp. n.

<http://zoobank.org/F740D7E3-6C8D-4A0E-AD62-0FBDBE6A042D>

Figures 3–11

2004 “*Carychium*” sp. Min, Lee, Koh and Je, Mollusks in Korea. Min Molluscan Research Institute, Seoul, Korea. 566 pp., 342–343, fig. 1080.

2011 “*Zospeum*” sp. Prozorova, Lee and Zasyapkina, Korean Journal of Soil Zoology 15(1–2): 1–4, figs 1–3.

**Material.** *Type material.* Holotype (NMBE 534197/1): South Korea, North Chungcheong Province, Danyang County, Nodong cave, 36°57.186'N, 128°22.938'E, alt. ca. 271 m, moist muddy walls in cave, 13.01.2000, leg. Jun-Sang Lee.

Paratypes: *locus typicus*: 3 fragments (NMBE 534361/2), data as the holotype; 1 broken shell (IBSS FEB RAS 7787), *ibid.*; 5 shells, 1 broken (ZIN RAS 1), *ibid.*

**Diagnosis.** Shell small, thin, ovate-conic, smooth, fine spiral rows of interconnected pits constant throughout teleoconch, plicate apertural lip may or may not be present (side profile).

**Description.** *Koreozospeum nodongense* sp. n. is characterized by a very small, alabastrine, ovate conical shell with 5 regular, moderately increasing whorls. The penultimate whorl is slightly angularly shouldered at the uppermost extension of the peristome in left and right profile positions (Fig. 3B–C). Peristome oblong, auriform,

oblique to shell axis, partially adnate to ultimate whorl, otherwise slightly detached (Fig. 3K), more or less thickened (Fig. 3A, D–E); the lip is folded back onto the body whorl and thickly plicate 3/4 of the lip side-view height (Figs 3C, 4B, E); deep umbilical notch (Figs 3 H–I) with wrinkles projecting into notch behind peristome region (Fig. 4D); robust columellar lamella running into the shell interior (Figs 3A, D–E, 5I–K). The protoconch is obtuse and shows a pattern of spiral interconnected pits (Fig. 4); the teleoconch bears tightly spaced irregular spiral striae of densely interconnected pits (Figs 4, 9) and shows a marbled surface pattern of faint, horizontally-elongated chevrons intercalating with each successive whorl (Fig. 5 A, C). Suture irregular and shallow, bordered by white marginal zone at each increasing abapical whorl (Figs 3C, F, 4). Interior perspectives show a parietal structure consisting of a partially discontinuous lamellar ridge on the roof of the penultimate whorl (Fig. 4I–K), which then develops into the uniformly shaped annular lamella running directly under the penultimate whorl into the aperture. The columella is moderately slender, clavate (Fig. 5G–H) with a single, annular lamella (Fig. 5G–L).

**Measurements** (in mm). Holotype (NMBE 534197/1) (Figs 3A–G, 7): H = 1.72; SW = 1.19; HLWH = 1.13; PH = .78; PD = .69; SA = 68.6; W = 5.65; WD = .81. See also Table 1.

**Etymology.** The new species is named after Nodong cave, the type locality.

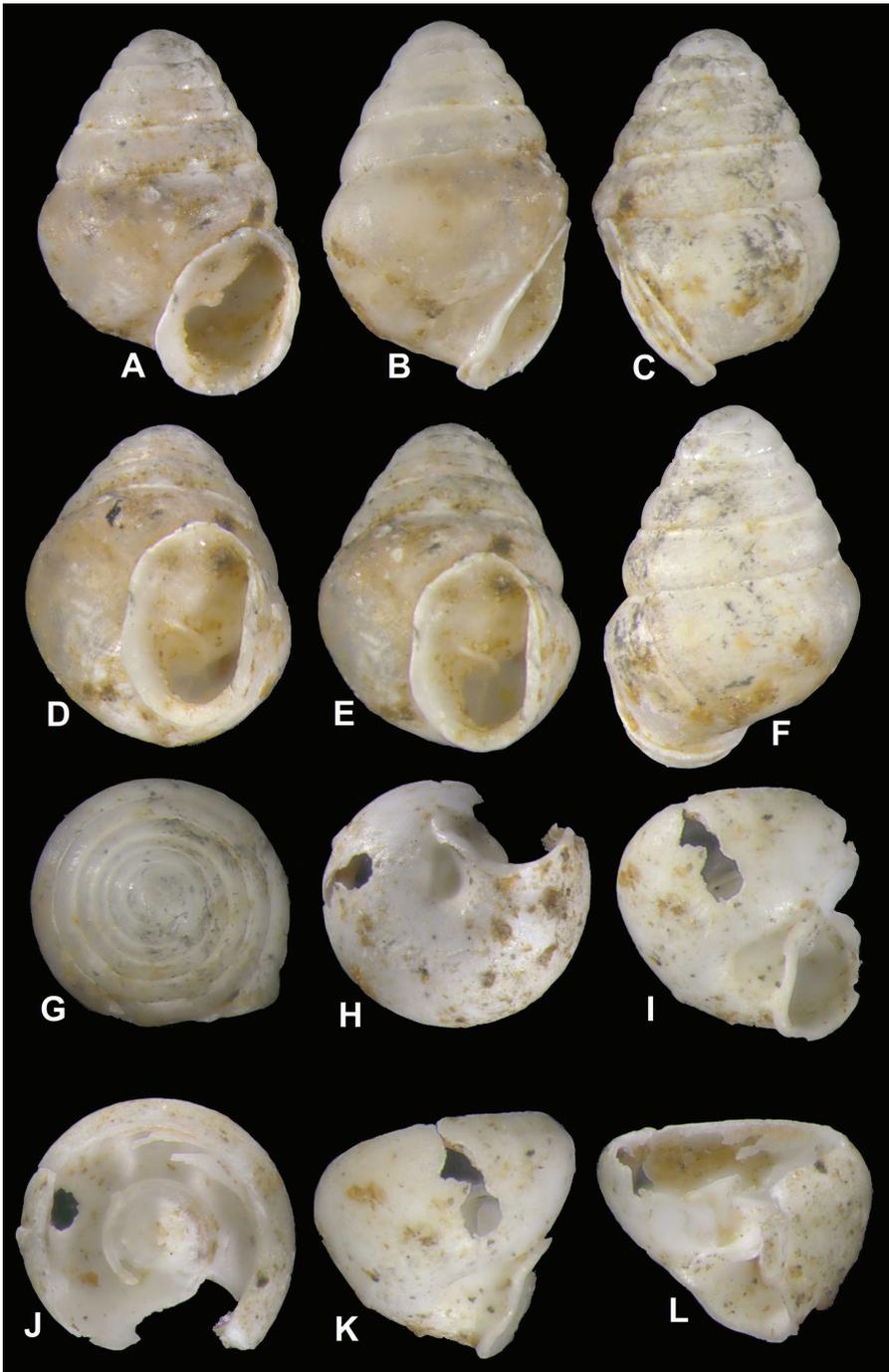
**Type locality.** South Korea, North Chungcheong Province, Danyang County, Nodong cave, 36°57.186'N, 128°22.938'E, alt. ca. 270 m, moist muddy walls in cave.

**Distribution.** Only known from the type locality.

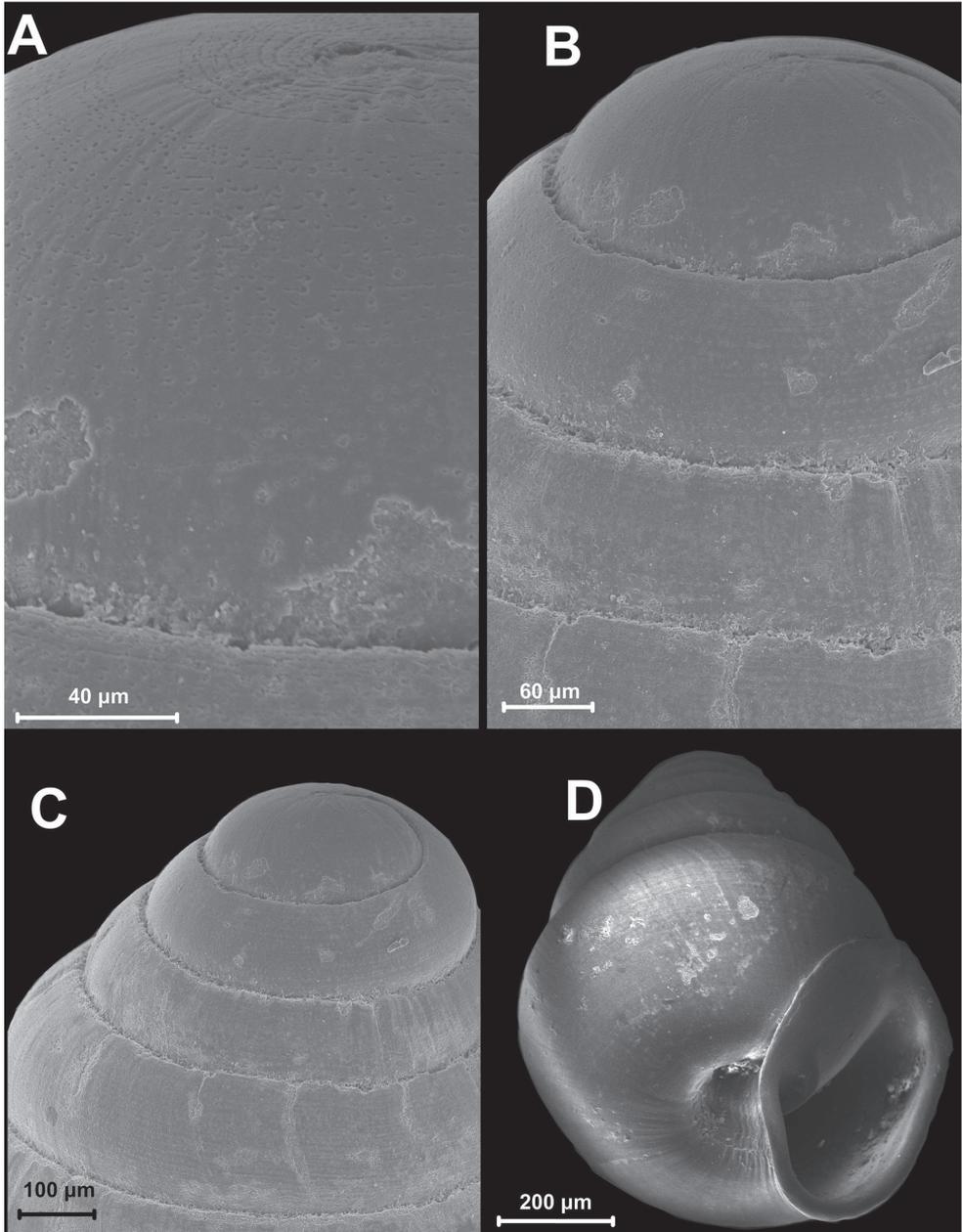
**Ecology.** Suggested mix of volcanic elements in cave mud of Nodong cave.

**Conservation status.** A cursory search through the Internet indicates that the region harboring caves encompassed within the administrative boundaries of Danyang County is greatly threatened. Due to the abundance of limestone in the area, cement factories are big industries there. Of more immediate threat, however, is the frequent human traffic that the caves of Nodong, Gosu and Cheondong receive in light of their popularity as tourist attractions. To exacerbate concerns, a newly built stairway into the deepest, darkest sections of the cave has made Nodong more accessible (Lee 2012). Since *K. nodongense* sp. n. is known to live in only one locality and the area is potentially declining due to human encroachment, this species is Critically Endangered (CR) under IUCN criteria (IUCN 2014).

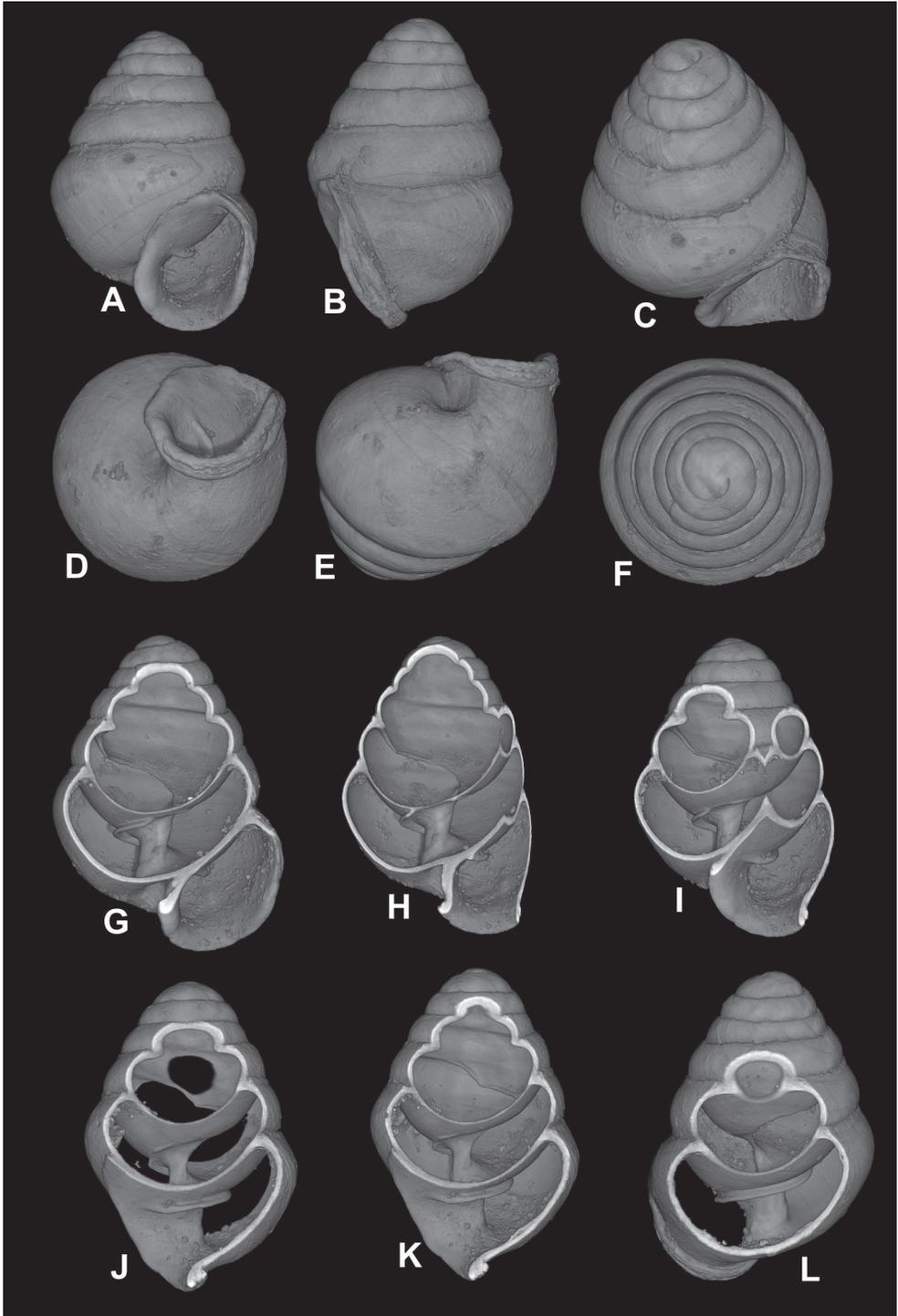
**Remarks.** *Koreozospeum nodongense* sp. n. appears to be polymorphic in regards to the configuration of a plicate versus non-plicate apertural lip (side view). This elaboration of the lip was apparent in two shells (NMBE 534197/1; ZIN RAS 1) of the five examined shells (1 juvenile with undeveloped lip). We have little doubt that the plicate and non-plicate specimens co-occurring at Nondong cave are conspecific. Prozorova et al. (2011) initially examined the paratype specimen (IBSS FEB RAS 7787) using SEM (Fig. 4). This work revealed microstructural pitting on the protoconch in sync with the concentric pitting pattern reported by Jochum (2011) as a consistent character for the worldwide members of the extant Carychiidae. Protoconch pitting is also known in Eastern European carychiid fossils examined via SEM (Strauch 1977, Stworzewicz



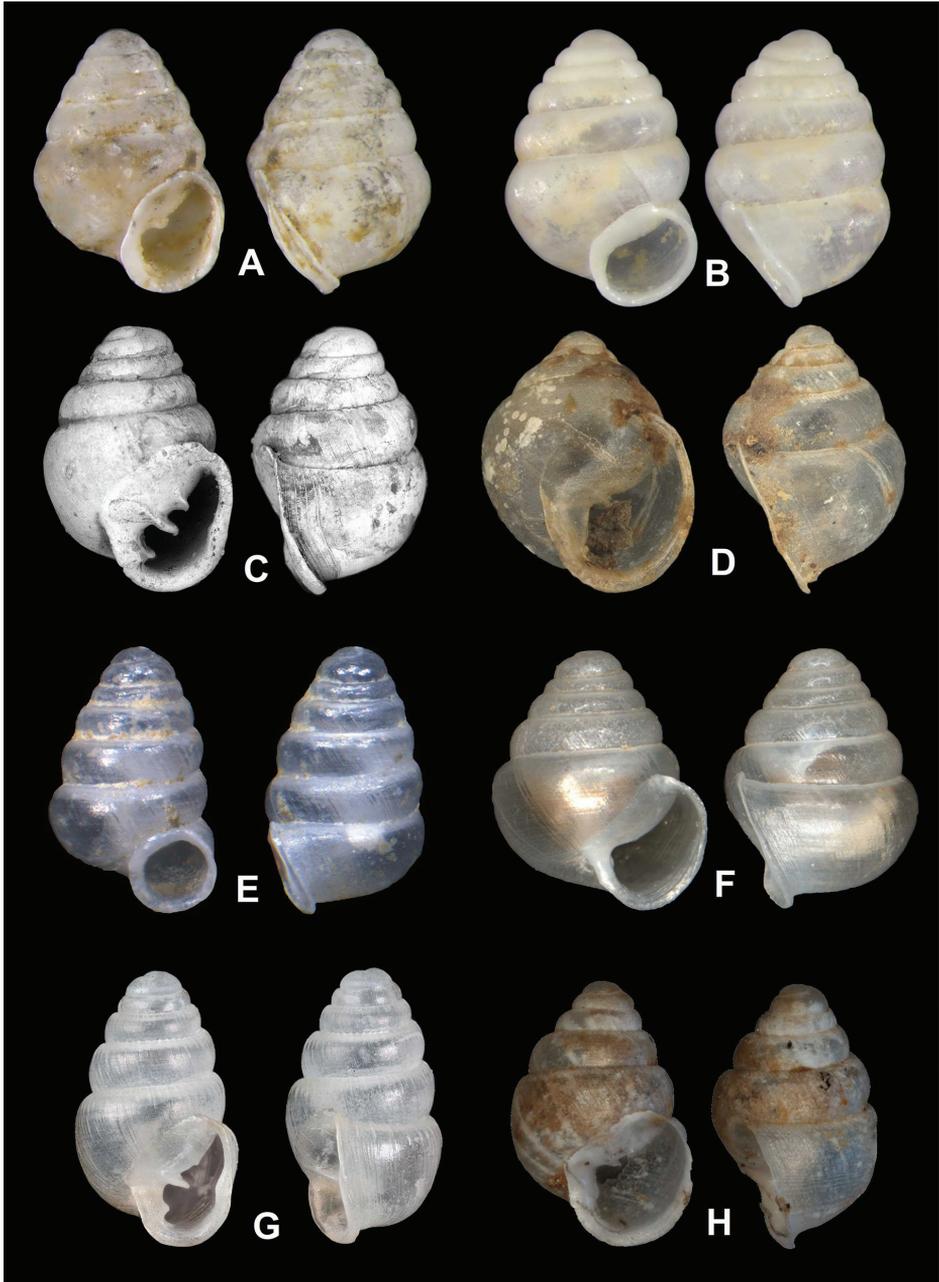
**Figure 3.** *Koreozospeum nodongense* sp. n., **A–G** different views of holotype (NMBE 534197/1) **H–L** different views of body whorl fragment of paratype (NMBE 534361/2) **H** umbilical notch **I, K** side view of umbilical region **J** areal view of columella surrounded by the single, low annular lamella **L** side view of lamella and orientation to the columella.



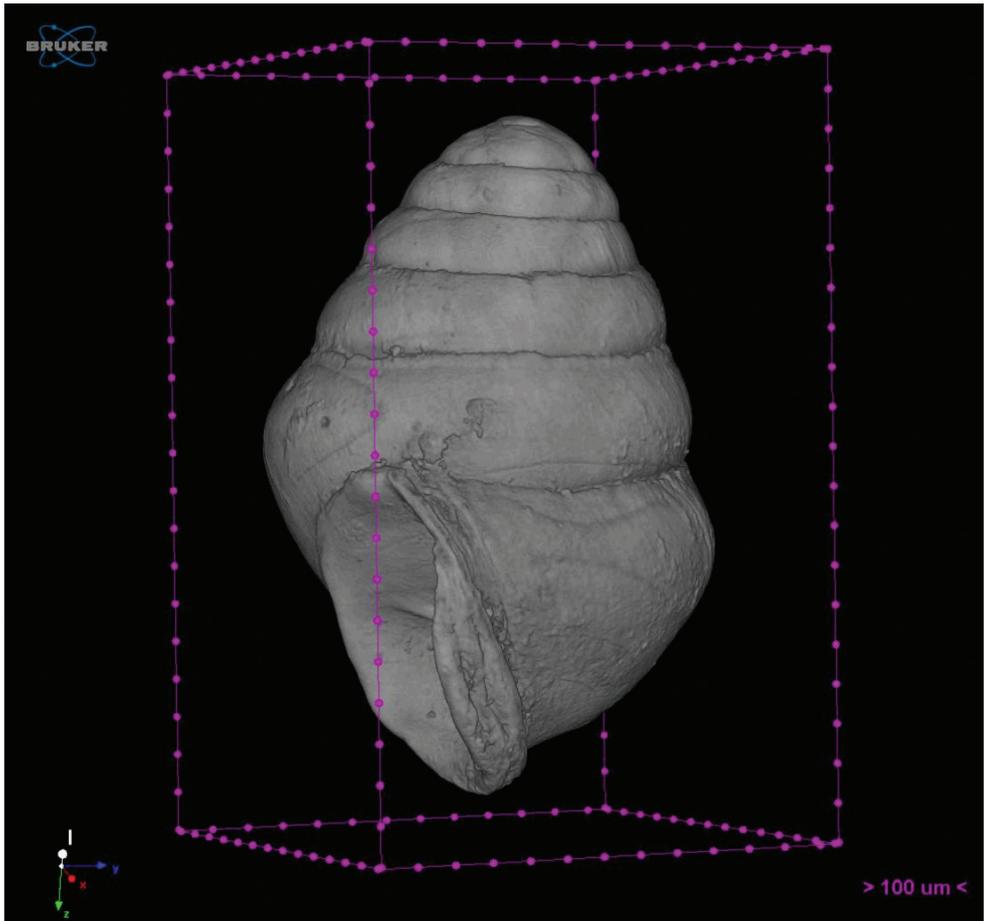
**Figure 4.** SEM of paratype (IBSS FEB RAS 7787). **A** Protoconch and **B–C** apical whorls showing pitted pattern of microstructure and shallow suture **D** umbilical notch showing wrinkles behind the peristome. Scale bar increments  $\mu\text{m}$ .



**Figure 5.** Nano-CT images of *Koreozospeum nodongense* sp. n., **A–F** different views of holotype (NMBE 534197/1) **G–L** cross sections showing shell interior **G–H** clavate columella **I–L** annular lamella.



**Figure 6.** Comparative images of European *Zospeum* Bourguignat, 1856. Museum type material showing ventral and side views. **A** *Koreozospeum nodongense* sp. n. Holotype (NMBE 534197/1) **B** *Z. bellesi* E. Gittenberger, 1973 (Syntype ZUPV/EHU 188) **C** *Z. lautum* (Frauenfeld, 1854) (Holotype ANSP 22529); **D** *Z. obesum* (Frauenfeld, 1854) (Syntype MHNG 7904) **E** *Z. vasconicum* Prieto, De Winter, Weigand, Gómez & Jochum, 2015 (Holotype MNCN15.05/60147H) **F** *Z. zaldivarae* Prieto, De Winter, Weigand, Gómez and Jochum, 2015 (Holotype MNCN15.05/60148H); **G** *Z. spelaeum schmidtii* (Frauenfeld, 1854) (Syntype NHMUK 1991027) **H** *Z. exiguum* Kuščer, 1932 (Holotype NHMW 32008).



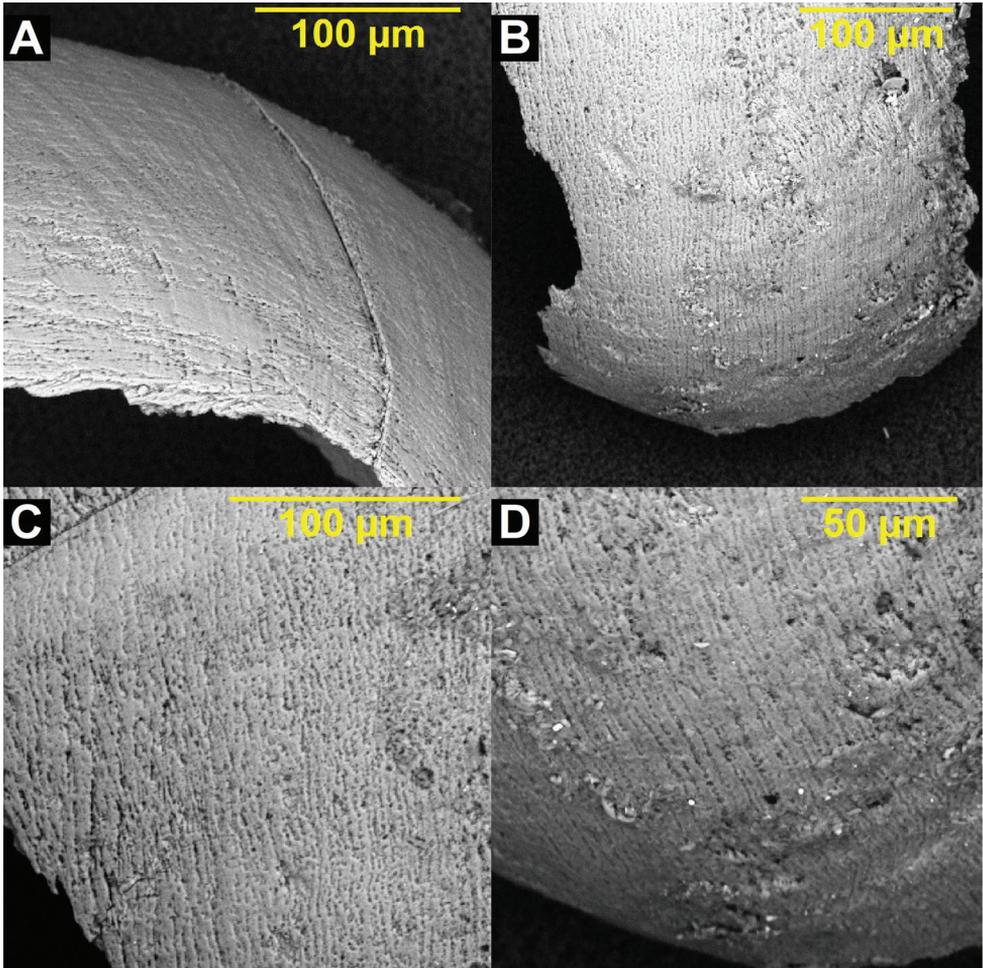
**Figure 7.** Nano-CT film of *Koreozospeum nodongense* sp. n. holotype (NMBE 534197/1) YouTube link: [https://youtu.be/SU020\\_GmLaA](https://youtu.be/SU020_GmLaA).

1999, Harzhauser et al. 2014a, 2014b, Jochum et al. 2015). In congruence with the findings of Prozorova et al. (2011), the fragments of *K. nodongense* sp. n. here show tightly spaced irregular spiral striae of densely interconnected pits with some occasional, non-pitted patchy zones over the entire teleoconch (Fig. 9). This dense pattern of total teleoconch pitting is also found in *Zospeum isselianum* Pollonera, 1887 and *Zospeum bellesi* Gittenberger, 1973 (Jochum, unpublished data).

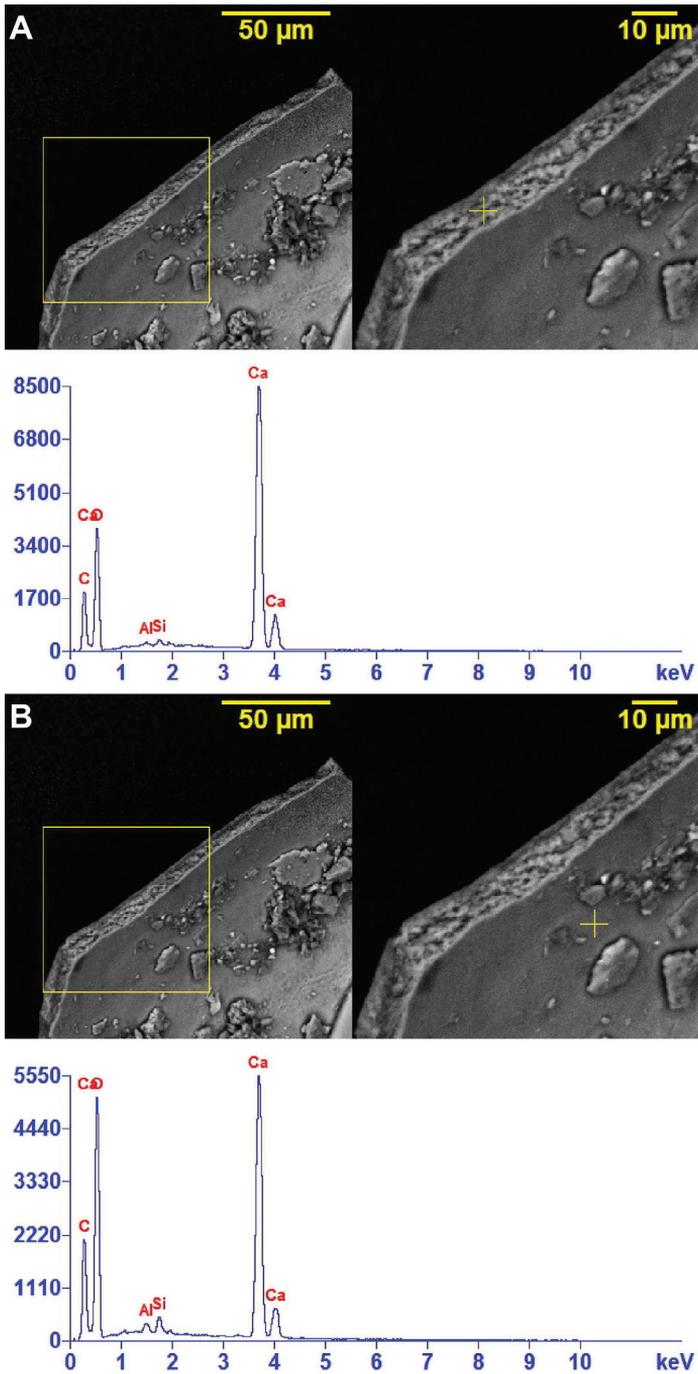
The SEM-EDX analysis (Fig. 10A–B) of the surface structure located in the central zone of the fragment edge and the internal surface of the shell shows varying concentrations of the same elements, including calcium (Ca), aluminum (Al), silicon (Si), oxygen (O) and carbon (C) for these two separate regions of the shell. A band (Fig. 11A) of likely volcanic origin of the mud (i.e. lava and alkali basalt) is indicated on the surface of one of the shell fragments. This band contains fractions of the elements calcium (Ca), aluminum (Al), silicon (Si), oxygen (O), carbon (C), iron (Fe), zinc (Zn), chromium (Cr), chlorine (Cl), magnesium (Mg) and potassium (K). The non-banded



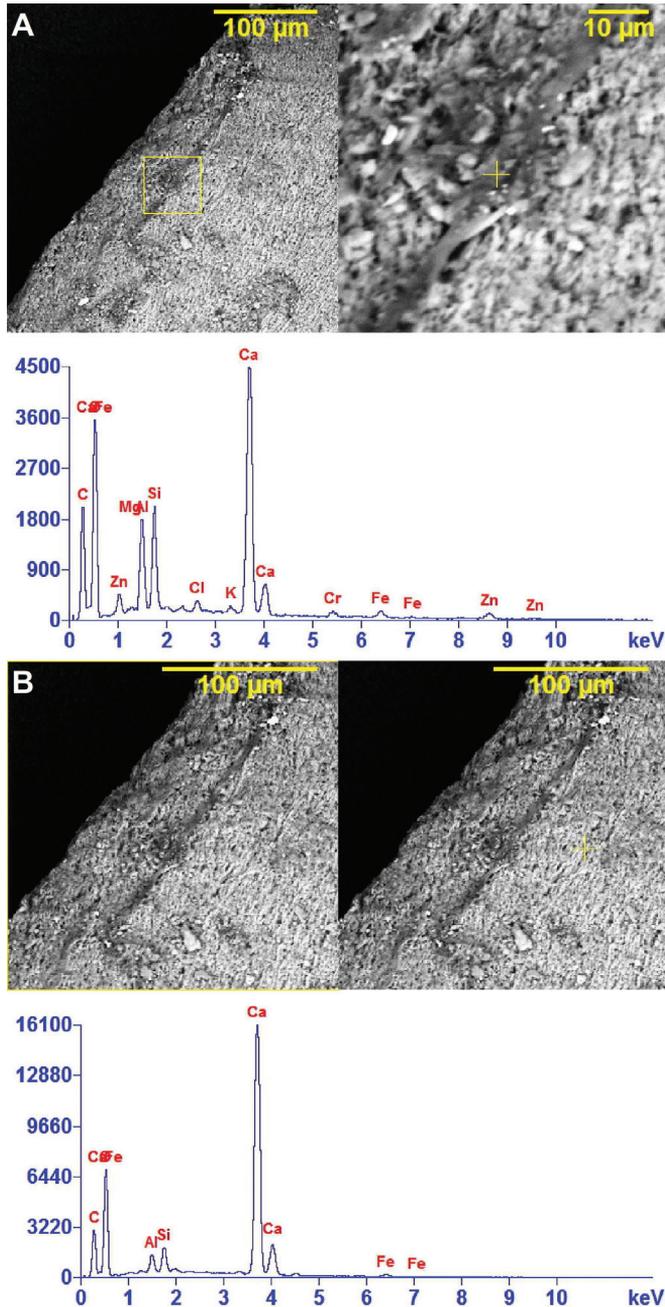
**Figure 8.** *Koreozospeum nodongense* sp. n. paratype shells (ZIN RAS 1). Scale bar increments 1 mm.



**Figure 9.** SEM of microstructure pattern on surface of teleoconch fragments of *Koreozospeum nodongense* sp. n. paratype (NMBE 534361/2) showing tightly spaced irregular spiral striae of densely interconnected pits.



**Figure 10.** SEM-EDX spectroscopic images showing the spectrum of the elemental content in two regions of the inner shell of *K. nodongense* sp. n. paratype (NMBE 534361/2). **A** surface of shell edge **B** the inner layer of the shell. Both regions (yellow +) show the presence of calcium (Ca), aluminum (Al), silicon (Si) and carbon (C).



**Figure 11.** SEM-EDX spectroscopic images showing the elemental spectrum of two regions (yellow +) on the outside surface of the shell of *K. nodongense* sp. n. paratype (NMBE 534361/2). **A** band of compacted residue (sediment?) on the surface of the shell containing calcium (Ca), aluminum (Al), silicon (Si), oxygen (O), carbon (C), Iron (Fe), zinc (Zn), chromium (Cr) and potassium (K) **B** region to the left of **A** showing presence of calcium (Ca), aluminum (Al), silicon (Si), oxygen (O), carbon (C) and iron (Fe).

**Table 1.** Measurements of six paratypes (ZIN RAS 1) and holotype (NMBE 534197/1) of *K. nodongense* sp. n., including shell condition (SC) and apertural lip configuration (ALC) in side view. Measurements in mm. Spire angle (SA) in degrees.

	Holotype NMBE 534197/1	P-type 1 ZIN RAS 1	P-type 3 ZIN RAS 1	P-type 4 ZIN RAS 1	P-type 5 ZIN RAS 1	P-type 6 ZIN RAS 1	P-type 2 IBSS FEB RAS 7787
SC			partly broken, top separated		apical whorls compressed	juvenile	broken after SEM study
ALC	plicate	plicate	non-plicate, thin	non-plicate, thin	thin lip	undeveloped lip	non-plicate, thin
SH	1.72	1.75	1.75	1.63	1.75	1.43	1.69
HLWH	1.13	0.6	0.57	0.58	0.55	0.45	0.69
PH	0.78	0.9	0.9	0.85	0.95	0.68	0.79
SW	1.19	1.30	1.35	1.15	1.25	1.05	1.14
PD	0.69	0.63	0.73	0.65	0.8	0.65	0.69
W	5.65	5.75	5.75	5.7	5.5	5.1	5.7
SA	68.6	68.0	72.0	68.0	76.0	73.5	66.5

region of shell (Fig. 11B) shows varying concentrations of calcium (Ca), aluminum (Al), silicon (Si), oxygen (O), carbon (C) and iron (Fe).

Interestingly for *K. nodongense* sp. n. is that the trace elements, aluminum (Al) and silicon (Si), might potentially be involved in the biomineralization process of the shell matrix. It is not clearly discernable whether or not they are intrinsic to the shell or represent contaminants from the substrate. Further study, independent of this work, involving major- and trace element analysis coupled with isotope geochemical analysis might suggest the relatively large variability of elements found in our SEM-EDX analyses to be due to the heterogeneous nature of different magmas mixing at different stages of their evolution in historic volcanic eruptions in South Korea (Brenna et al. 2012). Eroded lava particulates and ash may well constitute the sediment overlying the Ordovician limestone of Danyang County.

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## References

- Bourguignat MJR (1856) Aménités malacologiques. § LI. Du genre *Zospeum*. Revue et Magasin de Zoologie pure et appliquée (2) 8: 499–516. <http://www.biodiversitylibrary.org/item/19522#page/505/mode/1up>
- Bourguignat MJR (1857) Aménités Malacologiques LXIV. Du genre *Carychium*. Revue et Magasin de Zoologie pure et appliquée (2) 9: 209–232. <http://www.biodiversitylibrary.org/item/48710#page/217/mode/1up>
- Brenna M, Cronin SJ, Smith IEM, Maas R, Sohn YK (2012) How small-volume basaltic magmatic systems develop: a case study from the Jeju Island volcanic field, Korea. *Journal of Petrology* 53(5): 985–1018. doi: 10.1093/petrology/egs007
- Call RE (1897) Notes on the flora and fauna of Mammoth Cave. *American Naturalist* 31: 377–391. doi: 10.1086/276615
- Gittenberger E (1973) Three notes on Iberian terrestrial gastropods. *Zoologische Mededelingen* 55(17): 201–212.
- Harzhauser M, Neubauer TA, Gross M, Binder H (2014a) The early Middle Miocene mollusc fauna of Lake Rein (Eastern Alps, Austria). *Palaeontographica Abteilung A* 302(1–6): 1–71. [https://www.schweizerbart.de/papers/pala/detail/302/82451/The\\_early\\_Middle\\_Miocene\\_mollusc\\_fauna\\_of\\_Lake\\_Rein](https://www.schweizerbart.de/papers/pala/detail/302/82451/The_early_Middle_Miocene_mollusc_fauna_of_Lake_Rein)
- Harzhauser M, Neubauer TA, Georgopoulou E (2014b) The Early Miocene (Burdigalian) mollusc fauna of the North Bohemian Lake (Most Basin). *Bulletin of Geosciences* 89: 819–908. doi: 10.3140/bull.geosci.1503
- IUCN Standards and Petitions Subcommittee (2014) Guidelines for Using the IUCN Red List Categories and Criteria. Version 11. Prepared by the Standards and Petitions Subcommittee 11: 16–59.
- Jeffreys JG (1830) A synopsis on the testaceous pneumonobrancheous Mollusca of Great Britain. *Transactions of the Linnean Society of London* 16: 323–362. <http://www.biodiversitylibrary.org/item/13695#page/344/mode/1up>
- Jochum A, De Winter AJ, Weigand AM, Gómez B, Prieto C (2015) Two new species of *Zospeum* Bourguignat, 1856 from the Basque-Cantabrian Mountains, Northern Spain (*Eupulmonata*, *Ellobioidea*, *Carychiidae*). *ZooKeys* 483: 81–96. doi: 10.3897/zookeys.483.9167

- Jochum A, Neubauer TA, Harzhauser M (2015) Microstructural details in shells of the gastropod genera *Carychiella* and *Carychium* of the Middle Miocene. *Lethaia*, 1–15. doi: 10.1111/let.12134
- Kashima N, Suh MS, Pae SK (1978) A note on the speleo-minerals in South Korea. *International Journal of Speleology* 10: 157–165. doi: 10.5038/1827-806X.10.2.2
- Kerney MP, Cameron RAD (1979) A field guide to the land snails of Britain and North-West Europe. Collins, London, 288 pp.
- Kwon OK, Min DK, Lee JR, Lee JS, Je JG, Choe BL (2001) Korean Mollusks with Color Illustrations. Hanguel Publishing, Busan, Korea, 332 pp.
- Lee CH-J (2012) Frommer's South Korea. 3rd Edition. John Wiley & Sons, Inc., West Sussex, UK, 440 pp.
- Lee JS, Min DK (2002) A catalogue of molluscan fauna in Korea. *Korean Journal of Malacology* 18(2): 93–217. [http://malacol.or.kr/bbs/board.php?bo\\_table=ju\\_list&wr\\_id=104&page=27](http://malacol.or.kr/bbs/board.php?bo_table=ju_list&wr_id=104&page=27) [In Korean with English abstract]
- Min DK, Lee JS, Koh DB, Je JG (2004) Mollusks in Korea. Min Molluscan Research Institute, Seoul, Korea, 566 pp. [In Korean]
- Müller OF (1774) *Vermivm terrestrium et fluviatilium, seu animalium infusoriorum, helminthicorum, et testaceorum, non marinorum, succincta historia. Volumen alterum.* Heineck & Faber, Havniæ & Lipsiæ, I–XXXVI [= 1–36], 1–214, [1–10] pp. <http://www.biodiversitylibrary.org/item/100435#page/5/mode/1up>
- Prozorova LA, Noseworthy R, Lee JS, Zasyapkina MO (2010) Korean cave malacofauna with emphasis on troglobitic carychiids (Pulmonata, Ellobioidea, Carychiidae). 17<sup>th</sup> International Congress of Unitas Malacologica, World Congress of Malacology 2010, Phuket, Thailand, 18–24 July 2010. *Tropical History Supplement* 3: 135.
- Prozorova LA, Lee JS, Zasyapkina MO (2011) Korean hypogean malacofauna: First record in Asia of troglobitic *Zospeum*-like snails (Pulmonata, Ellobioidea, Carychiidae). *Korean Journal of Soil Zoology* 15(1–2): 1–4. <http://ibss.febras.ru/files/00010502.pdf>
- Strauch F (1977) Die Entwicklung der europäischen Vertreter der Gattung *Carychium* O. F. Müller seit dem Miozän (Mollusca: Basommatophora). *Archiv für Molluskenkunde* 107: 149–193.
- Stworzewicz E (1999) Miocene land snails from Belchatów (Central Poland), III: Carychiinae (Gastropoda; Pulmonata: Ellobiidae). *Paläontologische Zeitschrift* 73: 261–276. doi: 10.1007/BF02988039
- Weigand AM, Jochum A, Pfenninger M, Steinke D, Klussmann-Kolb A (2011) A new approach to an old conundrum – DNA barcoding sheds new light on phenotypic plasticity and morphological stasis in microsnailed gastropods (Gastropoda, Pulmonata, Carychiidae). *Molecular Ecology Resources* 11: 255–265. doi: 10.1111/j.1755-0998.2010.02937.x
- Weigand AM, Jochum A, Fukumori H, Kano Y, Klussmann-Kolb A (2013a) History of the diversification of surface and subterranean microgastropods (Ellobioidea: Carychiidae). *World Congress of Malacology 2013, Ponta Delgada, São Miguel, Açores, Portugal, July 22–28, 2013.* *Açoreana* 8: 138–139.
- Weigand AM, Jochum A, Slapnik R, Schnitzler J, Zarza E, Klussmann-Kolb A (2013b) Evolution of microgastropods (Ellobioidea, Carychiidae): integrating taxonomic, phylogenetic

and evolutionary hypotheses. *BMC Evolutionary Biology* 13: 1–23. doi: 10.1186/1471-2148-13-18

Woo KS, Choi DW, Kim R (2001) The geological investigation of the limestone caves in South Korea. 13<sup>th</sup> International Congress of Speleology, 4<sup>th</sup> Speleological Congress of Latin America and Caribbean, 26<sup>th</sup> Brazilian Congress of Speleology, Brasilia DF, 15–22 July 2001. Abstracts, 77–79.



# *Lamprops donghaensis* sp. n. (Crustacea, Cumacea, Lampropidae), a new species from Korean waters

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## Abstract

A new species of Cumacea belonging to the genus *Lamprops* Sars was collected from the East Sea of Korea. This new species resembles *Lamprops comatus* Zimmer, *L. carinatus* Hart, *L. flavus* Harada, *L. pumilio* Zimmer, *L. tomalesi* Gladfelter, and *L. obfuscatus* (Gladfelter) in lacking lateral oblique ridges on the carapace and lateral setae on the telson. The new species, however, is distinguished from its congeners by having a dorsal concave groove and a lateral rounded depressed area on pereonite 2. The new species is fully illustrated and compared with related species. A key to the world *Lamprops* species lacking lateral ridges on the carapace is also provided.

## Keywords

Cumacea, Lampropidae, *Lamprops*, new species, Korea, key, taxonomy

## Introduction

The genus *Lamprops* Sars, 1863, belonging to the family Lampropidae, commonly inhabits cool water, is bipolar in distribution and is also a shallow water marine benthos (Day 1978; Tsareva and Kepel 2001). This genus is morphologically characterized by having a distinct antennal notch, telson with 3–5 apical setae and male lacking pleopods (Given 1964; Gamô 1967; Kim et al. 2015). To date, 22 species have been reported worldwide (Tsareva and Vassilenko 2006; Roccatagliata and Mühlendhardt-Siegel 2012; WoRMS 2015). For the study on the Korean lampropid species, lampropid specimens

were collected from the East Sea of Korea. Recently, two *Lamprops* species, *L. carinatus* Hart, 1930 and *L. pseudosarsi* Tsareva & Vassilenko, 1993 were reported for the first time in Korean waters (Kim et al. 2015) and here we describe and illustrate a new species of the genus. Therefore, a total of four species of the lampropid species including *Hemilamprops californicus* (Zimmer, 1936) are reported from Korea.

## Material and methods

The specimens were collected using a light-trap (Holmes and O'Connor 1988; Kim 1992) from shallow water at Geojin Port, Goseong-gun, Gangwon-do, Korea. The specimens were fixed in 70–80% ethanol and dissected in glycerol on cobb's aluminum hole slides. Drawings and measurements were performed with the aid of a drawing tube. Measurements for the body length were made from the anterior tip of the carapace to the last abdominal segment and for each appendage were made along the mid-line of the articles, exclusive of the inflated outer angle. Type specimens were deposited at the National Institute of Biological Resources (NIBR), Incheon, Korea and at the Department of Biological Science, Dankook University (DKU), Cheonan, Korea. The terminology for the setae follows that used by Watling (1989) and Gerken (2010, 2013).

## Taxonomy

### Genus *Lamprops* Sars, 1863

**Type species.** *Lamprops fasciatus* Sars, 1863

**Species composition.** *Lamprops affinis* Lomakina, 1958; *L. augustinensis* Gerken, 2005; *L. beringi* Calman, 1912; *L. carinatus* Hart, 1930; *L. comatus* Zimmer, 1907; *L. fasciatus* G.O. Sars, 1863; *L. flavus* Harada, 1959; *L. fuscatus* Sars, 1865; *L. hexaspinula* Liu & Liu, 1990; *L. kensleyi* Haye & Gerken, 2005; *L. korroensis* Derzhavin, 1923; *L. lomakiniae* Tsareva & Vassilenko, 1993; *L. multifasciatus* Zimmer, 1937; *L. obfuscatus* (Gladfelter, 1975); *L. pseudosarsi* Tsareva & Vassilenko, 1993; *L. pumilio* Zimmer, 1937; *L. quadriplicatus* S.I. Smith, 1879; *L. sarsi* Derzhavin, 1926; *L. serratus* Hart, 1930; *L. tenuis* Tsareva & Vassilenko, 2006; *L. tomalesi* Gladfelter, 1975; and *L. triserratus* (Gladfelter, 1975).

### *Lamprops donghaensis* sp. n.

<http://zoobank.org/06DB8C52-2FE2-4509-BE5D-59560D13C29E>

Korean name: Dong-Hae-sap-kko-ri-ol-chaeng-i-sae-u, new

Figures 1–5

**Type material.** Holotype: adult male, 7.9 mm, NIBRIV0000317121, Geojin Port, Geojin-eup, Goseong-gun, Gangwon-do, Korea, 38°26'44"N 128°27'40"E, S.S.



**Figure 1.** *Lamprops donghaensis* sp. n., paratype, male, 7.6 mm, Geojin Port, Geojin-eup, Goseong-gun, Gangwon-do, Korea. Scale bar: 2.0 mm.

Hong and S.H. Kim, 11 April 2013. Paratypes: 320 males, 7.6–8.9 mm, DKUCUM 201501, 11 April 2013, same station data as holotype.

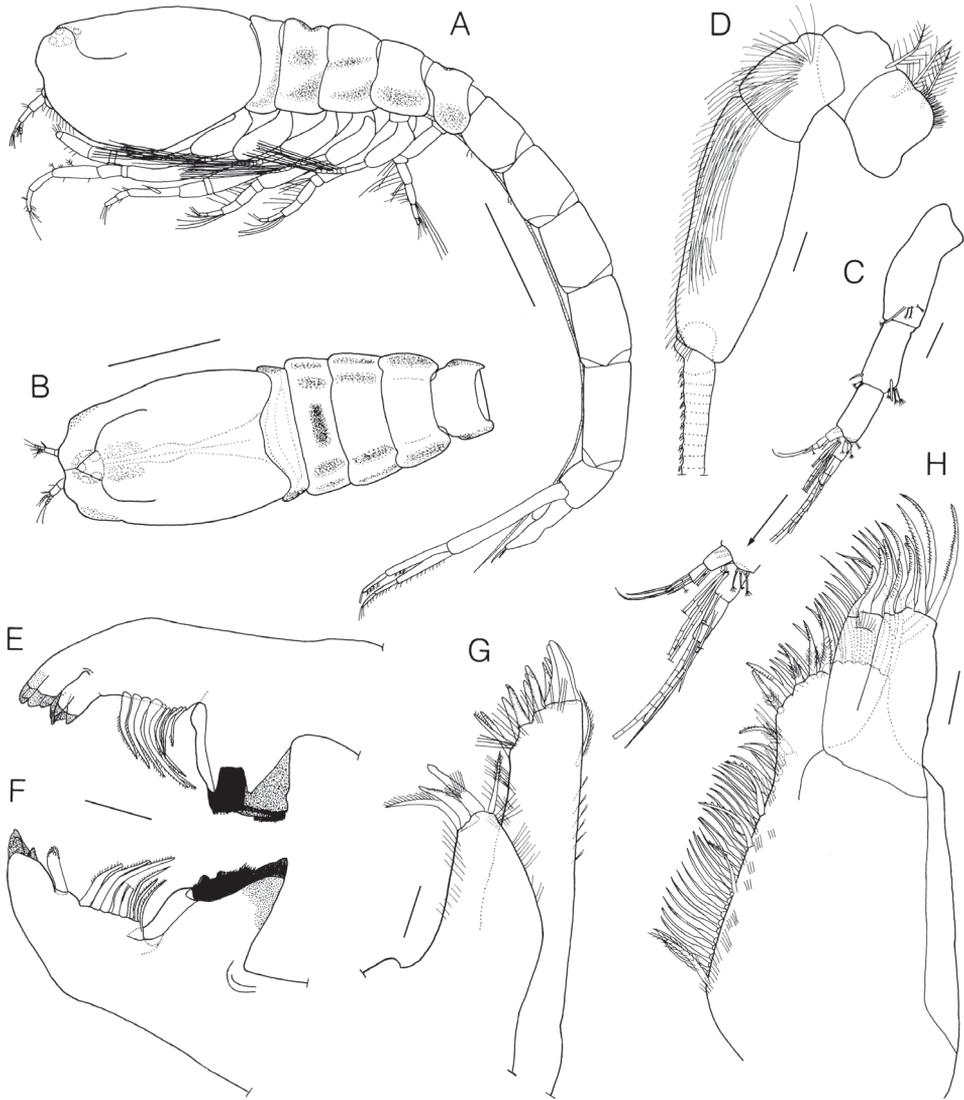
**Additional material examined.** 5 males, 7.9–8.4 mm, 15 February 2012, same station data as holotype; 1 male, 8.0 mm, Gangneung Port, Gyeonso-dong, Gangneung-si, Gangwon-do, Korea, 37°46'15.9"N, 128°57'05.2"E, S.S. Hong and S.H. Kim, 30 March 2012; 1 male, 8.3 mm, Cheongchoho, Cheongcho-dong, Sokcho-si, Gangwon-do, Korea, 38°12'01.7"N, 128°35'37.2"E, S.S. Hong and S.H. Kim, 12 April 2013; 9 males, 7.7–8.7 mm, 15 February 2014, same station data as holotype; 1 male, 8.6 mm, Oeongchi Port, Daepo-dong, Sokcho-si, Gangwon-do, Korea, 37°46'15.9"N, 128°57'05.2"E, S.S. Hong and S.H. Kim, 30 March 2012.

**Description. Holotype, adult male, NIBRIV0000317121.**

Body (Fig. 2A) 7.9 mm long, surface with a scale-like sculpturing. Carapace (Fig. 2A, 2B) smooth, without oblique ridges, subovate in lateral view, subrectangular in dorsal view,  $1.35 \times$  wide,  $0.23 \times$  body, subequal to pereonites 1–5, dorsal carina reaching  $0.94 \times$  distal end of carapace. Pereonite 2 (Fig. 2A) with dorsal transverse groove, concave dorsomesially in lateral view, lateral portion with concave rounded area.

Antenna 1 (Fig. 2C) peduncle triarticulate; proximal article subequal to remaining articles combined, with 1 simple and 3 complex pedunculate setae subdistally; article 2  $0.55 \times$  proximal article, with 5 simple and 4 complex pedunculate setae distally; distal article  $0.78 \times$  article 2, with 2 simple and 3 complex pedunculate setae; main flagellum 4-articulated, with 5 aesthetascs and 6 simple setae; accessory flagellum short, 3-articulated, with 8 simple and 1 complex pedunculate setae.

Antenna 2 (Fig. 2D) elongate, slightly extending beyond end of telson; peduncle 5-articulated, article 2 stubby, subequal to article 3, with 2 plumose setae and short



**Figure 2.** *Lamprops donghaensis* sp. n., holotype, male, **A** habitus, lateral **B** cephalothorax, dorsal (from paratype, 7.6 mm) **C** antenna 1 **D** antenna 2 **E** left mandible **F** right mandible **G** maxilla 1 **H** maxilla 2. Scale bars: 1.0 mm (**A**, **B**), 0.1 mm (**C–F**), 0.05 mm (**G**, **H**).

setules; articles 4–5 with numerous simple setae; each article of flagellum with 1 or 2 small simple setae.

Left mandible (Fig. 2E) boat-shaped, incisor with 4 cusps, with row of 9 lifting setae and lacinia mobilis.

Right mandible (Fig. 2F) similar to left one except incisor with 3 cusps and lacking lacinia mobilis.

Maxilla 1 (Fig. 2G) outer endite with row of 2 stout simple, 10 stout microserrate, and 1 stout serrate setae terminally, tufts of setules subterminally, 1 pappose seta and 6 setules on lateral margin; inner endite approximately half length of outer, with 1 pappose, 1 stout pappose, 1 stout microserrate, and 1 plumose setae terminally.

Maxilla 2 (Fig. 2H) broad endite with 8 plumose, 13 simple, 4 papposerrate, and 1 microserrate setae terminally, medial face with a row of 30 simple, 1 papposerrate, 3 serrate, 1 pappose, and hair-like setae; each outer and inner narrow endite with 7 or 3 stout microserrate setae terminally.

Maxilliped 1 (Fig. 3A) basis subrectangular, subequal to the following articles combined, medial lobe with 2 hook, 6 pappose, and hair-like setae medially, 1 stout knoblike, 2 simple, and 1 pappose setae distally; ischium absent; merus with 3 pappose setae medially; carpus subequal to merus, with plumose, simple, and comb-like setae medially, 1 plumose seta laterally; propodus with 4 plumose, 1 pappose, 1 papposerrate, and numerous simple setae distally; dactylus with 2 simple setae terminally.

Maxilliped 2 (Fig. 3B) basis elongate, longer than remaining articles combined, with 3 plumose and hair-like setae; ischium short, unarmed; merus  $0.80 \times$  carpus, with 1 plumose seta distally; capus with 11 plumose and 7 simple setae medially, 1 plumose and 1 simple setae laterodistally; propodus  $0.80 \times$  carpus, with 13 simple setae medially, 2 plumose setae distally; dactylus  $0.51 \times$  propodus, with 1 stout microserrate and 5 simple setae.

Maxilliped 3 (Fig. 3C) basis much longer than remaining articles combined, with 1 simple, 11 plumose setae, and tufts of setules posteriorly, 12 plumose and hair-like setae anteriorly, 2 plumo-annulate and 1 plumose setae anterodistally; ischium very short, with 1 small plumose seta posteriorly; merus  $0.69 \times$  carpus, with 1 pappose and 2 plumose setae posteriorly, 1 plumose seta anterodistally; carpus with 9 plumose and 7 simple setae posteriorly, 2 plumose setae anterodistally; propodus  $0.47 \times$  carpus, with 10 simple setae posteriorly, 1 plumose seta anterodistally; dactylus with 1 stout microserrate seta terminally, and 6 simple setae subterminally; exopod shorter than basis, flagellum with 1 simple and numerous plumo-annulate setae.

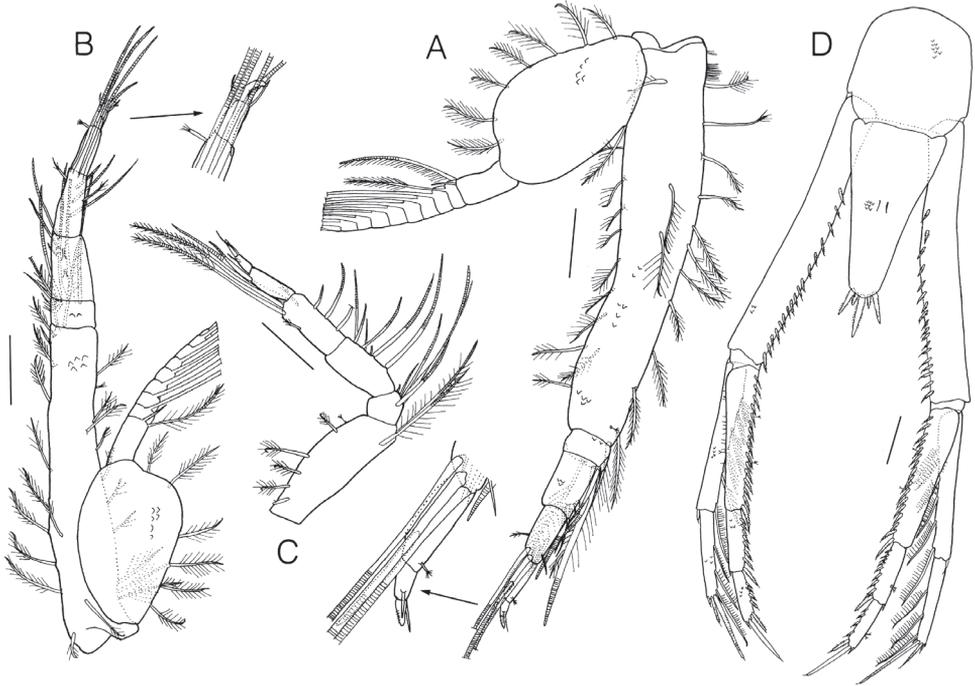
Pereopod 1 (Fig. 3D) basis somewhat curved,  $1.29 \times$  remaining articles combined, with 17 plumose, 2 papposerrate, 1 small simple setae, and tufts of setules posteriorly, 7 plumose and some hair-like setae anteriorly, 2 plumose and 1 small setae anterodistally; merus  $0.45 \times$  carpus, with 2 plumose setae posteriorly and anterodistally; propodus  $0.64 \times$  carpus, with 5 simple setae; dactylus  $0.93 \times$  propodus, with 2 microserrate and 12 simple setae, terminal seta elongate, slightly shorter than dactylus; exopod shorter than basis, flagellum with 1 simple and numerous plumo-annulate setae.

Pereopod 2 (Fig. 3E) basis slightly curved,  $1.25 \times$  remaining articles combined, with 1 simple, 8 plumose, 1 pappose setae, and tufts of setules posteriorly, row of 11 plumose setae anteriorly; carpus subrectangular,  $1.96 \times$  merus, with 2 plumose and 2 papposerrate setae posteriorly, 1 microserrate seta with single subapical setule anteriorly, 4 microserrate and 1 simple setae terminally; propodus short,  $0.26 \times$  carpus, with 1 simple seta with single subterminal setule; dactylus  $1.72 \times$  propodus, with 4 microserrate and 3 simple setae; exopod shorter than basis, flagellum with 1 simple and numerous plumo-annulate setae.



**Figure 3.** *Lamprops donghaensis* sp. n., holotype, male, **A** maxilliped 1 **B** maxilliped 2 **C** maxilliped 3 **D** pereopod 1 **E** pereopod 2. Scale bars: 0.2 mm (**C–E**), 0.1 mm (**A, B**).

Pereopod 3 (Fig. 4A) basis longer than remaining articles combined, with 10 plumose setae posteriorly, 3 plumose and 1 complex pedunculate setae on lateral surface, 8 plumose setae anteriorly, and 2 plumose setae on medial surface; ischium short,  $0.51 \times$  merus, with 4 annulate, 1 simple, and 1 plumose setae; merus  $0.95 \times$  carpus, with 4 an-



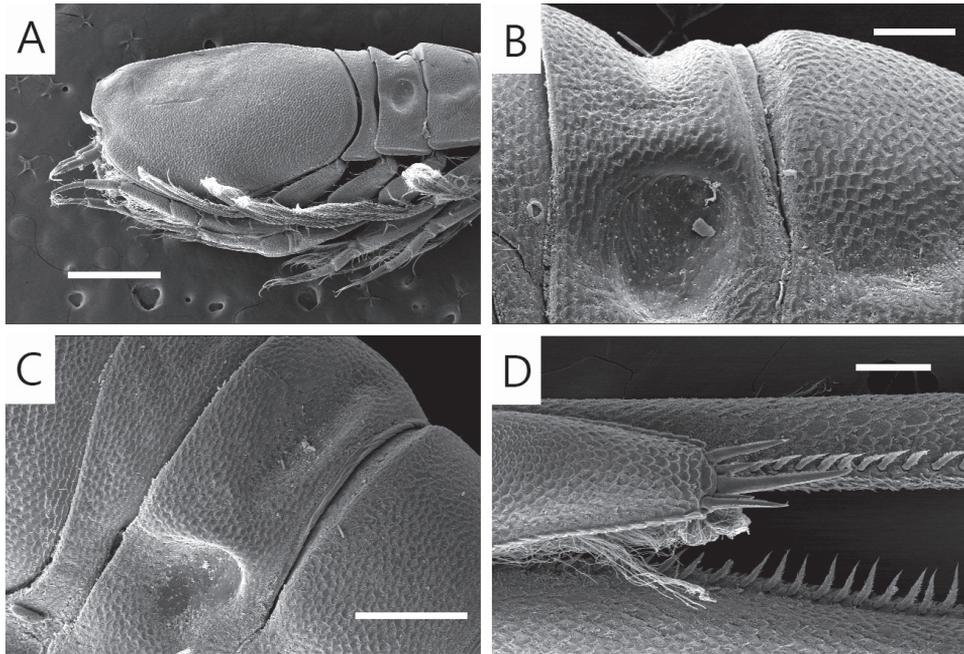
**Figure 4.** *Lamprops donghaensis* sp. n., holotype, male. **A** pereopod 3 **B** pereopod 4 **C** pereopod 5 **D** Telson and uropod. Scale bars: 0.2 mm.

nulate and 1 small simple setae posterodistally; propodus  $0.77 \times$  carpus, with 1 annulate and 1 complex pedunculate setae on lateral surface; dactylus  $0.33 \times$  propodus, with 1 simple seta on lateral surface, 1 stout micro serrate and 1 simple setae terminally; exopod shorter than basis, flagellum with 1 simple and numerous plumo-annulate setae.

Pereopod 4 (Fig. 4B) basis longer than remaining articles combined, with 8 plumose and 1 complex pedunculate setae posteriorly, 3 plumose setae on lateral surface, 9 plumose and 1 complex pedunculate setae anteriorly, 2 plumose setae mediolaterally; merus subequal to carpus, with 4 annulate and 1 simple setae on medial surface; carpus  $1.34 \times$  propodus; propodus longer than dactylus, with 1 annulate seta on lateral surface, 1 complex pedunculate seta posterodistally; exopod subequal to basis, flagellum with 1 simple and numerous plumo-annulate setae.

Pereopod 5 (Fig. 4C) basis subrectangular,  $0.60 \times$  remaining articles combined, with 5 plumose, 1 complex pedunculate, and 2 long plumo-annulate setae; ischium  $0.40 \times$  merus, with 5 annulate and 1 small simple setae anterodistally; merus subequal to carpus, with 5 annulate and 2 simple setae anteriorly; carpus  $1.47 \times$  propodus, with 3 annulate setae anteriorly, 1 long annulate and 2 long plumo-annulate setae posterodistally; propodus with 1 annulate seta posterodistally; dactylus  $0.42 \times$  propodus; exopod absent.

Telson (Fig. 4D) equilaterally triangular, width  $0.53 \times$  length,  $1.42 \times$  pleonite 6, without lateral setae, with 2 simple setae dorsomesially, 5 stout micro serrate distal setae



**Figure 5.** *Lamprops donghaensis* sp. n., paratype, **A** carapace, lateral view **B** pereonite 2, lateral view **C** pereonite 2, dorsal view **D** telson and uropod. Scale bars: 0.5 mm (**A**), 0.25 mm (**C**), 0.125 mm (**B**), 0.1 mm (**D**).

of which middle one is longest, a pair of neighboring setae short,  $0.31 \times$  middle one, the distolateral setae  $0.74 \times$  middle one.

Uropodal peduncle (Fig. 4D)  $1.66 \times$  telson, with a row of 17–18 small stout microserrate setae medially; endopod triarticulate,  $0.87 \times$  peduncle; proximal article  $2.27 \times$  article 2, with 16–17 small stout microserrate and 2 complex pedunculate setae medially; article 2  $1.22 \times$  distal article, with 8–9 small stout microserrate setae medially; distal article with 4 small stout microserrate setae medially, 1 stout microserrate and 2 unequal simple setae terminally; exopod biarticulate, slightly shorter than the endopod, proximal article  $1.69 \times$  article 2, with 6 plumose setae medially and 1 small simple seta on lateral distal corner; article 2 with 3 plumose setae medially, 2 small simple setae and 2 microserrate setae terminally.

Female. Unknown.

**Remarks.** This new species resembles *Lamprops comatus* Zimmer, 1907, *L. carinatus* (Hart, 1930), *L. flavus* (Harada, 1959), *L. pumilio* (Zimmer, 1937), *L. tomalesi* Gladfelter, 1975, and *L. obfuscatus* (Gladfelter, 1975) in lacking an oblique ridges on the carapace and lateral setae on the telson. *Lamprops donghaensis* sp. n., however, is distinguished from its congeners by the dorsal concave groove and lateral concave depressed area on pereonite 2. The characteristics are listed in Table 1 as well as in the key. The new species is more similar to *Lamprops carinatus* in having a similar medium-sized body, a similar terminal setae type of telson, and similar length ratio for the uropodal exopod

**Table 1.** Comparison of morphological characteristics among *Lamprops donghaensis* sp. n. and related species.

Characteristics and distribution	Species						
	<i>L. donghaensis</i> sp. n. (male)	<i>L. carinatus</i> (male)	<i>L. flavus</i> (male)	<i>L. pumilio</i> (male)	<i>L. tomalesi</i> (female)	<i>L. obfuscatus</i> (female)	
Body length (mm)	7.6–8.9	6.0–7.9	2.6 (without telson)	3.5	4.0	4.0	
Dorsomedian carina	0.94 × carapace concave	0.88 × carapace flat	?	?	?	?	
Pereonite 2, dorsal side	with rounded area	without rounded area	flat	flat	flat	flat	
Pereonite 2, lateral side	with rounded area	without rounded area	without rounded area	without rounded area	without rounded area	without rounded area	
Maxilliped 3, anterior margin of basis	with plumose setae	without plumose setae	?	?	with plumose setae	?	
Antenna 2, length	more than telson	reaching base of the telson	reaching middle of the pleonite 5	reaching end of the thorax	vestigial	vestigial	
Pereopod 1, basis	1.29 × remaining articles combined	1.30 × remaining articles combined	?	?	0.87 × remaining articles combined	1.29 × remaining articles combined	
Uropodal peduncle, number of inner setae	17–18	11	12	8–10	8–10	4	
Uropod, exopod length	0.91 × endopod	0.98 × endopod	0.95 × endopod	?	0.92 × endopod	0.79 × endopod	
Uropodal endopod, distal article setae	2–4 medial stout setae	without medial setae	?	?	without medial setae	without medial setae	
Distribution	Korea (present study)	Korea (Kim et al. 2015), Alaska, Vancouver (Lomakina 1958), Gabriola Island (Hart 1930)	Shimoda Bay (Harada 1959)	South Kuril Islands, Okhotsk Sea (Lomakina 1958)	California (Gladfelter 1975)	California (Gladfelter 1975)	

and endopod (see Hart 1930, and Kim et al. 2015). However, the new species is distinguished from *L. carinatus* by the combination of the following features (*L. carinatus* condition in parentheses): 1) pereonite 2 concave dorsally, with dorsal transverse groove and lateral rounded depressed area (flat dorsally, without dorsal groove and lateral depressed area); 2) maxilliped 3, basis with a row of plumose setae anteriorly (without plumose setae anteriorly); 3) telson 1.48 × pleonite 6 (1.31 × pleonite 6); 4) uropodal peduncle with 17–18 small stout microserrate setae (with 11 setae); 5) uropodal endopod, distal article with 4 microserrate setae medially (without microserrate seta).

**Etymology.** The specific epithet *donghaensis* originates from the Korean word “Dong-Hae”, meaning the East Sea, named after the eastern Korean coast in which the species was discovered.

**Habitat.** The new species was collected together with *Lamprops carinatus* and *L. pseudosarsi* at the same location, in Geojin Port, Goseong-gun, Korea, which is a sandy substrate.

**Distribution.** Geojin Port, Geojin-eup, Goseong-gun, Gangwon-do, Korea.

#### Key to the species of genus *Lamprops* (without oblique ridge of carapace)

- |    |  |   |
|----|--|---|
| 1  | Telson with lateral setae.....   | 2                                       |
| –  | Telson without lateral setae.....  | 5                                       |
| 2  | Telson with 2 pairs of lateral setae .....   | <i>L. fuscatus</i> Sars, 1865           |
| –  | Telson with more than 2 pairs of lateral setae .....                                     | 3                                       |
| 3  | Telson with 5 or 6 lateral setae.....  | <i>L. serratus</i> Hart, 1930           |
| –  | Telson with 4 pairs of lateral setae .....   | 4                                       |
| 4  | Telson with 3 apical setae .....   | <i>L. kensleyi</i> Haye & Gerken, 2005  |
| –  | Telson with 5 apical setae .....   | <i>L. affinis</i> Lomakina, 1958        |
| 5  | Telson without lateral serration .....   | 6                                       |
| –  | Telson with lateral serration.....   | <i>L. comatus</i> Zimmer, 1907          |
| 6  | Body small, < 4.0 mm.....  | 7                                       |
| –  | Body medium, ≥ 4.0 mm.....   | 8                                       |
| 7  | Carapace, anteroventral corner subquadrate.....  | <i>L. flavus</i> Harada, 1959           |
| –  | Carapace, anteroventral corner rounded .....   | <i>L. pumilio</i> Zimmer, 1937          |
| 8  | Telson, lateral apical setae longest .....   | <i>L. korroensis</i> Derzhavin, 1923    |
| –  | Telson, middle apical seta longest .....   | 9                                       |
| 9  | Telson, apicolateral setae shortest.....   | <i>L. tomalesi</i> Gladfelter, 1975     |
| –  | Telson, apicolateral setae not shortest .....  | 10                                      |
| 10 | Pereonite 2 concave dorsally, with dorsal groove and lateral rounded depressed area..... | <i>L. donghaensis</i> sp. n.            |
| –  | Pereonite 2 flat dorsally, without dorsal groove and lateral rounded depressed area..... | 11                                      |
| 11 | Uropodal peduncle with 6–11 inner setae.....   | <i>L. carinatus</i> Hart, 1930          |
| –  | Uropodal peduncle with 4 inner setae.....  | <i>L. obfuscatus</i> (Gladfelter, 1975) |

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## References

- Day J (1978) Southern African Cumacea. Part 3. Families Lampropidae and Ceratocumatidae. *Annals of the South African Museum* 76(3): 137–189.
- Gamô S (1967) Studies on the Cumacea (Crustacea, Malacostraca) of Japan Part II. Publication of the Seto Marine Biological Laboratory 15: 245–274.
- Gerken S (2010) *Watlingia*, a new genus (Cumacea: Lampropidae) from the waters of New Zealand. *Journal of Crustacean Biology* 30: 296–306. doi: 10.1651/09-3188.1
- Gerken S (2013) New Zealand Bodotriidae (Crustacea: Cumacea). *Zootaxa* 3630(1): 1–38. doi: 10.11646/zootaxa.3630.1.1
- Given RR (1964) The Cumacean fauna of the southern California continental shelf. No 2. The new Mesolampropidae. *Crustaceana* 7: 284–292. doi: 10.1163/156854064X00489
- Gladfelter WB (1975) Quantitative distribution of shallow-water Cumacea from the vicinity of Dillon Beach, California, with descriptions of five new species. *Crustaceana* 29(3): 241–251. doi: 10.1163/156854075X00289
- Harada I (1959) Cumacean fauna of Japan I. Family Lampropidae. *Japanese Journal of Zoology* 12(3): 229–246.
- Hart JFL (1930) Some Cumacea of the Vancouver island region. *Contributions to Canadian Biology and Fisheries* 6: 23–40. doi: 10.1139/f31-003
- Holmes JMC, O'Connor JP (1988) A portable light-trap for collecting marine crustaceans. *Journal of the Marine Biological Association of the United Kingdom* 68(2): 235–238. doi: 10.1017/S0025315400052140
- Kim IH (1992) Using a light-trap for collecting marine Crustaceans. *The Newsletter of the Korean Society of Systematic Zoology* 16: 6–7. [In Korean]
- Kim SH, Lee CH, Kim YH (2015) Two New Records of *Lamprops* Species (Cumacea, Lampropidae) from Korea. *The Korean Society of Systematic Zoology* 31(1): 51–65. doi: 10.5635/ased.2015.31.1.051
- Lomakina NB (1958) Cumacea of the regions of the Kuril-Sakhalin expedition works. *Exploration of the Far Eastern Seas of USSR* 5: 205–216.
- Roccatagliata D, Mühlendhardt-Siegel U (2012) Remarks on the deep-sea genus *Pseudolamprops* (Cumacea: Lampropidae). *Zootaxa* 3542: 69–79.
- Tsareva LA, Vassilenko SV (1993) Four new species of Cumacea from Peter the Great Bay, Sea of Japan. *Asian Marine Biology* 10: 13–26.

- Tsareva LA, Kepel AA (2001) Cumacean *Lamprops pumilio* – A new species for the Sea of Japan. Russian Journal of Marine Biology 27(4): 268–269. doi: 10.1023/A:1011979706707
- Tzareva L, Vassilenko S (2006) Two new species of Cumacea (Malacostraca, Peracarida) from Peter the Great Bay (Sea of Japan). Zootaxa 1174: 41–48.
- Watling L (1989) A classification system for crustacean setae based on the homology concept. In: Felgenhauer BE, Watling L, Thistle AB (Eds) Functional morphology of feeding and grooming in Crustacea. Crustacean Issues 6. AA Balkema, Rotterdam, 15–26.
- WoRMS (2015) World Register of Marine Species. <http://www.marinespecies.org> [at VLIZ, accessed 2015-05-18]

# Review of the green lacewing genus *Chrysacanthia* Lacroix with a new species from Nigeria (Neuroptera, Chrysopidae)

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## Abstract

The genus *Chrysacanthia* Lacroix (Chrysopidae: Belonopterygini) is reviewed and a new species is described from Nigeria. With the addition of the new species described herein, the genus contains four Old World species known from Madagascar, Nigeria, India, Thailand and China.

## Keywords

Afrotropical, Neuroptera, Belonopterygini

## Introduction

Chrysopidae (green lacewings) represent the second largest family of Neuroptera, with approximately 80 genera comprising over 1200 species in found throughout all major biogeographical regions, particularly the tropics (Brooks and Barnard 1990). Chrysopids are divided into three extant subfamilies, Apochrysinae Handlirsch, Nothochrysinae Navás and Chrysopinae Schneider. Apochrysinae contains six pantropical genera of large, delicate lacewings frequently found in densely forested habitats (Kimmins 1952; Winterton and Brooks 2002). The subfamily Nothochrysinae comprises nine extant genera world-wide (plus numerous fossil taxa) with many species that exhibit plesiomorphic characteristics



**Figure 1.** *Chrysacanthia esbeniana* Lacroix. Habitus, India (Photo: Poorani Janakiraman).

(Adams 1967; Brooks and Barnard 1990; Adams and Penny 1992). The majority of the generic and species-level diversity in green lacewings is found in the subfamily Chrysopinae, which includes approximately 97% of all living species. This subfamily is additionally subdivided into four tribes: Belonopterygini Navás, Chrysopini Schneider, Leucochrysin Adams and Ankylopterygini Navás (Brooks and Barnard 1990; Winterton and de Freitas 2006). Belonopterygini (formerly Italo-chrysin Hölzel) represents one of the smallest of these tribes, with 14 genera distributed in all major biogeographic regions. Most individuals in this tribe are relatively large and robust chrysopids, frequently having dark yellow to brownish-tan colouration and dark markings on the body.

The distinctive Old World genus *Chrysacanthia* Lacroix is reviewed and *Chrysacanthia iwo* sp. n. described from Nigeria. All previously described species placed in *Chrysacanthia* were originally the bases for monotypic genera. The type species *C. esbeniana* Lacroix, (Fig. 1) was described from India (Lacroix 1923). Fraser (1951) subsequently described a second species in the genus *Nesochrysa* Fraser from Madagascar (Fig. 3B) and Yang and Yang (1991) (Fig. 3C) described a third species from China in the genus *Xanthochrysa* Yang & Yang. Brooks and Barnard (1990) and Brooks (1997) consolidated these genera into one genus containing three distinct, but clearly closely related, species with a highly disparate distribution. The genus *Chrysacanthia* is diagnosed relative to this expanded species composition and a key to species of *Chrysacanthia* presented.

## Materials and methods

Terminology follows Tjeder (1966) and Brooks and Barnard (1990). Genitalia were macerated in 10% KOH to remove soft tissue, then rinsed in distilled water and dilute glacial acetic acid, dissected in 80% ethanol and subsequently stained with a solution of Chlorazol Black in 40% ethanol. The dissected genitalia were placed in glycerine in a genitalia vial mounted on the pin beneath the specimen.

## Taxonomy

### Tribe Belonopterygini Navás

#### *Chrysacanthia* Lacroix

*Chrysacanthia* Lacroix, 1923: 120. Type species: *Chrysacanthia esbeniana* Lacroix, 1923: 121, by monotypy.

*Nesochrysa* Fraser, 1951: 29. Type species: *Nesochrysa varicella* Fraser, 1951: 29, by monotypy.

*Xanthochrysa* Yang & Yang, 1991: 207. Type species: *Xanthochrysa hainana* Yang & Yang, 1991: 207, by monotypy.

**Diagnosis.** Small to medium sized lacewings: forewing length: 14–17 mm; hindwing length: 12–14 mm. Wings with dark markings, particularly on forewing; four rings of setae on flagellomeres; palpi rounded apically; pronotum relatively broad; Sc and R widely separated; Sc terminating well before wing apex; cell im short, broad and ovate (not quadrangular); m2 relatively short; gradates in two series; inner gradate series meeting Psm; male veins not crassate basally; c1 1.5–2.0 times length of c2; abdomen whitish-coloured, sternite 7 dark, tergites 4–8 polished black-brown; male 9<sup>th</sup> tergite+ectoproct yellowish-brown, lacking elongate processes; parameres elongate, extending beyond apex of abdomen; gonarcus broad with elongate gonocornua; gonosaccus with a few dispersed gonosetae; female sternite 7 with posteromedial swelling; praegenitale distinct on sternite 7.

**Included species.** *Chrysacanthia esbeniana* Lacroix, *C. hainana* (Yang); *C. varicella* (Fraser); *C. iwo* sp. n.

**Distribution.** Afrotropical: Nigeria, Madagascar; Oriental: China, India, Thailand.

**Comments.** *Chrysacanthia* is a distinctive genus is easily recognized by the dark head and thorax, with cream-coloured abdomen with black tergites posteriorly, and dark markings on the wings (Figs 1–3). Fewer than 10 specimens of this genus have been collected and the four species described are disparately distributed throughout the Oriental and Afrotropical regions. In the Afrotropical region *Oyochrysa* Brooks is superficially similar with extensive wing and body markings, but it is larger with distinctly different male genitalia.

### Relationships among Belonopterygini genera and position of *Chrysacanthia*

Few comprehensive estimates of green lacewing higher-level phylogeny have been published, either based on morphology (*e.g.*, Brooks and Barnard 1990; Winterton and Brooks 2002) or on DNA sequence data (*e.g.*, Winterton and de Freitas 2006; Haruyama et al. 2008). Consequently detailed knowledge of subfamilial, tribal or generic relationships within Chrysopidae remains poorly understood. This is particularly

true of our understanding of Belonopterygini phylogeny. Brooks and Barnard (1990) suggested that the tribe represented the sister to all other Chrysopinae, as members display numerous plesiomorphic characteristics. They also identified a number of genitalic features shared by both Belonopterygini and Leucochrysinini which support a sister group relationship between the two tribes, a hypothesis also supported (along with Ankylopterygini) by DNA sequence data (Winterton and de Freitas 2006). Belonopterygini are differentiated from other Chrysopinae by (1) the relative distal placement of the basal subcostal crossvein, (2) broad pronotum, (3) thick apical palpal segment, (4) relatively broad flagellomeres, (5) wing cell c1 longer than c2, (6) male terminalia typically with parameres, and (7) female terminalia with praegenitale usually present (Brooks 1984; Brooks and Barnard 1990). In Chrysopidae, when the parameres articulate with the gonarcus they are referred to as entoprocesses (Adams 1962; Tjeder 1966). The homology of these structures is not confirmed in all taxa though, as in at least *Abachrysa* Banks, both are present (Brooks and Barnard 1990). In Belonopterygini the parameres are a distinctive component of the male genitalic armature; they do not articulate with the gonarcus and are partially fused medially. The gonarcus is often arched and in some genera non-articulating lateral processes termed gonocornua are present (e.g., *Nesochrysa* Navás) (Brooks and Barnard 1990), presumably analogous to entoprocesses. Generic concepts within Belonopterygini are largely defined (among other characters) based on the shape of the wing cell *im* and genitalic complement (e.g., presence/absence of parameres, entoprocesses and praegenitale). Although lost in some genera, praegenitale are only found in Belonopterygini and are considered an apomorphy of the group (Brooks and Barnard 1990).

As previously stated, generic relationships are largely unknown in Belonopterygini, yet certain patterns are evident which suggest likely groupings of genera. Genus groups within the tribe can be identified based on the complement of male genitalic structures (Brooks and Barnard 1990). Along with the presence and absence of parameres, the gonarcus may have articulating entoprocesses or non-articulating gonocornua present. In the New World there are three genera, *Nacarina* Navás, *Abachrysa* and the enigmatic type genus *Belonopteryx* Gerstaecker. These genera appear to be closely related and likely form a clade sister to the remaining Belonopterygini (Brooks and Barnard 1990). Among other shared characteristics, *Belonopteryx* and some species of *Nacarina* lack parameres and a praegenitale, structures typically found in the male and female terminalia (respectively) of most other genera in this tribe. Brooks and Barnard (1990) described the genus *Evanochrysa* Brooks & Barnard from the Oriental region and suggested that it was closely related to *Nacarina* based characteristics such as this lack of male parameres as well as the presence of gonosetae.

The greatest generic diversity in Belonopterygini is in the Old World, principally the Afrotropical region, where genera such as *Oyochrysa*, *Dysochrysa* Tjeder, *Turnerochrysa* Kimmins, *Chrysaloyisia* Navás and *Nesochrysa* are endemic. Besides *Evanochrysa*, the Oriental and Eastern Palaearctic regions contain endemic genera such as *Stigmachrysa* Navás and *Nodochrysa* Banks. There is only a single endemic genus (*Calochrysa* Banks) in the Australasian region. Two genera that are widely distributed throughout

the Old World are *Italochrysa* Principi and *Chrysacanthia*. With approximately 100 species, many more than all other genera combined, *Italochrysa* is the dominant genus of Belonopterygini and occurs throughout the Afrotropical, Palaearctic, Oriental and Australasian regions (Tjeder 1966; Brooks and Barnard 1990; New 1980). Conversely, *Chrysacanthia* contains only four species, but is similarly widely distributed throughout the Afrotropical and Oriental regions.

Among Old World genera, gonocornua are present in genera such as *Nesochrysa*, *Dysochrysa*, *Chrysaloysia*, *Stigmachrysa* and *Chrysacanthia*. Apical lobes on ectoprocts and/or sternite 8+9 in the male suggest a further close relationship among *Nesochrysa*, *Nodochrysa* and *Stigmachrysa*; these lobes are lacking in the other genera in this group with gonocornua. Moreover, the elongate shape of the gonocornua indicates a close relationship among *Chrysaloysia*, *Dysochrysa* and *Chrysacanthia* (Brooks and Barnard 1990). The putative sister genus to *Chrysacanthia* is likely to be *Dysochrysa* based on the shape of the male genitalia and the sub-triangular forewing cell im. *Chrysacanthia* is readily distinguished from *Dysochrysa* based on the extensive wing patterning, which is absent in *Dysochrysa* (Tjeder 1966).

*Turnerochrysa* is a monotypic genus with greatly reduced wing venation associated with its unusually small size for members of this tribe. Relationships of this genus to other Belonopterygini are unclear, but the lack of gonocornua suggests a possible relationship with *Italochrysa* and *Oyochrysa* (Tjeder 1966; Brooks 1984; Brooks and Barnard 1990). *Oyochrysa* and *Italochrysa* are in turn closely related based on the elongate extension of sternite 7 in the female. *Calochrysa* is clearly closely related to *Italochrysa* and is distinguished largely by the presence of a forked vein  $Cu_2$  in the forewing (New 1980; Brooks and Barnard 1990).

Tauber et al. (2006) and Tauber (2006, 2007) recently proposed the transfer of *Vieira* Navás from Leucochrysinini to Belonopterygini based on a series of adult and larval characteristics. *Vieira* is typical of Leucochrysinini and does not fit comfortably in Belonopterygini as it is presently defined. Indeed, most of the characters identified supporting this transfer are highly variable even within the tribe, and their value for placement in a phylogenetic context has not been fully tested. Those Belonopterygini characters found in *Vieira* could as easily represent shared plesiomorphies and therefore do not discount a basal position in Leucochrysinini. *Vieira* is retained in Leucochrysinini for the present until a more comprehensive quantitative phylogenetic analysis can be undertaken on the group.

The immature stages of chrysopids in the tribe Belonopterygini are poorly known, and larvae are documented for only three genera (*Calochrysa*, *Nacarina* and *Italochrysa*) (Weber 1942; Principi 1943, 1946; New 1983, 1986; Tauber and Winterton 2014). Most chrysopid larvae are arboreal generalist predators and many larvae carry a debris packet lodged in elongate setae on their dorsum for camouflage and physical deterrence (Perez de-la Fuente et al. 2012). The larvae are confirmed specialized predators in ant nests in both *Nacarina* and *Italochrysa* (Weber 1942, Principi 1943, 1946; Tauber and Winterton 2014). Belonopterygini larvae have a large number of short hooked setae on the dorsum, presumably enabling carriage of a dense debris packet for

physical defence against attack by ants in the nest (Principi 1946; Tauber et al. 2014; Tauber and Winterton 2014). The record by Weber (1942) of *Nacarina* is anomalous in that the larvae did not have a debris packet, suggesting that there is also chemical camouflage to aid in defence against ant attacks. This life history and associated dense debris packet appears specific to Belonopterygini and is considered a synapomorphy for the tribe. Interestingly, the first instar of *Vieira elegans* (Guérin-Ménéville), which was described by Tauber et al. (2006), retains much of the chaetotaxy characteristic of non-Belonopterygini tribes.

### Key to species of *Chrysacanthia*

- 1 Head and thorax extensively dark brown with pale linear markings (Fig. 3); (Afrotropical)..... **2**
- Head and thorax uniform dark brown, or yellowish brown with distinct brown markings (Oriental) ..... **3**
- 2 Wing markings very dark; hind wing with two spots along posterior margin; legs with multiple dark bands on femora (Madagascar).....  
..... ***C. varicella* (Fraser)** (Fig. 2B)
- Wing markings relatively pale; hind wing with single spot along posterior margin; legs with femora unmarked (Nigeria)..... ***C. iwo* sp. n.** (Fig. 2A).
- 3 Head and thorax mostly dark brown, with some blackish markings; forewing with mark present at base of inner gradate series (India, Thailand).....  
..... ***C. esbeniana* Lacroix** (Fig. 1).
- Head yellowish brown with darker markings on vertex and across face; prothorax yellowish medially, dark brown laterally; forewing with mark absent at base of inner gradate series (China) ***C. hainana* (Yang & Yang)** (Fig. 2C)

### *Chrysacanthia iwo* sp. n.

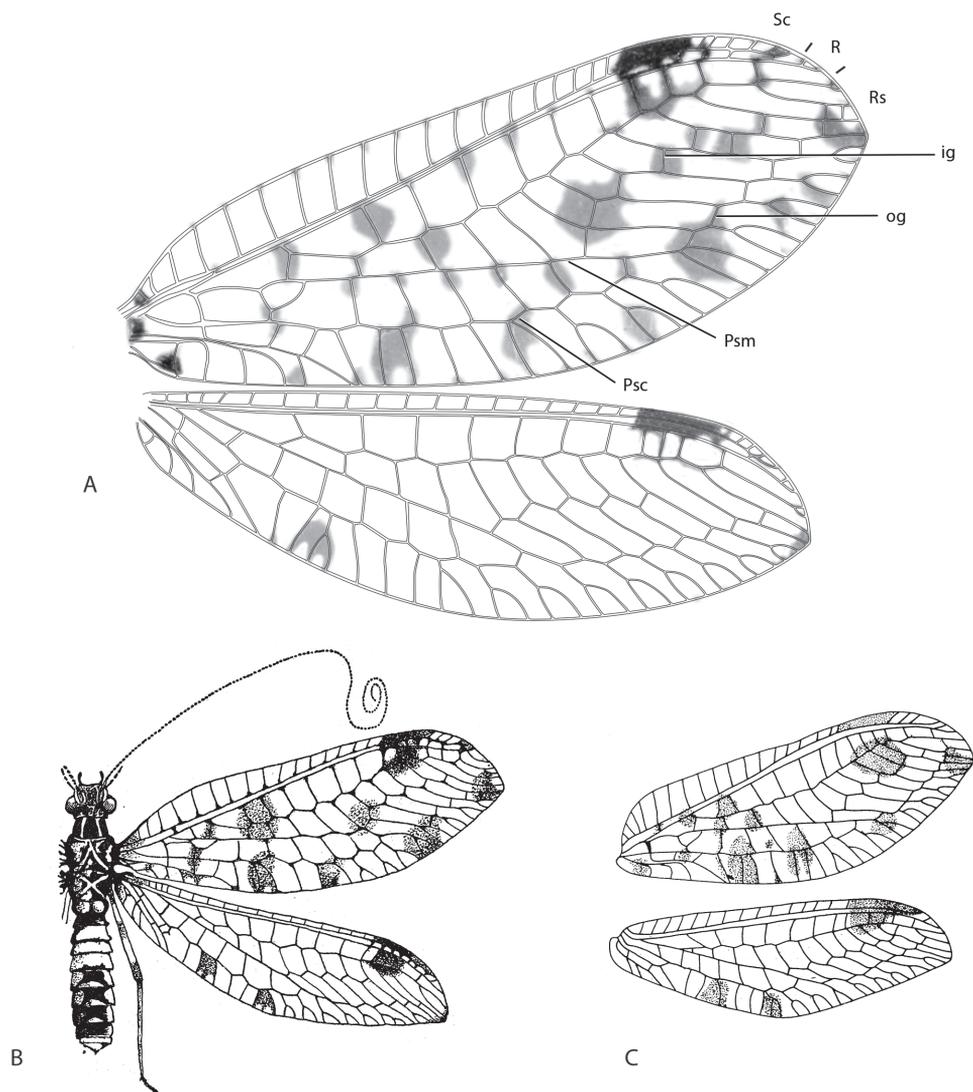
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Figures 2–4

**Type material.** **Holotype** male, NIGERIA: Osun State: Iwo, 2.iii.1973, cashew leaf, pres. By Comm. Inst. Ent. B.M. 1977-1, BMNH(E) 1201743 (Natural History Museum, London). Type condition: poor, damaged: antennae missing, abdomen and genitalia dissected.

**Diagnosis.** Head and thorax dark with pale linear markings; hind wing with single mark along posterior margin at pseudomedial crossveins 2–3; femora unmarked.

**Description.** Male: Wing length (forewing: 15.0 mm; hindwing: 13.0 mm). Overall colouration very dark brown to black, with cream coloured abdomen with black polished tergites posteriorly and dark markings in wings. Head (Fig. 3). Dark brown with white markings; vertex with pale crescent marking around base of an-



**Figure 2.** *Chrysacanthia* spp. **A** *Chrysacanthia iwo* sp. n., forewing and hind wing (Forewing length: 15.0 mm) **B** *Chrysacanthia varicella* (Fraser), body and wings (after Fraser 1951: figure 8) **C** *Chrysacanthia hainana* (Yang & Yang) forewing and hind wing (after Yang and Yang 1991: figure 2). Abbreviations: *ig*, inner gradate series; *psc*, pseudocubital vein; *psm*, pseudomedial vein; *og*, outer gradate series (drawings not to scale; vestiture omitted).

tenna, behind eye and posteriorly along vertex ridge; labrum and gena pale, clypeus with pale suffusion laterally with white band across lower margin; antennal scape dark brown, flagellum colour unknown (missing in specimen); palpi light brown-tan, unmarked. Thorax (Fig. 3). Prothorax dark brown dorsally, cream ventrally, medium length pale setae sparsely distributed; pronotum with two longitudinal mid-dorsal stripes, curving outwards and approximating posterolateral corner, stripes overlain

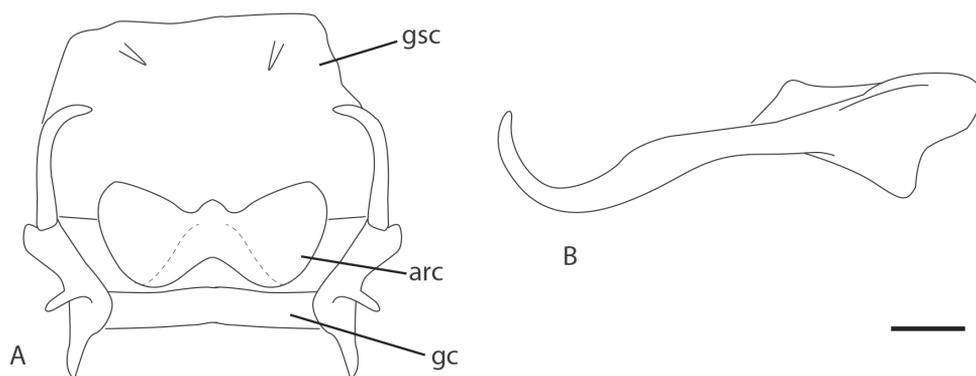


**Figure 3.** *Chrysacanthia iwo* sp. n. male head and thorax [abdomen dislodged during dissection].

with short dense silver pubescence; mesonotum and metanotum dark brown with pale markings, overlain with pubescence, denser and silvery posteriorly and medially, admixed with sparse pale setae; pleuron dark brown on upper portion, cream on lower portion; legs pale with white setae, tibiae with a narrow dark brown mark at midpoint dorsally; claws pale basally, brownish apically on all legs, claw dilated basally; wings hyaline with extensive markings, especially in forewing; forewing with seven inner gradate crossveins, one set doubled apically, meeting Psm posteriorly; eight outer gradate crossveins, one set doubled apically; two crossveins between  $Cu_1$  and  $Cu_2$ , 1st posterior marginal crossvein joining wing margin proximal to  $Cu_2$ ; hind wing with five inner gradate crossveins, seven outer gradate crossveins; wing hyaline with markings as per Figure 2A, forewing more extensively marked than hindwing; venation mostly white, brown when crossing infusate areas and at junctions of crossveins with major veins; basal subcostal crossvein dark; pterostigma very dark in both wings; single mark along posterior margin of hind wing and at apex of fore wing. Abdomen. Predominantly white; tergites 4–7 polished black-brown; sternites 7–8+9 brown; sternite 7 with conical posteromedial process; tergite 8 and 9+ectoproct pale. Male terminalia (Fig. 4): Trichobothria *ca.* 35; paramere elongate, upturned apically, not extending beyond apex of abdomen; gonarcus relatively short, broad, with elongate gonocornua; arcessus broad with lateral hook-like process; gonosaccus weakly developed with paired lateral gonosetae.

Female: unknown.

**Comments.** This Afrotropical species of *Chrysacanthia* is easily differentiated from other species in the genus by the head and thoracic markings (*i.e.*, dark brown with



**Figure 4.** *Chrysacanthia iwo* sp. n., male. **A** gonarcus complex **B** paramere. Abbreviations: *arc*, arcessus; *gc*, gonarcus; *gsc*, gonosaccus. Scale line: 0.2 mm.

pale stripes and arch-like markings), unmarked femora, relatively short paramere, single spot on the posterior margin of the hind wing, and well developed mark at the base of the inner gradate series of the forewing. *Chrysacanthia iwo* sp. n. is known only from the holotype male collected on cashew in Iwo, Nigeria.

Members of this genus are very distinctive based on wing venation and markings on the head and thorax. The Malagasy *Chrysacanthia varicella* was excellently figured by Fraser (1951) (reproduced here; Fig. 2B). This species is very similar to *C. iwo* sp. n., but can be differentiated by the presence of two wing spots along the posterior margin of the hind wing; in *C. iwo* sp. n. only one spot is present. The Afrotropical species are typified by pale markings on a dark head and thorax, while in the Oriental species are more uniform dark. *Chrysacanthia esbeniana* (India) is distinguished from the other Oriental species, *C. hainana* (China, Thailand), by the presence of a dark spot at the base of the inner gradate series in the forewing (Figs 1, 2C).

**Etymology.** This new species is named after the type locality, the township of Iwo, SW Nigeria.

## Acknowledgements

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## References

- Adams PA (1962) A stridulatory structure in Chrysopidae (Neuroptera). *Pan-Pacific Entomologist* 38: 178–180.

- Adams PA (1967) A review of the Mesochrysinæ and Nothochrysinæ (Neuroptera: Chrysopidae). *Bulletin of the Museum of Comparative Zoology* 135: 215–238.
- Adams PA, Penny ND (1992) Review of the South American genera of Nothochrysinæ (Insecta: Neuroptera: Chrysopidae). In: Canard M et al. (Eds) *Current Research in Neuropterology*. SACCO, Toulouse, 35–41.
- Brooks SJ (1984) A redefinition of the Italo-chrysini (Chrysopidae), with the description of a new genus from Nigeria. *Neuroptera International* 3: 79–88.
- Brooks SJ (1997) An overview of the current status of Chrysopidae (Neuroptera) systematics. *Deutsche Entomologische Zeitschrift*, Berlin (N.F.) 44: 267–275.
- Brooks SJ, Barnard PC (1990) The green lacewings of the world: A generic review (Chrysopidae). *Bulletin of the British Museum of Natural History (Entomology)* 59: 117–286.
- Fraser FC (1951) A revision of the Madagascar Neuroptera with a key to their identifications and descriptions of new species. I. Osmylidae, Hemerobiidae and Chrysopidae. *Naturaliste Malgache* 3: 15–31.
- Kimmins DE (1952) A revision of the genera of the Apochrysinæ (Fam. Chrysopidae). *Annals and Magazine of Natural History* (12) 5: 929–944. doi: 10.1080/00222935208654370
- Lacroix JL (1923) Chrysopides nouveaux [Planipennia]. *Bulletin de la Société Entomologique de France* 1923: 119–122.
- New TR (1983) The egg and first instar of *Italo-chrysa insignis* (Neuroptera, Chrysopidae). *Australian Entomological Magazine* 10: 29–32.
- New TR (1986) Some early stages of *Calochrysa* Banks (Neuroptera, Chrysopidae). *Australian Entomological Magazine* 13: 11–14.
- Pérez-de la Fuente R, Delclòs X, Peñalver E, Speranza M, Wierzchos J, Ascaso C, Engel MS (2012) Early evolution and ecology of camouflage in insects. *PNAS* 109: 21414–21419. doi: 10.1073/pnas.1213775110
- Principi MM (1943) La *Nothochrysa italica* Rossi ed i suoi singolari costumi (Neuroptera - Chrysopidae). *Bollettino della Società Entomologica Italiana* 75: 117–118.
- Principi MM (1944–1946) Contributi allo studio dei Neurotteri Italiani. IV. *Nothochrysa italica* Rossi. *Bollettino dell'Istituto di Entomologia della Università degli Studi di Bologna* 15: 85–102.
- Tauber CA (2006) A new species of *Berchmansus* (Neuroptera: Chrysopidae) and nomenclatural notes on *B. elegans* (Guérin-Méneville). *Proceedings of the Entomological Society of Washington* 108: 830–841.
- Tauber CA (2007) Review of *Berchmansus* and *Vieira* and description of two new species of *Leucochrysa* (Neuroptera: Chrysopidae). *Annals of the Entomological Society of America* 100: 110–138. doi: 10.1603/0013-8746(2007)100[110:ROBAVA]2.0.CO;2
- Tauber CA, Tauber MJ, Albuquerque GS (2006) *Berchmansus elegans* (Neuroptera: Chrysopidae): larval and adult characteristics and new tribal affiliation. *European Journal of Entomology* 103: 221–231. doi: 10.14411/eje.2006.024
- Tauber CA, Tauber MJ, Albuquerque GS (2014) Debris-carrying in larval Chrysopidae: unravelling its evolutionary secrets. *Annals of the Entomological Society of America* 107: 295–314. doi: 10.1603/AN13163

- Tauber CA, Winterton SL (2014) Third instar of the myrmecophilous *Italochrysa insignis* (Walker) from Australia (Neuroptera: Chrysopidae: Belonopterygini). *Zootaxa* 3811: 95–106. doi: 10.11646/zootaxa.3811.1.5
- Tjeder B (1966) Neuroptera-Planipennia. The lacewings of southern Africa. 5. Family Chrysopidae. *South African Animal Life* 12: 228–534.
- Weber NA (1942) A neuropterous myrmecophile, *Nadiva valida* Erichs. *Psyche* 49: 1–3. doi: 10.1155/1942/38909
- Winterton SL, Brooks SJ (2002) Phylogeny of the Apochrysin green lacewings (Neuroptera: Chrysopidae: Apochrysinae). *Annals of the Entomological Society of America* 95: 16–28. doi: 10.1603/0013-8746(2002)095[0016:POTAGL]2.0.CO;2
- Winterton SL, de Freitas S (2006) Molecular phylogeny of the green lacewings (Neuroptera: Chrysopidae) *Australian Journal of Entomology* 45: 235–243. doi: 10.1111/j.1440-6055.2006.00537.x
- Yang C, Yang X (1991) Two new genera of Chrysopidae from China. *Entomotaxonomia* 13: 205–210.



# Review of the planthopper genus *Neodurium* Fennah, 1956 (Hemiptera, Fulgoromorpha, Issidae)

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## Abstract

The planthopper genus *Neodurium* Fennah is reviewed and *N. fennahi* Chang & Chen, **sp. n.** (Hemiptera: Fulgoromorpha: Issidae) from China (Yunnan), is described and illustrated. A checklist of the species of *Neodurium* is given and a key provided for their separation. The female genitalia of *Neodurium* species are described for the first time.

## Keywords

Fulgoroidea, planthopper, Oriental region, female genitalia, new species

## Introduction

The Chinese planthopper genus *Neodurium* (Issidae) was established by Fennah (1956) for *N. postfasciatum* Fennah based on a female specimen from Hubei in China. Later, Ran et al. (2005) added information on the male genitalia for this species and described two more species. Subsequently, Zhang and Chen (2008) placed the genus in the Issidae, tribe Parahiraciini Cheng & Yang, and added further two new species. Then Wang and Wang (2011) described another new species. Accordingly the genus *Neodurium* is en-

demic to China and currently comprises seven species including the species described below. The tribe Parahiraciini is endemic to Indo-Malayan Realm with few taxa distributed also in the Eastern Palaearctic Subrealm and comprises 14 genera (Gnezdilov 2013).

Herein, a further new species of *Neodurium* from China is described and illustrated, and all other species are reviewed. A checklist to the species of *Neodurium* is given together with a key for their separation. The female genitalia of the genus is described for the first time.

## Material and methods

The morphological terminology of the head and body follows Chan and Yang (1994), and the terminology of male and female genitalia follows Gnezdilov (2002) and Gnezdilov (2003). Dry specimens were used for descriptions and illustrations. External morphology was observed under a stereoscopic microscope. Measurements are given in millimeters. The genital segments of the examined specimens were macerated in 10% KOH, washed in water and transferred to glycerine. Illustrations of the specimens were made with a Leica MZ 12.5 stereomicroscope. Photographs were taken with a KEYENCE VHX-1000C.

The type specimens and other specimens are deposited in the following institutions whose names are abbreviated in the text as follows:

<b>IEGU</b>	The Institute of Entomology, Guizhou University, Guiyang, China.
<b>BMNH</b>	The Natural History Museum, London, UK.
<b>IZCAS</b>	Zoological Museum, Institute of Zoology, Chinese Academy of Sciences, Beijing, China.
<b>NWAFU</b>	The Entomological Museum, Northwest A & F University, Xi'an, China.
<b>CAAS</b>	The California Academy of Sciences, San Francisco, USA.

## Taxonomy

### Genus *Neodurium* Fennah, 1956

*Neodurium* Fennah, 1956: 511; Ran et al. 2005: 570; Zhang and Chen 2008: 64; Wang and Wang 2011: 551.

**Type species.** *Neodurium postfasciatum* Fennah, 1956

**Diagnosis.** Small-sized issids. Vertex pentagonal, anterior margin obtuse-angled convex, posterior angulately excavate, marginal carinae straight. Pronotum as long as vertex, with small pit between median carina and lateral carina. Mesonotum shorter than vertex and pronotum together, with median cargin obscure. Forewings oval, with claval suture absent or obscure, M simple. Hind wings incised on the margin into two lobes, anal lobe absent or excessively reduced, veins simple. Fore- and mesofemora flattened; hind tibia with a small sub-basal spine and two distinct lateral spines.

**Checklist of species of *Neodurium* Fennah**

- Neodurium digitiformum* Ran & Liang, 2005: 571: figs 9–16; China (Hubei)  
*Neodurium duplicadigitum* Zhang & Chen, 2008: 66: figs 10–18; China (Yunnan)  
*Neodurium fennahi* Chang & Chen, sp. n.: figs 2–3; China (Yunnan)  
*Neodurium flatidum* Ran & Liang, 2005: 572: figs 17–24; China (Yunnan)  
*Neodurium hamatum* Wang & Wang, 2011: 553: figs 1–24; China (Yunnan)  
*Neodurium postfasciatum* Fennah, 1956: 513: figs 24E–I; China (Hubei, Sichuan, Yunnan)  
*Neodurium weiningensis* Zhang & Chen, 2008: 65: figs 1–9; China (Guizhou)

**Key to species of *Neodurium* (males)**

- 1 Anal tube without lobes (Figs 5A); genital styles without triangular process at midlength of dorsal margin in lateral view (Fig. 5D).....***N. hamatum* Wang & Wang**  
 – Anal tube with sub-basal angular lobes in dorsal view (Figs 2G, 4A, 6A, 7A); genital styles with triangular process in midlength of dorsal margin in lateral view (Fig. 2F: c).....**2**  
 2 Phallobase without any process on dorsal surface (see Ran et al. 2005: fig. 23) .....***N. flatidum* Ran & Liang**  
 – Phallobase with a process on dorsal surface (Figs 2J–I, 4C, 6C, 7C) .....**3**  
 3 Anal tube subquadrate, truncate in apical margin (Fig. 4A); ventrally with “V”-shape process near middle (Fig. 4B) ..... ***N. duplicadigitum* Zhang & Chen**  
 – Anal tube not truncate, with several lobes in apical margin ..... **4**  
 4 Phallobase with small finger-like process (see Ran et al. 2005: Fig. 15) .....  
 ..... ***N. digitiformum* Ran & Liang**  
 – Phallobase with fan-like or strap-shaped process (Figs 2J, 6C, 7C) .....**5**  
 5 Phallobase with two pairs of strap-shaped processes (Fig. 2J), one pair of processes connected medially (Fig. 2I).... ***N. fennahi* Chang & Chen, sp. n.**  
 – Phallobase with fan-like process (Fig. 6C) ..... **6**  
 6 Phallobase with small dentate tooth near fan-like process on dorsal margin; aedeagus with pair of long hooks (Fig. 6C) .....***N. postfasciatum* Fennah**  
 – Phallobase without teeth near fan-like process on dorsal margin; aedeagus with a pair of short hooks (Fig. 7C)..... ***N. weiningensis* Zhang & Chen**

**Key to species of *Neodurium* (females)**

Note: Females of *N. digitiformum*, *N. flatidum* and *N. postfasciatum* are unknown.

- 1 Anal tube pear-shaped with basal half broad (Fig. 3D).....  
 ..... ***N. fennahi* Chang & Chen, sp. n.**  
 – Anal tube of another shape (Figs 4D, 5E, 7D) ..... **2**  
 2 Posterior connective lamina of gonapophyse VIII with ventral posterior lobes bent at broad angle, apical part hook-like (Fig. 5H: a); median field with dorsomedial process club-like (Fig. 5H: b).....***N. hamatum* Wang & Wang**

- Posterior connective lamina of gonapophyse VIII with ventral posterior lobes bent at slender angle, blade-like; median field with dorsomedial process broad ..... **3**
- 3 Posterior connective lamina with dorsomedial processes arcuate (Fig. 4G: b) ...  
..... *N. duplicadigitum* Zhang & Chen
- Posterior connective lamina with dorsomedial process sub-quadrated (Fig. 7G: b)..... *N. weiningensis* Zhang & Chen

***Neodurium fennabi* Chang & Chen, sp. n.**

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Figs 1E, 2–3

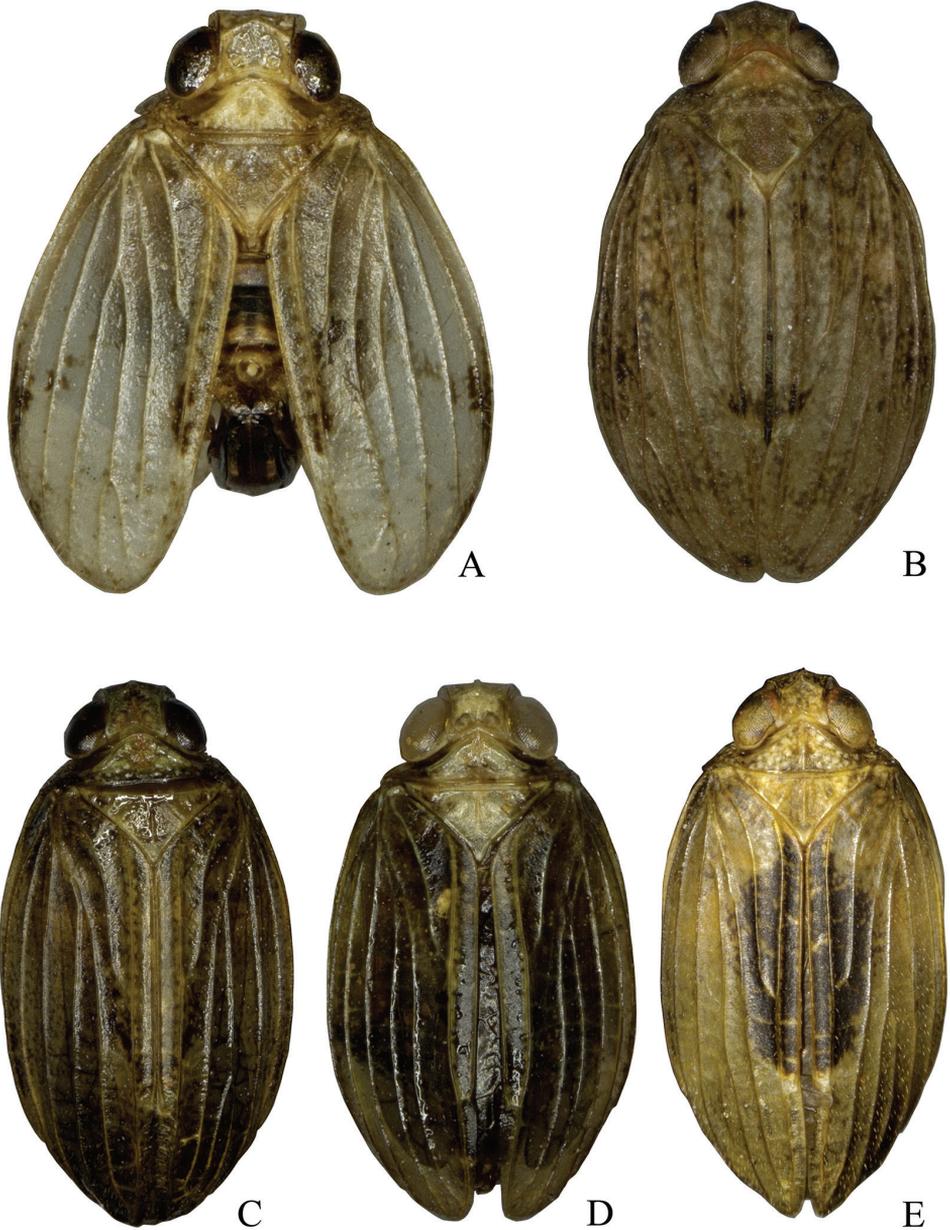
**Type material.** Holotype: ♂, China: Guizhou, Yuxi, Ailao Mountain National Nature Reserve (24°12'N, 101°19'E), 21 July 2011, S.-Y. Xu, W.-B. Zheng and W.-C. Yang (IEGU); paratypes: 11♂♂, 6♀♀, same data as holotype (IEGU); 1♂, 1♀, same data as holotype (BMNH).

**Description.** Body length (from apex of vertex to tip of forewing): male 6.0–6.2 mm, female 6.8–7.0 mm; Forewing: male 5.0–5.2 mm, female 5.6–5.8 mm.

**Coloration.** General colour (Figs 1E, 2A–C) brown with pale mottling on the vertex and pronotum and base of frons. Eyes reddish brown to dark brown; antenna dark brown; frons (Fig. 2B) with dark brown spot dorsomedially; clypeus brown to dark brown; rostrum dark brown. Forewings (Fig. 1E) with dark semicircular mark on clavus forming ovoid patch with wings at rest. Legs with tips of spines on hind tibiae and tarsi black.

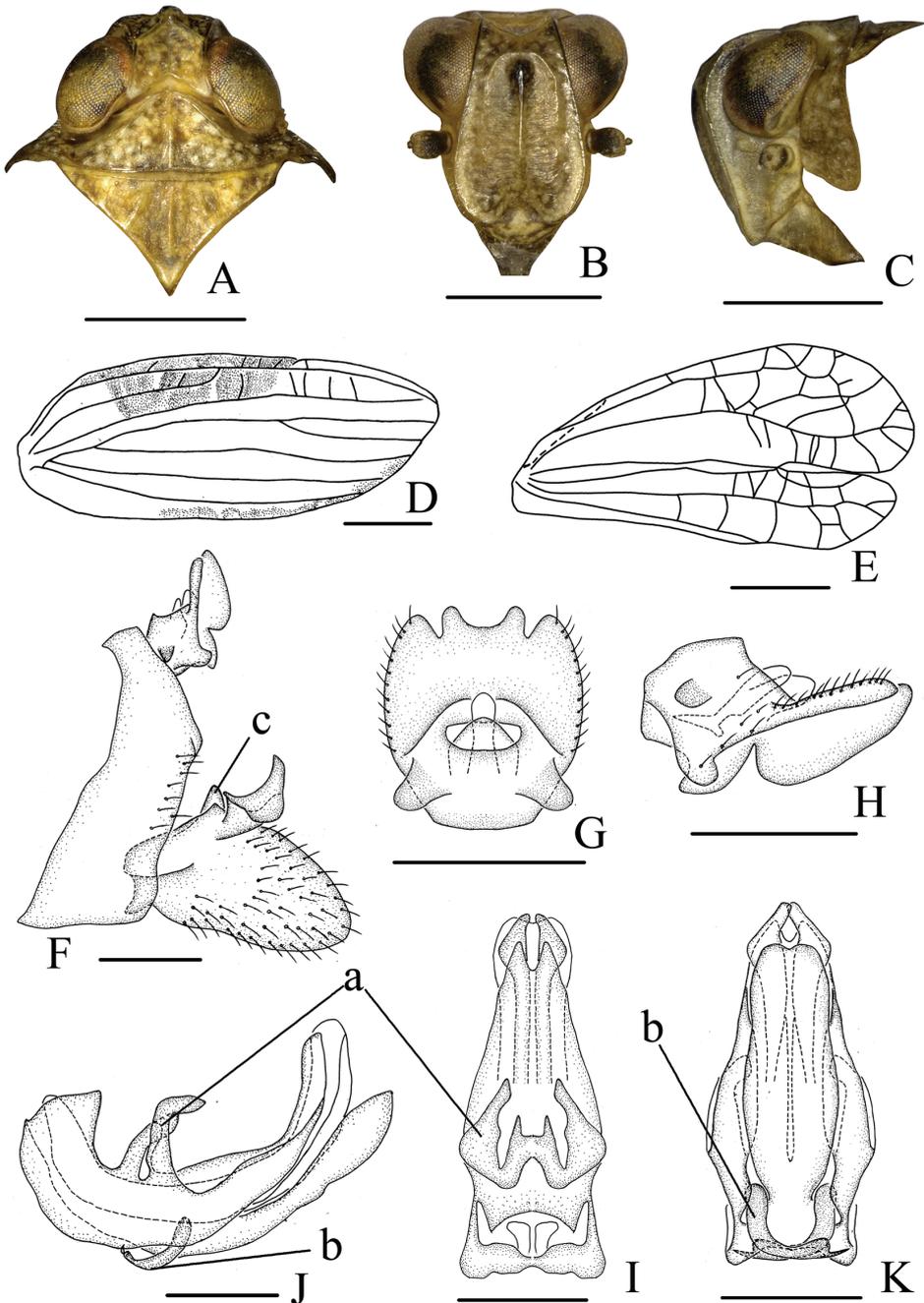
**Head and thorax.** Head (Fig. 2A) including eyes narrower than pronotum (0.74: 1.00). Vertex (Fig. 2A) shorter in middle than the wide at base (0.70: 1.00), strongly dorsoventrally depressed; disc of vertex with one obscure median carina. Frons (Fig. 2B) flat, disc slightly depressed, basal margin arched in acute angle, apical margin obtusely rounded, lateral margin ridged, lateral margins of frons incurved below level of socket of antennae, longer in middle than the widest breadth (1.00: 0.78), with median carina and lateral carina, lateral carina reaching to the level of antennae. Pronotum (Fig. 2B) with median carina and lateral carina, lateral carina not reaching to the posterior margin. Mesonotum (Fig. 2A) triangular, with median carina and lateral carina. Hind tibiae each with one small spine near base and two distinct lateral spines, spinal formula of hind leg 8-14-2. Forewings (Fig. 2D) long, subquadrate, 2.8 times as long as maximum width; longitudinal veins distinct, Sc+R vein long, reaching beyond half length of tegmen, Sc and R separated near base, M vein divided into three branches, CuA vein (cubitus anterior) not forked, claval vein Pcu (postcubitus) and A<sub>1</sub> veins uniting in middle of tegmina. Hind wings (Fig. 2E) incised on apical margin into two lobes, anal lobe reduced, reticulate apically.

**Male genitalia.** Anal tube (Fig. 2G) relatively short, subquadrate in dorsal view, with two lobes near basal part, with four blunt lobes in apical margin. Anal column (Fig. 2G) short, located at the middle of anal tube. Pygofer (Fig. 2E) irregular subquadrate in lateral view, anterior margin moderately concave, posterior margin bended

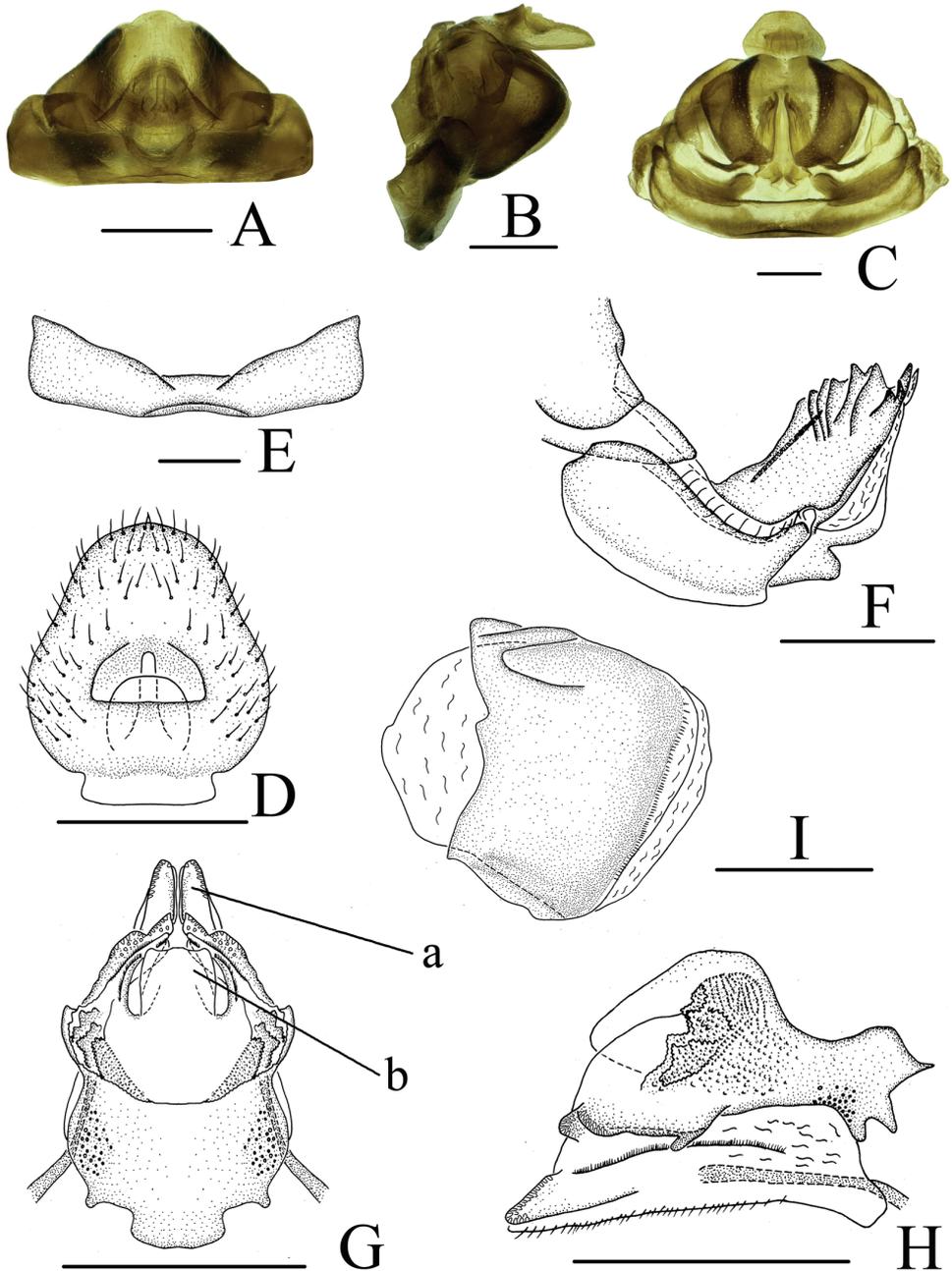


**Figures 1.** Dorsal habitus of *Neodurium* species. **A** *N. duplicadigitum* Zhang & Chen, 2008 **B** *N. hamatum* Wang & Wang, 2011 **C** *N. postfasciatum* Fennah, 1956 **D** *N. weiningensis* Zhang & Chen, 2008 **E** *N. fennahi* Chang & Chen, sp. n.

to ventro-lateral side. Genital styles (Fig. 2E) moderately long, dorsal margin producing a triangular inward lobe near capitulum; capitulum of style narrowing apically on short neck. Phallobase with dorsal lobe relatively long, not reaching the tip of lateral



**Figure 2.** *Neodurium fennabi* Chang & Chen, sp. n., male **A** head and thorax, dorsal view **B** head, ventral view **C** head and thorax, lateral view **D** forewing **E** hind wing **F** male genitalia, lateral view **G** anal segment, dorsal view **H** anal segment, lateral view **I** aedeagus and phallobase, dorsal view **J** aedeagus and phallobase, lateral view **K** aedeagus and phallobase, ventral view. a- triangular process, b- strap-shaped processes, c- hook-like processes. Scale bars: 1.0 mm (**A–E**); 0.5 mm (**F–K**).



**Figure 3.** *Neodurium triprocessum* Chang & Chen, sp. n., female **A** female genitalia, dorsal view **B** female genitalia, lateral view **C** female genitalia, ventral view **D** anal segment, dorsal view **E** sternum VII, ventral view **F** anterior connective lamina of gonapophyses VIII, lateral view **G** posterior connective lamina of gonapophyses IX, dorsal view **H** posterior connective lamina of gonapophyses IX, lateral view **I** gonoplasts, lateral view. a- posterior ventral lobes, b- process of median field. Scale bars: 0.5 mm (**A-I**).

lobe; with two pairs of strap-shaped processes (dorsal process) near base in lateral view (Fig. 2J) and one pair of processes intermediately connected, forming “H”- shaped bridge in dorsal view (Fig. 2I); ventral lobe long, apex weakly sinuate in ventral view (Fig. 2K); lateral lobe split into two branches in ventral view (Fig. 2K). Aedeagus with pair of long convergent hook-like processes (Fig. 2I).

**Female genitalia.** Hind margin of sternum VII with deep and wide median concavity (Figs 3C, 3E) in ventral view. Anal tube (Fig. 3D) pear-shaped with basal 1/2 broader; anal column short, located at basal 1/3 of anal tube. Hind margin of gonocoxa VIII lobe-shaped in proximal part, endogonocoxal lobe relative broad; endogonocoxal process gradually narrowing (Fig. 3F). Anterior connective lamina of gonapophyses VIII (Fig. 3F) with 5 teeth bearing 5 keels in lateral group and 3 teeth in apical group; lateral fields of posterior connective lamina of gonapophyses IX (Fig. 3G, H) broad, with one obtuse and lamellar process on lateral margins; with scaly bulges between lateral margin and median field; median field with a subquadrate prominence (medial dorsal process) (Fig. 3G: b); ventroposterior lobes bent at obtuse angle (posterior ventral lobes) (Fig. 3G: a). Gonoplasts (Fig. 3I) without keels.

**Etymology.** The new species is named for the memory of R.G. Fennah, who established the genus *Neodurium*.

**Distribution.** China (Yunnan).

**Remarks.** This species can be distinguished from other congeners by the dark oval patch on the forewings (Fig. 1E), phallobase with dorsal lobe (Fig. 2J) with two pairs of strap-shaped processes in lateral view (Fig. 2I).

### *Neodurium digitiformum* Ran & Liang, 2005

*Neodurium digitiformum* Ran & Liang, 2005: 571: figs 9–16; Wang and Wang 2011: 552.

**Material examined.** No specimens have been studied by the authors.

**Remarks.** This species was described after the holotype [1 male] from China (Hubei), deposited in IZCAS.

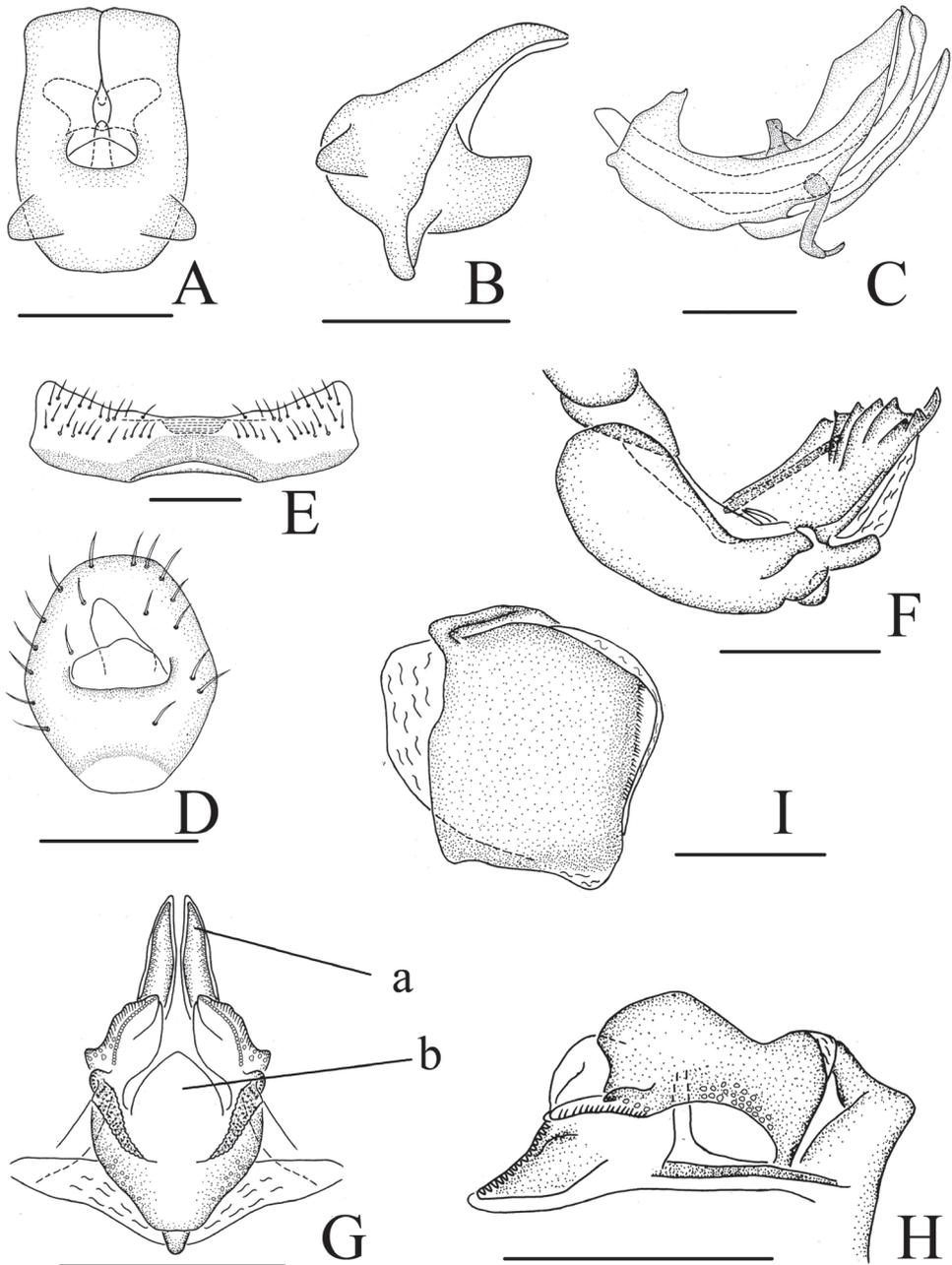
### *Neodurium duplicadigitum* Zhang & Chen, 2008

Figs 1A, 4

*Neodurium duplicadigitum* Zhang & Chen, 2008: 66: figs 10–18.

**Material examined.** 2 ♂♂, 1 ♀ China, Yunnan, Dali, 4 Aug. 2006, Z.-G. Zhang (IEGU).

**Female genitalia.** As in *N. fennahi* but hind margin of sternum VII (Fig. 4E) with more wider median concavity in ventral view. Anal tube (Fig. 4D) approximately oval, truncate apically, the widest breadth in the middle; anal column located in the middle



**Figure 4.** *Neodurium duplicadigitum* Zhang & Chen, 2008. **A–C** male **A** anal segment, dorsal view **B** anal segment, lateral view **C** aedeagus and phallobase, lateral view **D–I** female **D** anal segment, dorsal view **E** sternum VII, ventral view **F** anterior connective lamina of gonapophyses VIII, lateral view **G** posterior connective lamina of gonapophyses IX, dorsal view **H** posterior connective lamina of gonapophyses IX, lateral view **I** gonoplace, lateral view. a- posterior ventral lobes, b- process of median field. Scale bars: 0.5 mm (**A–I**).

of anal tube. Anterior connective lamina of gonapophyses VIII (Fig. 4F) with 4 teeth bearing 4 keels in lateral group. Posterior connective lamina of gonapophyses (Fig. 4G: b) IX with median field with a semicircular prominence (medial dorsal process); distal parts of posterior ventral lobes bent at slender angle, blade-like (Fig. 4G: a).

**Remarks.** This species was described from the holotype and paratypes from China (Yunnan), deposited in IEGU.

### *Neodurium flatidum* Ran & Liang, 2005

*Neodurium flatidum* Ran & Liang, 2005: 572: figs 17–24.

**Material examined.** No specimens have been studied by the authors.

**Remarks.** This species was described after the holotype [1 male] from China (Yunnan), deposited in IZCAS.

### *Neodurium hamatum* Wang & Wang, 2011

Figs 1B, 5

*Neodurium hamatum* Wang & Wang, 2011: 552: figs 17–24.

**Material examined.** 1♂1♀, China, Yunnan, Ruili, 6–7 June 2011, J.-K. Long (IEGU); 1♂, Yunnan, Yingjiang, 1 June 2011, J.-K. Long (IEGU); 2♂♂, Yunnan, Ruili, 17 July 2013, W.-C. Yang (IEGU); 1♀, Yunnan, Gaoligong Mountain, Baihualing, 8 May 2009, Z.-H. Yang (IEGU).

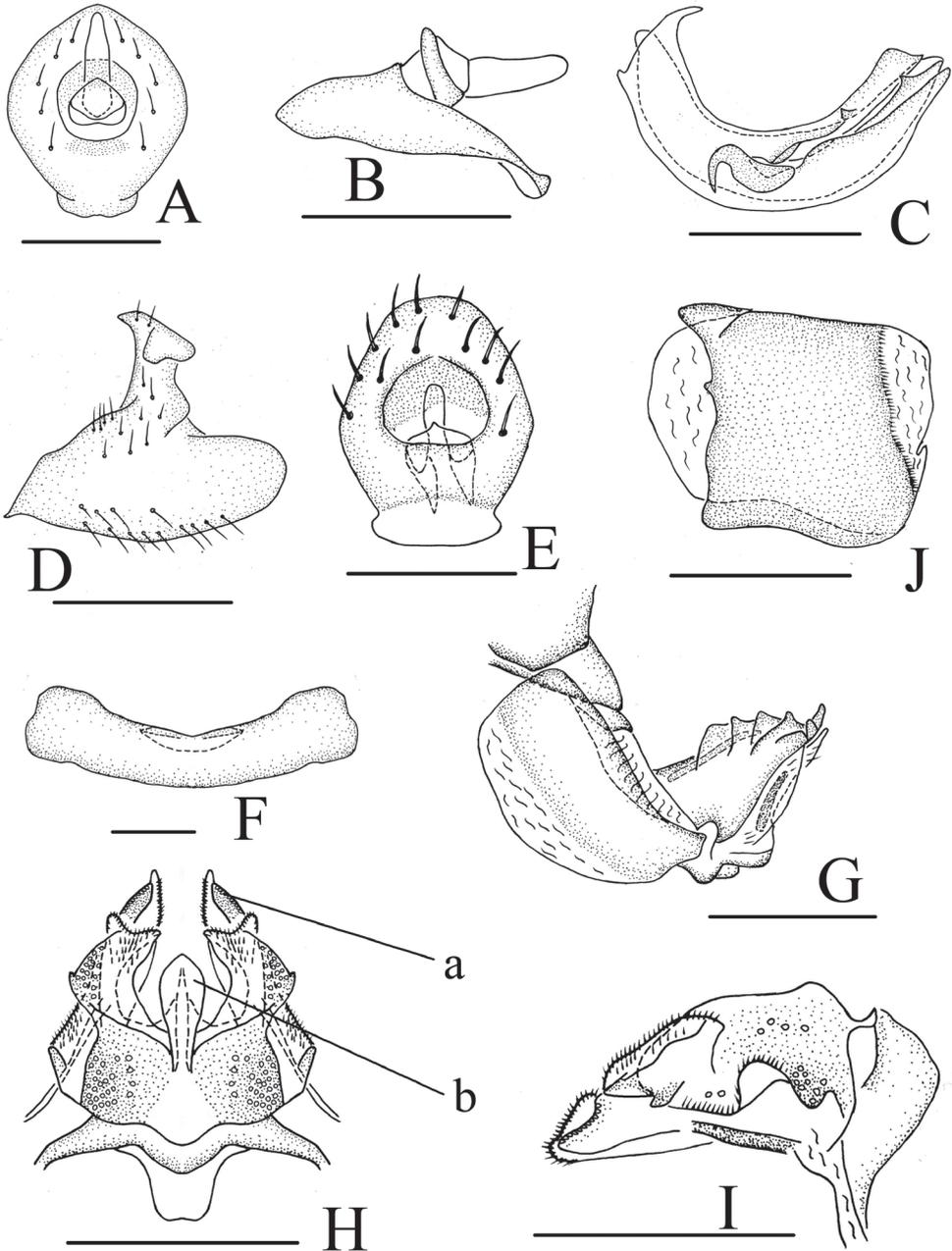
**Female genitalia.** As in *N. fennahi* but hind margin of sternum VII (Fig. 5F) with wide median concavity in ventral view. Anal tube (Fig. 5E) approximately oval, truncate apically, the widest breadth in the middle; anal colum located in the middle of anal tube. Anterior connective lamina of gonapophyses VIII (Fig. 5G) with 4 teeth bearing 4 keels in lateral group. Posterior connective lamina of gonapophyses IX with median field with a bat-like prominence (medial dorsal process) (Fig. 5H: b); distal parts of posterior ventral lobes bent under broad angle, olecranon-shaped (Fig. 5H: a).

**Remarks.** This species was described after the holotype [1 male] from China (Yunnan), deposited in NWFU.

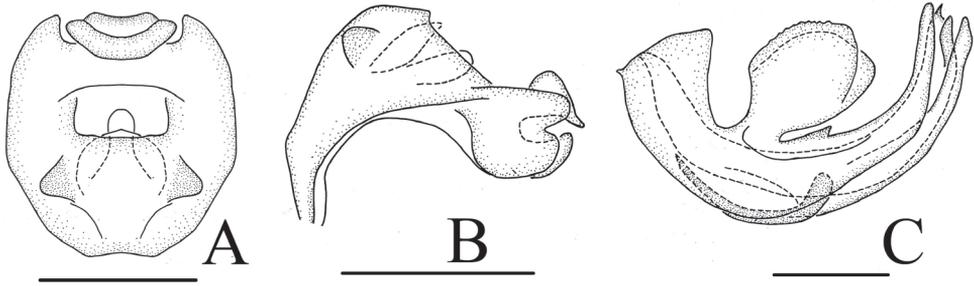
### *Neodurium postfasciatum* Fennah, 1956

Figs 1C, 6

*Neodurium postfasciatum* Fennah, 1956: 513: figs 24E–I; Ran et al. 2005: 570: figs 1–8; Wang and Wang 2011: 552.



**Figure 5.** *Neodurium hamatum* Wang & Wang, 2011. **A–D** male **A** anal segment, dorsal view **B** anal segment, lateral view **C** aedeagus and phallobase, lateral view **D** genital styles, lateral view **E–J** female **E** anal segment, dorsal view **F** sternum VII, ventral view **G** anterior connective lamina of gonapophyses VIII, lateral view **H** posterior connective lamina of gonapophyses IX, dorsal view **I** posterior connective lamina of gonapophyses IX, lateral view **J** gonoplasts, lateral view. a- posterior ventral lobes, b- process of median field. Scale bars: 0.5 mm (**A–J**).



**Figure 6.** *Neodurium postfasciatum* Fennah, 1956 male. **A** anal segment, dorsal view **B** anal segment, lateral view **C** aedeagus and phallobase, lateral view. Scale bars: 0.5 mm (**A–C**).

**Material examined.** 1♂, China, Hubei, Wudang Mountain, 23 May 23, L.-M. Wang (IEGU); 1♂, Hubei, Houhe National Nature Reserve, 22 July 2013, Z.-M. Chang (IEGU).

**Male genitalia.** Anal tube (Fig. 6A, B) relatively short, subquadrate in dorsal view, with two lobes near basal part, with three lobes in apical margin, median lobe ship-like. Anal column (Fig. 6A, B) short, located at the middle of anal tube. Phallobase (Fig. 6C) with dorsal lobe relatively long, not reaching the tip of lateral lobe, with fan-like process on dorsal margin, with small dentate tooth after fan-like process; lateral lobe split into two branches in lateral view, apical part with sharp tooth. Aedeagus (Fig. 6C) with pair of long hook-like processes in lateral view.

**Remarks.** This species was firstly described of females from China (Hubei), deposited in CAAS (Fennah 1956). It was subsequently redescribed including the male genitalia by Ran et al. (2005).

### *Neodurium weiningensis* Zhang & Chen, 2008

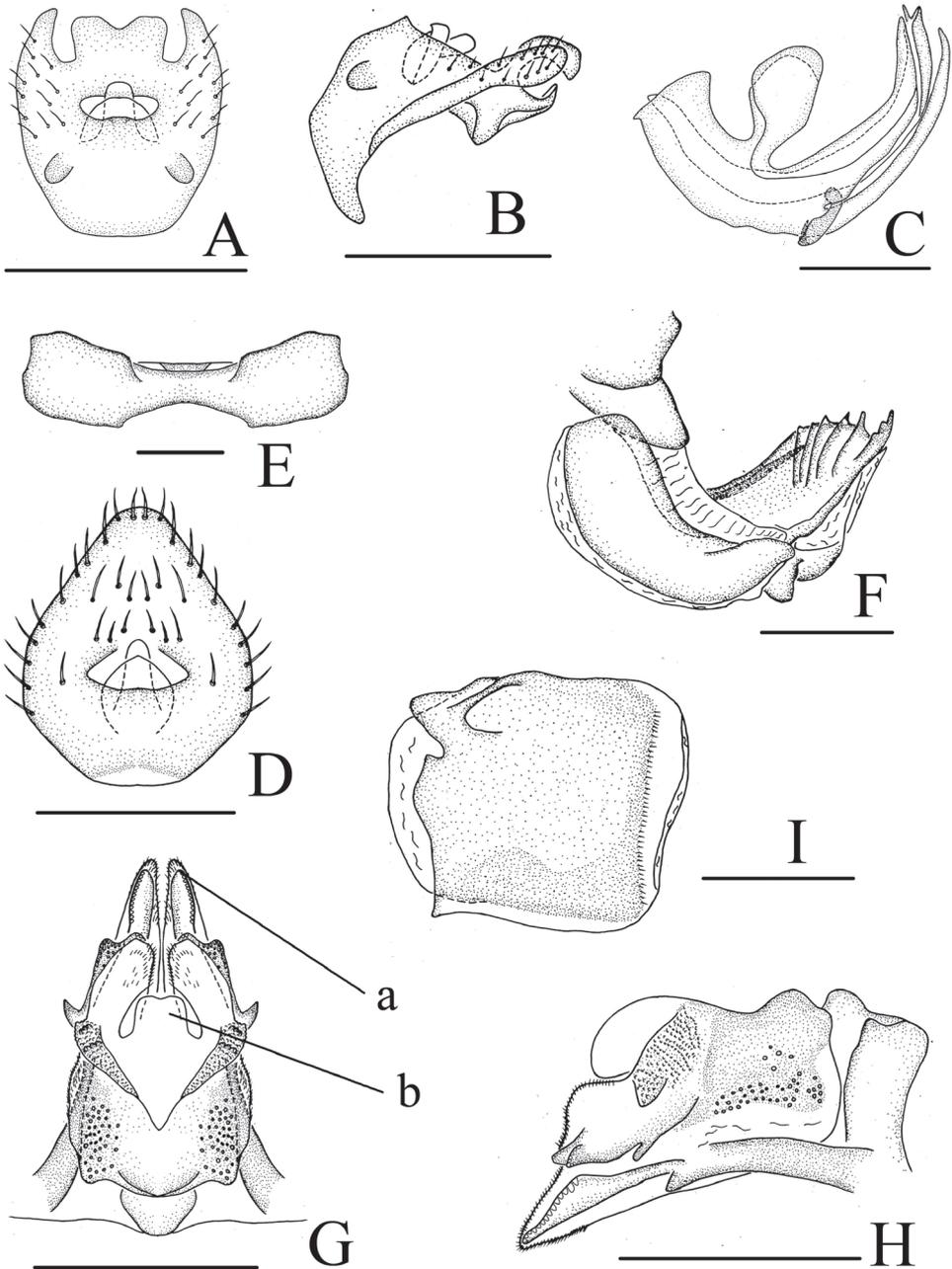
Figs 1D, 7

*Neodurium weiningensis* Zhang & Chen, 2008: 65: figs 1–9.

**Material examined.** 3♂♂, 3♀♀, CHINA, Guizhou, Weining, 20 Aug. 1983, Z.-Z. Li (IEGU); 3♂♂, 3♀♀, Guizhou, Weining, 24 Aug. 2008, Y. Liu (IEGU); 1♂, Guizhou, Weining, 29 Sept. 2005, Q.- R. Liao (IEGU); 1♂, 1♀, Guizhou, Weining, 24 Aug. 2008, Y. Liu (BMNH.).

**Female genitalia.** As in *N. fennahi* but anal tube (Fig. 7D) sub-rhomboid, apical part truncate then broad, the widest breadth at the basal 1/3; anal column short moderately slender, located the basal 1/3 of anal tube. Anterior connective lamina of gonapophyses VIII (Fig. 7F) with 5 teeth bearing 5 keels in lateral group. Posterior connective lamina of gonapophyses IX with median field with a sub-quadrate prominence (medial dorsal process), apical part wavy (Fig. 7G: b); distal parts of posterior ventral lobes bent at slender angle, blade-like (Fig. 7G: a).

**Remarks.** This species was described after the holotype and paratypes [three males and four females] from China (Guizhou), deposited in IEGU.



**Figure 7.** *Neodurium weiningensis* Zhang & Chen, 2008. **A–C** male **A** anal segment, dorsal view **B** anal segment, lateral view **C** aedeagus and phallobase, lateral view **D–I** female **D** anal segment, dorsal view **E** sternum VII, ventral view **F** anterior connective lamina of gonapophyses VIII, lateral view **G** posterior connective lamina of gonapophyses IX, dorsal view **H** posterior connective lamina of gonapophyses IX, lateral view **I** gonoplasts, lateral view. a- posterior ventral lobes, b- process of median field. Scale bars: 0.5 mm (**A–I**).

## Discussion

Compared with the structure of male genitalia of this genus, we found that in the structure of the male genitalia *N. hamatum* differs significantly from other species of the genus by the following characters: genital styles without a hook-like process on the dorsal margin in lateral view (Fig. 5D); anal tube without two sub-basal lobes (Fig. 5A), without other lobes on apical margin in dorsal view and without various process ventrally in lateral view (Fig. 5B); anal column long and slender. Possibly *N. hamatum* belongs to another subgenus. On the other side, according to the female genitalia of this genus, *N. hamatum* is distinctly different from other species as follows: Anterior connective lamina of gonapophyses VIII short, relatively broad (Fig. 5G). Posterior connective lamina of gonapophyses IX broad, distal parts of posterior ventral lobes bent under broad angle, olecranon-shaped (Fig. 5H). These characters also show that the above assumption seemed reasonable.

However, how much value does the female genitalia have in Parahiraciini? Hamilton (2011) stated that the ovipositor was an important character in Fulgoroidea and the female genitalia of Issidae have attracted increasing attention in recent years with some important characters being identified by Gnezdilov (2003, 2014). However, little information has been reported for Parahiraciini, except for *Bardunia*, *Flavina*, *Folifemurum*, *Narinosus*, *Scantinius* and *Tetricodes* (Gnezdilov 2011, Zhang et al. 2010, Che et al. 2013, Gnezdilov and Wilson 2005, 2007, Fennah 1956). Although, Che et al. (2013) discussed relationships within Parahiraciini with respect to characters of the vertex, forewings and hind wings, much still remains to be done to using the female genitalia.

## Acknowledgments

We are grateful to Mrs. S.-Y. Xu, Mr. J.-K. Long and Dr W.-C. Yang for collecting valuable specimens. This work on which this paper is based was supported by the National Natural Science Foundation of China (No. 31060290, 31093430, 31160163), the Program of Science and Technology Innovation Talents Team of Guizhou Province (No. 20144001) and the International Science and Technology Cooperation Program of Guizhou (No. 20107005), and the Graduate Innovation Foundation of Guizhou University (Agriculture No. 2015041).

## References

- Chan ML, Yang CT (1994) Issidae of Taiwan (Homoptera: Fulgoroidea). Chen Chung Book, Taichung, 188 pp.
- Che YL, Zhang YL, Wang YL (2013) A new genus of the tribe Parahiraciini from China, with notes on the tribe (Hemiptera: Fulgoroidea: Issidae). Zootaxa 3701(1): 76–82. doi: 10.11646/zootaxa.3701.1.6

- Fennah RG (1956) Fulgoroidea from southern China. Proceedings of the California Academy of Sciences. San Francisco 28(4): 441–527.
- Gnezdilov VM (2002) Morphology of the ovipositor in members of the subfamily Issinae (Homoptera, Cicadina, Issidae). Entomologicheskoe obozrenie 81(3): 605–626. [English translation published in Entomological Review 82(8): 957–974.]
- Gnezdilov VM (2003) Review of the family Issidae (Homoptera, Cicadina) of the European fauna, with notes on the structure of ovipositor in planthoppers. Chteniya pamyati N.A. Kholodkovskogo (Meetings in memory of N.A. Cholodkovsky), St. Petersburg 56(1): 1–145. [In Russian with English summary]
- Gnezdilov VM (2013) Modern classification and the distribution of the family Issidae Spinola (Homoptera, Auchenorrhyncha, Fulgoroidea). Entomologicheskoe obozrenie 92(4): 724–738. [English translation published in Entomological Review 94(5): 687–697.]
- Gnezdilov VM, Holzinger WE, Wilson MR (2014) The Western Palaearctic Issidae (Hemiptera, Fulgoroidea): an illustrated checklist and key to genera and subgenera. Proceedings of the Zoological Institute RAS 318(1): 1–118.
- Gnezdilov VM, Wilson MR (2005) New genera and species of the tribe Parahiraciini (Hemiptera: Fulgoroidea: Issidae). Acta Entomologica Slovenica 13(1): 21–28.
- Gnezdilov VM, Wilson MR (2007) Review of the genus *Scantinius* Stål with notes on the tribe Parahiraciini Cheng & Yang (Hemiptera: Auchenorrhyncha: Fulgoroidea: Issidae). Arthropod Systematic & Phylogeny 65(1): 101–108.
- Hamilton KGA (2011) Making sense of Fulgoroidea (Hemiptera): new phylogenetic evidence. Cicadina 12: 57–79.
- Ran HF, Liang AP, Jiang GM (2005) The issid genus *Neodurium* Fennah from China (Hemiptera, Fulgoroidea, Issidae). Acta Zootaxonomica Sinica 30(3): 570–576.
- Wang MQ, Wang YL (2011) Revision of the planthopper genus *Neodurium* Fennah (Hemiptera, Fulgoroidea, Issidae) with description of one new species from China. Acta Zootaxonomica Sinica 36(3): 551–555.
- Zhang YL, Che YL, Wang YL, Webb MD (2010) Two new species of the planthopper genus *Flavina* Stål (Hemiptera: Fulgoromorpha: Issidae) from China. Zootaxa 2641: 27–36.
- Zhang ZG, Chen XS (2008) Two new species of the Oriental genus *Neodurium* Fennah (Hemiptera: Fulgoromorpha: Issidae) from Southwest China. Zootaxa 1785: 63–69.



# New species and new records in Cerambycidae (Coleoptera) of the state of Bahia, Brazil

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## Abstract

Two new species are described from Bahia (Brazil): *Coleoxestia beckeri* (Cerambycini), and *Oncideres obliqua* (Onciderini). Nine species are recorded for the first time for Bahia (Brazil). Key to species of *Oncideres* Martins & Galileo, 1990 is provided. *Coleoxestia beckeri* is included in a previous key.

## Keywords

Neotropical, new records, new species, taxonomy

## Introduction

The study of the specimens sent by Vitor O. Becker from the state of Bahia in Brazil allowed the description of two new species, and also new records for the state. Many specimens were caught near Boa Nova, a small city located in the south central region of Bahia, in area of Caatinga, a kind of desert vegetation, common in northeastern Brazil. Previously, Martins et al. (2015) in a work about the cerambycid fauna of Bahia state, described 12 new species and recorded 52 species for the first time to that state.

## Material and methods

Photographs were taken with a Canon EOS Rebel T3i DSLR camera, Canon MP-E 65mm f/2.8 1-5X macro lens, controlled by Zerene Stacker AutoMontage software. Measurements were taken in “mm” using a micrometer ocular Hensoldt/Wetzlar - Mess 10 in the Leica MZ6 stereomicroscope, also used in the study of the specimen.

The identification of specimens was carried out with the aid of reference collection of the MZSP, with comparison between types, photographs of types, original descriptions, and redescriptions.

The collection acronyms used in this study are as follows:

**CVOB** Collection Vitor O. Becker, Camacan, Bahia, Brazil;

**MZSP** Museu de Zoologia, Universidade de São Paulo, São Paulo, Brazil.

## Systematics

**Cerambycinae Latreille, 1802**

**Cerambycini Latreille, 1802**

**Sphalotrichina Martins & Monné, 2002**

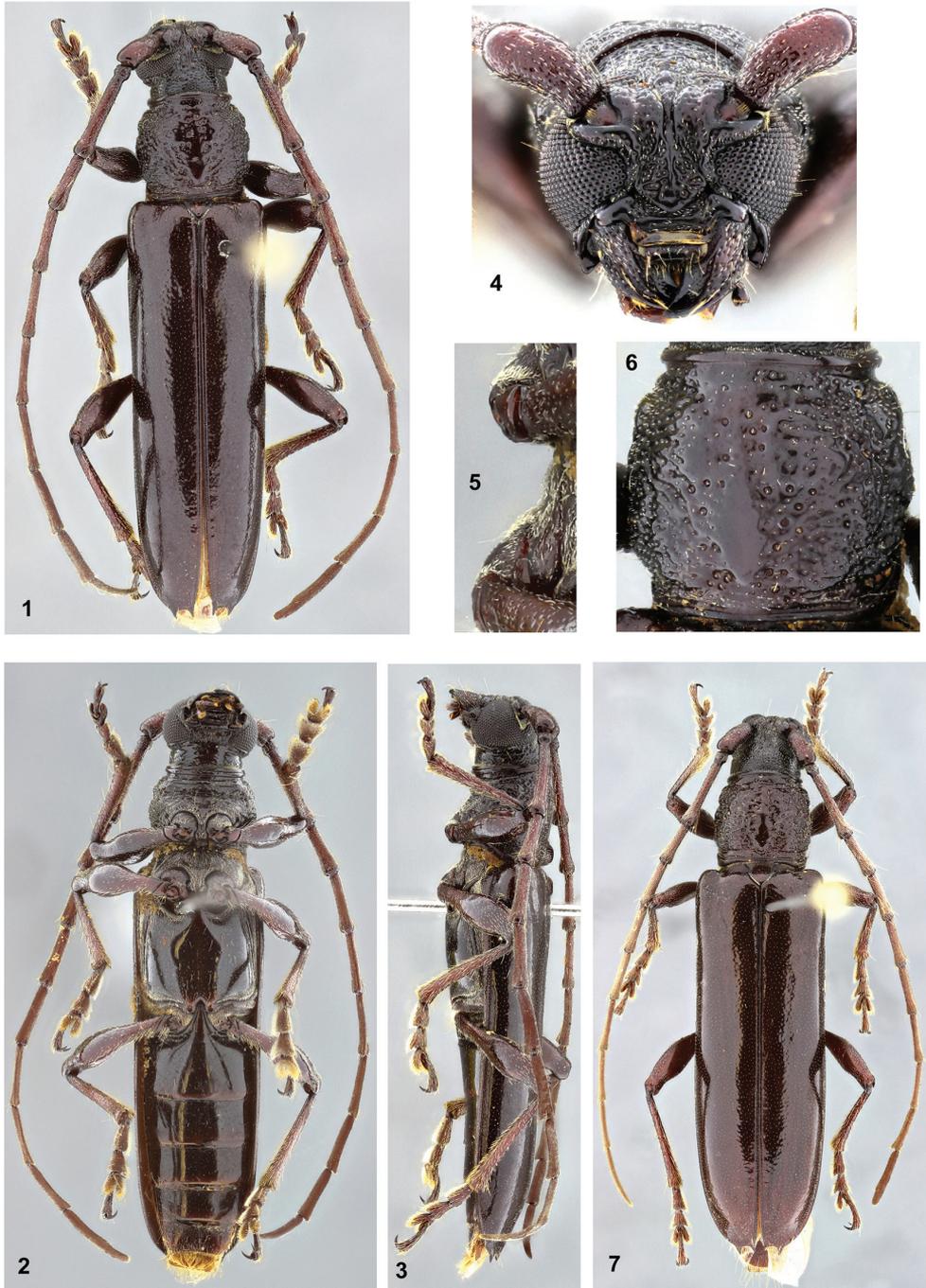
***Coleoxestia beckeri* sp. n.**

<http://zoobank.org/66B24B09-CC6B-4162-B1DD-D0746E19E77D>

Figs 1–7

**Description.** Holotype male (Figs 1–6). Integument dark brown, almost black on head and prothorax; elytra black on narrow band along suture and apical spines; scutellum blackish, with reddish-brown macula about center; antennomeres dark reddish-brown, except for narrow blackish area on apex of III–VI.

Head. Frons coarsely, confluent punctate, laterally with narrow carina from anterior margin to antennal tubercle (more distinct towards the latter); with very short, sparse setae. Area between antennal tubercles somewhat finely punctate; with very short, sparse setae. Area between upper eye lobes with elongate, smooth, glabrous tubercle, narrowed towards vertex; on each side of tubercle moderately coarsely, confluent punctate, with short, sparse setae. Vertex coarsely, partially confluent punctate, punctures finer towards prothoracic margin; with very short, sparse setae. Longitudinal sulcus distinct from clypeus to area between antennal tubercles, deeper towards the latter. Area behind upper eye lobes coarsely, confluent punctate; with very short and sparse setae, denser, interspersed with some long setae close to superior margin of eye. Area behind lower eye lobes longitudinally sulcate about middle; area close to eyes finely, abundantly punctate, with short setae interspersed with long setae; area close to prothorax moderately finely and sparsely punctate, almost glabrous. Antennal tubercles moderately finely punctate (frontally punctures finer, denser). Gula laterally transversely sulcate, moderately finely,



**Figures 1–7.** *Coleoxestia beckeri*. 1–6. Holotype male: 1 dorsal view 2 ventral view 3 lateral view 4 head, frontal view 5 prosternal and mesosternal process, lateral view 6 pronotum 7 female paratype, dorsal view.

sparsely punctate (center smooth). Submentum opaque, finely, abundantly punctate, interspersed with coarse punctures; anteriorly transversely sulcate close to anterior margin; anterior margin narrow, elevate; with short, abundant setae. Postclypeus moderately coarsely, abundantly punctate close to frons, laterally and anteriorly smooth; area close to frons depressed; punctate area with short setae and one long seta on each side. Labrum finely punctate; centrally with short setae, anteriorly and laterally with long setae. Mandibles laterally coarsely, moderately abundantly punctate; with short setae interspersed with some long setae. Distance between upper eye lobes equal to 0.40 times length of scape; distance between lower eye lobes, in frontal view, equal to 0.65 times length of scape. Antennae as long as 1.6 times elytral length; reaching the apex at middle of antennomere XI. Scape slightly enlarged towards apex; shiny, moderately coarsely, densely, confluent punctate on base, gradually finer, sparser towards apex (apex dorsally smooth and glabrous); with short moderately sparse setae interspersed with some long setae. Antennomeres III–IV straight, nodose at apex; outer side without carina and distinct sensorial area; finely, abundantly punctate (punctures denser, coarser laterally and ventrally), except for smooth apex; with short setae, ventrally and around apical smooth area interspersed with long setae. Antennomere V somewhat microsculptured, apex nodose, laterally slightly carinate; sensorial area slightly distinct at distal third; setae as on III and IV (short setae slightly denser). Antennomeres VI–X microsculptured, pubescent; outer apex dentate (slightly at VI); outer side carinate; sensorial area wide, from base to apex (dorsally less distinct on basal third of VI). Antennomere XI microsculptured, pubescent; not distinctly divided at area of constriction of outer side. Antennal formula (ratio) based on antennomere III: scape = 0.62; pedicel = 0.15; IV = 0.64; V = 0.73; VI = 0.76; VII = 0.76; VIII = 0.73; IX = 0.73; X = 0.71; XI = 1.00.

Thorax. Prothorax as long as 0.95 times largest width; laterally with three, not strong gibbosities. Pronotum coarsely punctate (vermiculate on some areas), except for smooth central sub-elliptical callosity, from basal fifth to about anterior third; around sub-elliptical callosity, punctures notably coarse, with fine punctures inside (mainly on anterior half); punctures denser on posterolateral sides; with very short, sparse setae, laterally denser. Lateral sides of prothorax coarsely vermiculate-punctate, except for anterior area finely punctate, interspersed with coarse punctures; with short, moderately sparse setae. Basal half of prosternum laterally coarsely, abundantly punctate, with short setae; center of basal half smooth, glabrous; anterior half coarsely, transversely striate, with short, very sparse setae. Prosternal process centrally smooth, glabrous on basal half; remaining surface with short setae; apex vertically inclined, concave in lateral view. Mesosternum and mesepisterna pubescent. Mesepimera pubescent towards elytra, distinctly less so towards procoxal cavity. Mesosternal process without tubercle, pubescent. Metepisterna pubescent. Metasternum with narrow band of pubescence close to metepisterna, meso- and metacoxal cavities; remaining surface with very short and sparse setae, interspersed with some long setae; finely, sparsely punctate. Scutellum triangular. Elytra. Shiny, finely, moderately abundantly punctate (mainly on basal half), except for narrow, slightly coarser, denser punctate area close to apex; with very short, sparse setae (invisible depending on angle of light); apex with two spines with

similar size. Legs. Femora with short, sparse setae, longer, more abundant on ventral side of peduncle (mainly on metafemora); apex of femora rounded.

Abdomen. Ventrites I–IV centrally smooth, glabrous (ventrite I with long, very sparse setae; IV with very short, sparse setae and fine, sparse punctures), laterally with short setae close to margin. Ventrite V slightly shorter than IV; finely, sparsely punctate, interspersed with some coarse punctures; with short, sparse setae, laterally and posteriorly denser, somewhat longer; apex widely sub-truncate.

Female (Fig. 7). Antennae as long as 1.4 times elytral length; reaching elytral apex. Ventrites I–IV with long, sparse setae, laterally narrowly pubescent. Ventrite V slightly longer than IV; moderately finely, abundantly punctate (distinctly sparser on center of basal half); apex rounded. Mesepimera pubescent.

Variation. Integument reddish-brown (mainly elytra); scutellum without reddish-brown macula; mesepimera in male pubescent throughout; legs totally or partially reddish-brown.

**Dimensions in mm (holotype/male/female).** Total length, 17.8/14.2–17.8/19.2–22.0; length of prothorax at center, 3.1/2.5–3.0/3.3–3.7; largest width of prothorax, 3.3/2.8–3.3/3.6–4.0; anterior width of prothorax, 2.5/2.1–2.6/2.7–3.0; posterior width of prothorax, 2.9/2.3–2.9/3.0–3.4; humeral width, 3.8/3.3–4.0/4.4–5.1; elytral length, 12.6/9.9–12.7/13.7–15.3.

**Type material.** Holotype male from BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), 4–8.XII.2013, V. O. Becker col. (MZSP). Paratypes (all from BRAZIL, *Bahia*): same data as holotype, 8 males (CVOB); Porto Seguro (Arraial d’Ajuda; 16°27'S, 39°03'W; 40 m), 3 males (CVOB), 4 females (3 CVOB, 1 MZSP), 23.XI.2013, V. O. Becker col. (MZSP); Aracatu (“Fazenda Lagoa do Tamburi”, Caatinga, 14°30,961'S, 41°27,512'W), female, 18.X.2012, A. S. Ferreira col. (MZSP).

**Etymology.** Named after Vitor Osmar Becker, collector of the type series.

**Remarks.** *Coleoxestia beckeri* sp. n. is similar to *C. nigropicea* (Bates, 1870), but differs as follows: frons coarsely, abundantly punctate; apex of scape not projected; pronotum with short setae; pronotum (Fig. 6) less coarsely punctate; elytra shiny. In *C. nigropicea* (see figs. 309–312 by Martins and Monné 2005; or fig. 14 by Fragoso 1993) the frons is not coarsely punctate, the scape is projected at inner side of apex, the pronotum is glabrous and coarser punctate, and the elytra is opaque on base. It differs from *C. atrata* (Gounelle, 1909) by the vertex more abundantly punctate, by the antennae in male distinctly surpassing the elytral apex, and by the pronotum not transversely sulcate and with short setae. In *C. atrata* the vertex is sparsely punctate or almost smooth, the antennae in male not surpassing the elytral apex, and the pronotum is transversely sulcate and glabrous.

*Coleoxestia beckeri* can be included in the alternative of couplet “33” from Martins and Monné (2005), considering the elytra as “black” (translated; modified):

- 33(32) Pronotum almost without wrinkles (not distinctly sulcate) .....33'
- Pronotum with wrinkles (distinctly sulcate) or densely punctate with some wrinkles .....34

- 33'(33) Scape projected at inner side of apex. Brazil (Pará).....  
 ..... *C. nigropicea* (Bates, 1870)  
 – Scape without projection at inner side of apex. Brazil (Bahia)... *C. beckeri* sp. n.

## LAMIINAE Latreille, 1825

### ONCIDERINI Thomson, 1860

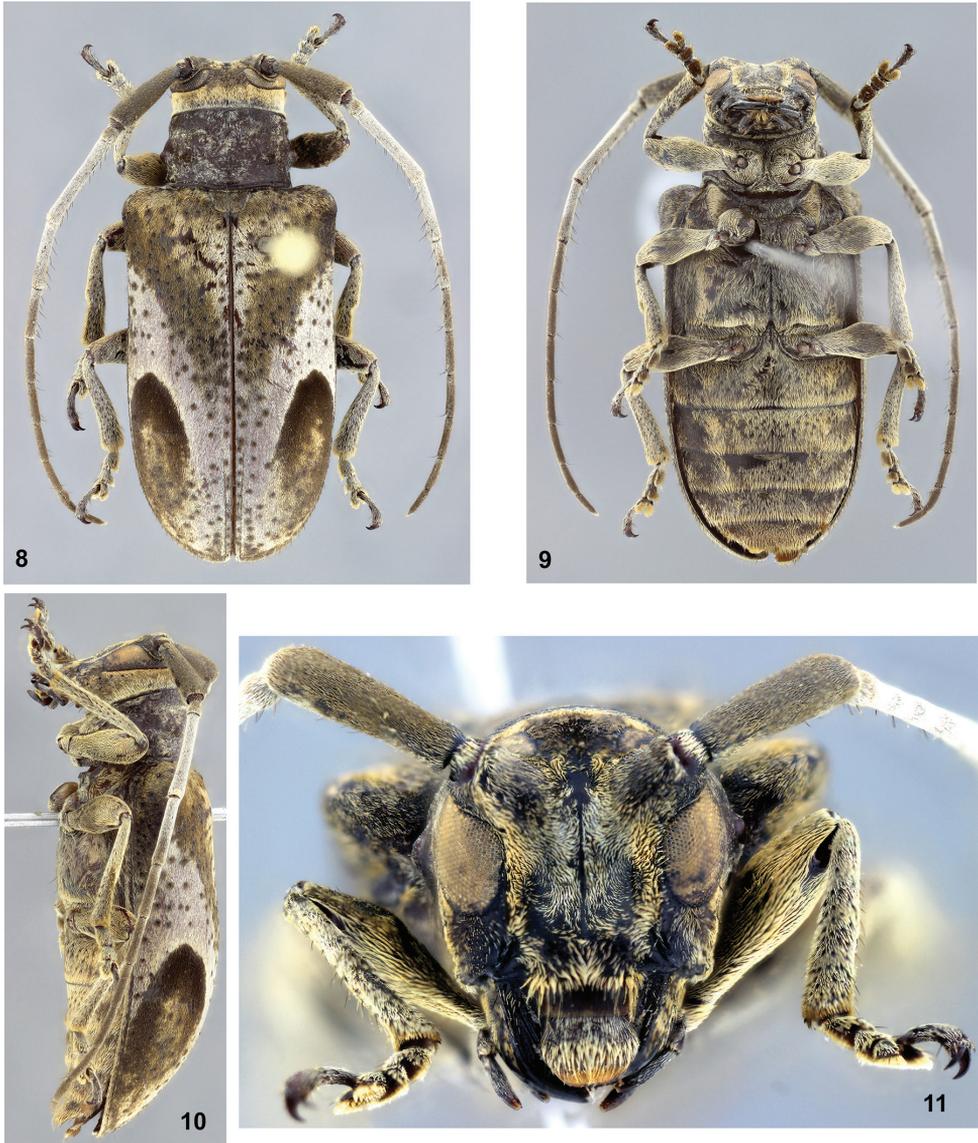
#### *Oncideres obliqua* sp. n.

<http://zoobank.org/97BA23A9-299E-42E3-9BAA-9913A4E7985B>

Figs 8–11

**Description.** Holotype female. Integument black.

Head. Frons elongate, centrally somewhat tumid; microsculptured, without punctures; pubescence centrally testaceous, short, moderately dense (distinctly sparser on area close to lateral band); lateral area close to eyes with narrow, yellowish band, from clypeus to apex of antennal tubercles. Central region between antennal tubercles with glabrous, smooth, irregular area. Postclypeus finely, abundantly punctate, except for lateral smooth area; laterally with yellowish band of pubescence, centrally with moderately wide central band of pubescence, areas between bands of pubescence with sparse yellowish setae; laterally, near anterior margin, with dark, long, sparse setae; distal margin with fringe of yellowish setae. Labrum basally with transverse band with short, testaceous pubescent, centrally with wide, transverse band with yellowish pubescence (longer than on base), distally with narrow band golden pubescence; lateral sides of area with yellowish pubescence with long, dark, sparse setae. Coronal suture distinct from clypeus to anterior margin of prothorax (less distinct from middle of eyes to prothorax). Antennal tubercles microsculptured; with short, testaceous pubescence on each side of central yellowish band (sparser on some areas). Area between upper eye lobes with short, brown, dense pubescence. Vertex and area behind eyes with dense, short, yellowish pubescence. Area behind lower eye lobes with sparse row of punctures (each puncture with dark, long, thick seta). Genae as long as 0.65 times lower eye lobes; laterally coarsely, sparsely punctate, with short, moderately abundant, yellowish setae; frontally moderately coarsely, confluent punctate, except for smooth area close to clypeus and frons, with moderately sparse, yellowish-brown setae, except for glabrous area close to clypeus and frons. Distance between upper eye lobes equal to 0.35 times length of scape. Lower eye lobes large, oblong; distance between them, in frontal view, equal to 0.70 times length of scape. Antennae as long as 1.5 times elytral length; reaching elytral apex at apex of antennomere IX; scape gradually expanded to apex, with brown pubescence, ventrally with short, sparse setae at distal half; antennomeres with whitish-gray pubescence, gradually brownish towards distal antennomeres; antennomeres ventrally with sparse, dark setae throughout (mainly III); antennal formula (ratio) based on antennomere III: scape = 0.87; pedicel = 0.19; IV = 0.69; V = 0.52; VI = 0.48; VII = 0.46; VIII = 0.44; IX = 0.39; X = 0.31; XI = 0.33.



**Figures 8–11.** *Oncioderes obliqua*, holotype female: **8** dorsal view **9** ventral view **10** lateral view **11** head, frontal view.

Thorax. Prothorax transverse; lateral sides with distinct tubercle near middle. Pronotum with two transverse, large, sub-fused gibbosities about middle of each side; center with large gibbosity, connected to the basal lateral gibbosity; pubescence yellowish-brown, distinctly not obliterating integument, interspersed with whitish pubescence on some areas. Lateral sides of prothorax with pubescence as on pronotum, but distinctly sparser. Prosternum and prosternal process with abundant, yellowish pubescence, distinctly longer than on pronotum. Mesosternum with yellowish-brown

pubescence, not obliterating integument. Mesepisterna with yellowish pubescence, longer and denser than on mesosternum. Metepisterna with yellowish-brown pubescence. Metasternum with yellowish-brown pubescence, laterally and close to metacoxae more yellowish. Scutellum with yellowish-brown pubescence. Elytra. Base with transverse band with yellowish-brown pubescence; from humerus to about middle, oblique, wide band with brownish pubescence, attaining suture; laterally from humerus to about apex of basal quarter, with brownish pubescence connected with oblique band at humerus; centrally, on basal third, between oblique bands, triangular area with yellowish-white pubescence; on distal half with large, elliptical macula with black pubescence on its basal third, brownish towards apex, except for small, irregular yellowish-white macula at base of brownish pubescence; remaining surface with whitish-gray pubescence, except for narrow area on apex with brownish pubescence, interspersed with yellowish; coarsely, deeply, sparsely punctate; apices rounded together. Legs. With dense, yellowish-white pubescence.

Abdomen. Ventrites coarsely, sparsely punctate (more distinctly on I–II); with yellowish-brown pubescence; ventrite V about as long as IV, trapezoidal, with apex slightly emarginate at center.

**Dimensions in mm (female).** Total length, 15.5; length of prothorax at center, 2.5; largest width of prothorax (between apices of tubercles), 4.2; anterior width of prothorax, 3.5; posterior width of prothorax, 3.8; humeral width, 6.5; elytral length, 11.5.

**Type material.** Holotype female from BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36’S, 40°26’W, 750 m), 4–8.XII.2013, V. O. Becker col. (MZSP).

**Etymology.** Latin, *obliqua* = oblique (feminine adjective); allusive to the oblique band with yellowish-brown pubescence on elytra.

**Remarks.** *Oncideres obliqua* sp. n. is similar to *O. piauiensis* Martins & Galileo, 2013, but differs as follows: more robust body; pubescence of head, pronotum and elytra shorter and less compact (mainly on pronotum); lateral tubercle of prothorax more distinct; elytra with oblique band from humerus to about middle; elytral punctures sparser. In *O. piauiensis*, the body is slender, the pubescence of head, pronotum and elytra are longer and more compact, the lateral tubercle of prothorax is smaller, the elytra have not oblique band from humerus to middle, and the elytral punctures are more abundant.

### Key to species of *Oncideres*

- 1 Lateral tubercle of prothorax very distinct; elytra with wide and oblique band with yellowish-brown pubescence from humerus to about middle. Brazil (Bahia) ..... ***Oncideres obliqua* sp. n.**
- Lateral tubercle of prothorax poorly elevated; elytra without wide and oblique band ..... **2**
- 2(1) Elytra with small, abundant, irregular white maculae of pubescence. Brazil (São Paulo) ..... ***O. picta* Martins & Galileo, 1990**

- Elytral pubescence distinctly more compact, forming large maculae ..... 3
- 3(2) Elytral pubescence predominantly orangish-yellow. Brazil (Piauí).....  
..... ***O. piauiensis* Martins & Galileo, 2013**
- Elytral pubescence predominantly yellowish-white. Brazil (Rondônia) .....  
..... ***O. rondoniae* Martins & Galileo, 1990**

**New records from Bahia (BRAZIL)**

**CERAMBYCINAE Latreille, 1802**

**CERAMBYCINI Latreille, 1802**

**CERAMBYCINA Latreille, 1802**

***Juiaparus batus lacordairei* (Gahan, 1892).** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), male, 4–8.XII.2013, V. O. Becker col. (CVOB).

This species was described from Argentina (Buenos Aires and Salta); currently it is recorded from Brazil (Goiás, Minas Gerais, Rio de Janeiro, São Paulo, Paraná, Santa Catarina), Bolivia, Paraguay, Argentina (Jujuy, Salta, Tucumán, Santiago del Estero, Chaco, Santa Fé, Córdoba), and Uruguay (Monné 2015a). Monné (2015a) did not record three provinces in Argentina: Buenos Aires, from where it was described the female syntype; and Misiones, recorded by Bosq (1934), Viana (1972), and Martins and Monné (2002). Viana (1972) also recorded the species from Guiana, and Mato Grosso (Brazil) (places not recorded in Monné 2015a). Martins and Monné (2002) did not exclude those places, only mentioning that Viana (1972) has listed them. Thus, formally, Guiana, the state of Mato Grosso in Brazil, and the provinces of Buenos Aires, Misiones and Corrientes in Argentina need to be added to the list by Monné (2015a).

**EBURIINI Blanchard, 1845**

***Eburodacrys lenkoi* Napp & Martins, 1980.** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), male, 4–8.XII.2013, V. O. Becker col. (CVOB).

*Eburodacrys lenkoi* was described and remains known only from Brazil (Minas Gerais, Espírito Santo, Rio de Janeiro, São Paulo) (Monné 2015a).

***Eburodacrys trilineata* (Aurivillius, 1893).** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), 3 males, 1 female, 4–8. XII.2013, V. O. Becker col. (CVOB).

Described from Brazil (Rio Grande do Sul). According to Martins (1999) the species occurs in Brazil (Minas Gerais, Espírito Santo, São Paulo, Santa Catarina, Rio Grande do Sul).

#### **ELAPHIDIINI Thomson, 1864**

***Mallocera umbrosa* Gounelle, 1909.** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 16°27'S, 39°03'W, 40 m), 2 males, 4–23.XI.2013, V. O. Becker col. (CVOB).

Described from Brazil (Goiás and Minas Gerais). Currently it is known from Brazil (Maranhão, Ceará, Distrito Federal, Goiás, Mato Grosso do Sul, Minas Gerais, São Paulo), Bolivia (Santa Cruz, Tarija), Paraguay, Argentina (Jujuy) (Monné 2015a).

***Stizocera jassuara* (Martins & Napp, 1983).** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), 2 females, 4–8.XII.2013, V. O. Becker col. (CVOB).

Described and it is known from Brazil (Espírito Santo and Rio de Janeiro) (Monné 2015a).

***Stizocera juati* Martins & Napp, 1983.** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), 1 male, 1 female, 4–8.XII.2013, V. O. Becker col. (CVOB).

Described from Brazil (Minas Gerais, Espírito Santo, Rio de Janeiro). Currently it is known also from Bolivia (Santa Cruz) (Monné 2015a).

#### **NEOIBIDIONINI Monné, 2012**

##### **COMPSINA Martins & Galileo, 2007**

***Engyum vicinum* Martins, Santos-Silva, Galileo & Oliveira 2014.** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), male, 4–8.XII.2013, V. O. Becker col. (CVOB).

The species was described and known from Brazil (Maranhão).

#### **PLEIARTHROCERINI LANE, 1950**

***Pleiarthroceus opacus* Bruch, 1914.** Material examined. BRAZIL, *Bahia*: 9 km W Boa Nova (“Caatinga”, 14°36'S, 40°26'W, 750 m), male, 4–8.XII.2013, V. O. Becker col. (CVOB).

Described from Argentina (Tucumán). Currently it is known from Brazil (Pernambuco, Paraíba, Alagoas), Bolivia (Santa Cruz), Argentina (Salta, Tucumán) (Monné 2015a).

### **LAMIINAE Latreille, 1825**

### **ACANTHODERINI Thomson, 1860**

*Psapharochrus bivittus* (White, 1855). Material examined. BRAZIL, Bahia: 9 km W Boa Nova (“Caatinga”, 14°36’S, 40°26’W, 750 m), male, 4–8.XII.2013, V. O. Becker col. (CVOB).

Described from Brazil (Pará). Currently known from Guatemala, Honduras, Nicaragua, Costa Rica, Panama, French Guiana, Brazil (Amazonas, Pará, Maranhão, Espírito Santo to São Paulo), Bolivia (La Paz, Santa Cruz) (Monné 2015b). Zajciw (1968a, 1968b) listed two states in Brazil, not included in Monné (2015b): Pernambuco, and Minas Gerais (a state that it is not clearly placed between Espírito Santo and São Paulo). Marques et al. (2014) recorded that species for the state of Mato Grosso (Brazil).

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### **References**

- Bosq JM (1934) Primera lista de coleópteros de la República Argentina dañinos a la Agricultura. Boletín del Ministerio de Agricultura de la Nación 36(4): 313–346.
- Fragoso SA (1993) On old and new species of *Coleoxestia* Aurivillius, 1912 (Coleoptera, Cerambycidae, Cerambycini). Revista Brasileira de Biologia 53(3): 327–343.
- Marques MI, Santos GB, Battirola LD (2014) Cerambycidae (Insecta, Coleoptera) associados à *Vochysia divergens* Pohl (Vochysiaceae) na região Norte do Pantanal de Mato Grosso, Brasil. EntomoBrasilis 7(2): 159–160. doi: 10.12741/ebrazilis.v7i2.317
- Martins UR (1999) Tribo Eburiini. In: Martins UR (Org.) Cerambycidae Sul-Americanos (Coleoptera). Taxonomia. Sociedade Brasileira de Entomologia, São Paulo, v. 3, 119–391.
- Martins UR, Monné MA (2002) Tribo Cerambycini. In: Martins UR (Org.) Cerambycidae Sul-Americanos (Coleoptera). Taxonomia. Sociedade Brasileira de Entomologia, São Paulo, v. 4, 145–248.
- Martins UR, Monné MA (2005) Tribo Cerambycini, Subtribo Sphallogtrichina. In: Martins UR (Org.) Cerambycidae Sul-Americanos (Coleoptera). Taxonomia. Sociedade Brasileira de Entomologia, São Paulo, v. 5, 1–218.

- Martins UR, Galileo MHM, Santos-Silva A (2015) New taxa and new records in Cerambycidae (Coleoptera) from the state of Bahia (Brazil) and notes on *Meridiotroctes* (Acanthoderini). Zootaxa 3973(2): 271–299. doi: 10.11646/zootaxa.3973.2.4
- Monné MA (2015a) Catalogue of the Cerambycidae (Coleoptera) of the Neotropical Region. Part I. Subfamily Cerambycinae. [http://www.cerambyxcat.com/Parte1\\_Cerambycinae.pdf](http://www.cerambyxcat.com/Parte1_Cerambycinae.pdf) [accessed May 2015]
- Monné MA (2015b) Catalogue of the Cerambycidae (Coleoptera) of the Neotropical Region. Part II. Subfamily Lamiinae. [http://www.cerambyxcat.com/Parte2\\_Lamiinae.pdf](http://www.cerambyxcat.com/Parte2_Lamiinae.pdf) [accessed May 2015]
- Viana MJ (1972) Aporte al Catálogo de Cerambycidae del Paraguay (Insecta, Coleoptera). Revista del Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”, Entomología 3(4): 207–405.
- Zajciw D (1968a) Contribuição para o estudo da fauna dos longicórneos do Nordeste Brasileiro (Coleoptera, Cerambycidae). Revista Brasileira de Entomologia 13: 119–130.
- Zajciw D (1968b) Novas ocorrências de *Acanthoderes* Serv., 1835 (Coleoptera, Cerambycidae, Lamiinae). Atas da Sociedade de Biologia 12(3): 141.

# A new species of *Monoliropus* Mayer, 1903 (Crustacea, Amphipoda, Caprellidae) from Korean waters

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## Abstract

A new species of the genus *Monoliropus* belonging to the family Caprellidae was collected from the Yellow Sea, Korea. The new species differs from *Monoliropus agilis* Mayer, 1903, *M. kazemii* Momtazi & Sari, 2013, and *Tripotella amica* Arimoto, 1970 as follows: 1) gnathopod 1 subrectangular; 2) pereonites 2–3 with acute triangular processes anterolaterally; 3) mandibular palp, apical article with four simple setae subdistally. The new species is fully illustrated and extensively compared with related species. This is the first record of the genus *Monoliropus* from Korean waters. A key to *Monoliropus* species is also given.

## Keywords

*Monoliropus*, Caprellidae, Amphipoda, new species, key, Korea

## Introduction

The genus *Monoliropus* Mayer, 1903 is one of 57 genera belonging to the family Caprellidae. *Monoliropus* is closely related to *Metaprotella* Mayer, 1890 and *Tripotella* Arimoto, 1970 and commonly characterized by having biarticulate flagellum of antenna 2; triarticulate mandibular palp; pereonites 3–4 with gills; unarticulate pereopods 3–4; well developed, 6-articulate pereopod 5; in male, abdomen with a

pair of biarticulate appendages and a pair of lobes (Arimoto 1976). To date, this genus *Monoliropus* is comprised of seven described species (Momtazi and Sari 2013; WoRMS 2015). In this article, a full description of the new species in the genus *Monoliropus* from Korean waters is provided, with a brief description of the female, focusing on the sexually dimorphic characters. This is the first record of the genus *Monoliropus* from Korea and a key to the world *Monoliropus* species is also provided.

## Material and methods

Specimens were collected by light trap from the subtidal zone of Bukahng Port, Mokpo-si, Korea in 2012 (Fig. 1). The specimens were fixed with 80% ethanol and dissected in glycerin on Cobb's aluminum hollow slides. Drawings and measurements were performed with the aid of a drawing tube, under a stereomicroscope (Olympus SZX12; Tokyo, Japan) and a differential interference contrast microscope with Nomarski optics (Olympus BX51). Type specimens were deposited at the National Institute of Biological Resources (NIBR), Incheon, Korea and the Department of Life Sciences, Dankook University (DKU), Cheonan, Korea.

## Taxonomy

### Genus *Monoliropus* Mayer, 1903

Korean name: Jjal-eun-a-ga-mi-da-ri-ba-da-dae-beol-rae-sok, new

**Type species.** *Monoliropus agilis* Mayer, 1903

**Diagnosis.** Antenna 2, flagellum biarticulate, swimming setae absent; mandibular palp bi- or triarticulate; pereonites 3–4 with gills; pereopods 3–4 present, uniarticulate; in male, abdomen with a pair of uni- or biarticulate appendages and a pair of lobes.

**Species composition.** The genus contains seven species, *Monoliropus agilis* Mayer, 1903, *M. concavimanus* Horton, 2008, *M. enodis* Rayol & Serejo, 2003, *M. falcimanus* Mayer, 1904, *M. hapipandi* Guerra-García, 2004, *M. kazemii* Momtazi & Sari, 2013, and *M. tener* Arimoto, 1968.

### *Monoliropus leae* sp. n.

<http://zoobank.org/4D5A1B2A-1B84-402A-B5E4-397084742D53>

Korean name: Jjal-eun-a-ga-mi-da-ri-ba-da-dae-beol-rae, new

Figures 1–5

**Type material.** Holotype: male, 9.3 mm, NIBRIV0000309619, Bukhang Port, Jukgyo-dong, Mokpo-si, Jeollanam-do, Korea, 34°48'00"N, 126°21'56"E, S.S. Hong and

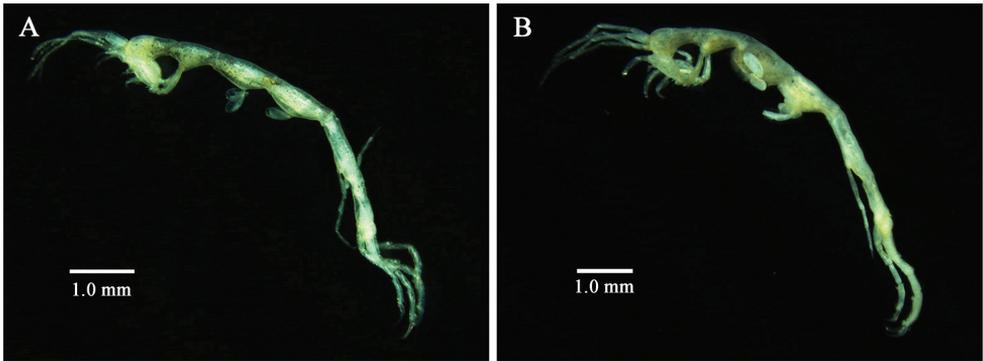


**Figure 1.** Distribution of *Monoliropus leae* sp. n. from Korean waters (◆: Bukhang Port, Jukgyo-dong, Mokpo-si, Jeollanam-do, Korea).

S.H. Kim, by light trap from 6–8 m depth, 11 July 2012. Paratypes: female, 11.7 mm, NIBRIV0000309620, 27 July 2012, same station data as holotype; 6 males, 5.3–6.7 mm, DKUAMP201501, 11 July 2012, same station data as holotype; 2 immature males and 5 immature females, 5.3–7.1 mm, DKUAMP201502, 27 July 2012, same station data as holotype.

**Description. Holotype, male,** NIBRIV0000309619.

Body (Fig. 3A) 9.3 mm long, slender and long, surface smooth. Head round and smooth without projection. Eye small, round. Head and pereonite 1 fused, suture present. Pereonite 1 nearly smooth, with 1 small bump anterodorsally and a pair of minute blunt processes posterodorsally. Pereonite 2 with acute triangular process anterolaterally. Pereonites 3–4 subequal in length, with small uniaarticulate pereopods and rounded gills ventrally, and tiny triangular process on both lateral sides. Pereonite 5 subrectangular, width  $0.30 \times$  length, with 6-articulate pereopod. Pereonite 6 smooth without process. Length ratio of pereonites 1–7 = 1.00 : 1.52 : 2.12 : 2.23 : 2.53 : 1.40 : 0.49.



**Figure 2.** *Monoliropus leae* sp. n. **A** male, 5.6 mm **B** immature female, 6.4 mm.

Antenna 1 (Fig. 3B)  $0.35 \times$  body; length ratio of peduncular articles 1–3 = 1.00 : 3.46 : 0.84; flagellum 9-articulate,  $0.76 \times$  peduncular articles, each article with 1 or 2 aesthetascs ventrodistally.

Antenna 2 (Fig. 3C) slightly shorter than antenna 1; length ratio of peduncular articles 3–5 = 1.00 : 2.75 : 3.45; peduncular articles 4–5 with unequal simple setae ventrally; flagellum biarticulate,  $0.30 \times$  peduncular articles, proximal article elongate,  $1.95 \times$  distal article.

Upper lip (Fig. 3D) rounded, notched midventrally with pubescence apically.

Lower lip (Fig. 3E) well developed, inner and outer lobes with patch of pubescence apically.

Left mandible (Fig. 3F) incisor and lacinia mobilis 5-teethed; setal row with 3 pectinated setae; molar well developed, truncate; mandibular palp slender, triarticulate, length ratio of articles 1–3 = 1.00 : 1.92 : 1.85, article 2 with 6 simple setae, distal article acute apically, with 4 simple setae.

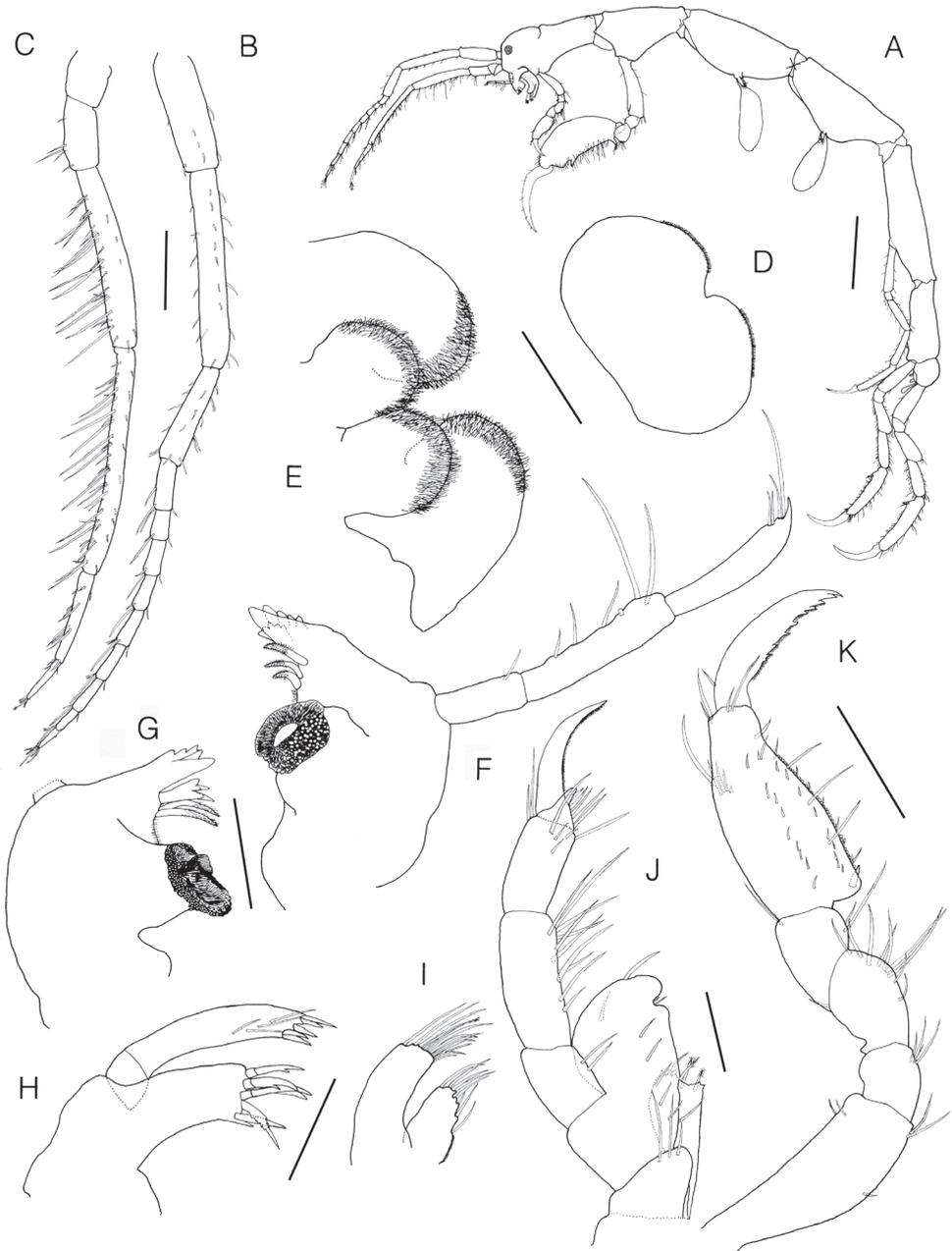
Right mandible (Fig. 3G) similar to left except setal row with 2 pectinated setae and molar flake present.

Maxilla 1 (Fig. 3H) inner plate absent; outer plate with 6 stout setal teeth (3 simple, 2 bifid and 1 denticulate) apically; palp biarticulate, distal article with 5 apical spines and 4 subapical setae.

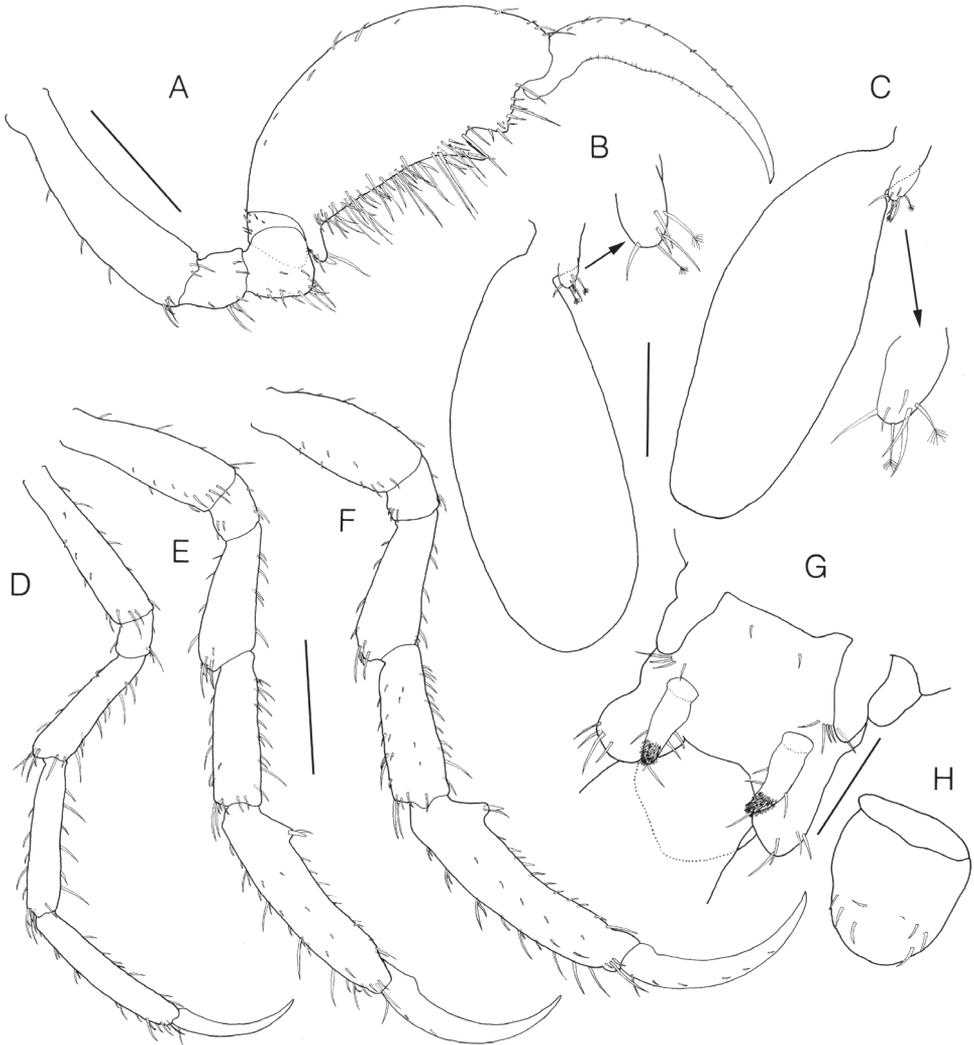
Maxilla 2 (Fig. 3I) inner plate with dense pubescence medially and 8 simple setae on apical and subapical margins; outer plate longer than inner, with 12 simple setae apically.

Maxilliped (Fig. 3J) inner plate subrectangular, with 1 forked and 3 penicillate setae apically; outer plate much larger than inner plate, distomedial portion with rounded groove, distal margin rounded with 1 simple seta; palp 4-articulate, article 3 with subacute process apically, distal article falcate, with a row of setules along inner margin, length ratio of articles 1–4 = 1.00 : 1.75 : 1.70 : 1.17.

Gnathopod 1 (Fig. 3K) propodus subrectangular, narrowing distally, width  $0.45 \times$  length, palm serrated with 1 proximal grasping spine; dactylus falcate, with irregular serrations on inner margin; length ratio of 6 articles = 1.00 : 0.26 : 0.38 : 0.34 : 1.02 : 0.77.



**Figure 3.** *Monoliropus leae* sp. n., holotype, male, 9.3 mm. **A** habitus, lateral view **B** Antenna 1 **C** Antenna 2 **D** upper lip **E** lower lip **F** left mandible **G** right mandible **H** maxilla 1 **I** maxilla 2 **J** right maxilliped **K** gnathopod 1. Scale bars: 1.0 mm (**A**), 0.3 mm (**B**, **C**), 0.2 mm (**K**), 0.1 mm (**D**–**J**).



**Figure 4.** *Monoliropus leae* sp. n., holotype, male, 9.3 mm. **A** gnathopod 2 **B** gill 3 and pereopod 3 **C** gill 4 and pereopod 4 **D** pereopod 5 **E** pereopod 6 **F** pereopod 7 **G** abdomen, ventral view **H** single dorsal lobe, dorsal view. Scale bars: 0.4 mm (**A**, **D–F**), 0.2 mm (**B**, **C**), 0.1 mm (**G**, **H**).

Gnathopod 2 (Fig. 4A) anterior margin of carpus very short; propodus massive, width  $0.44 \times$  length, anterior margin convex, with rounded angle, palmar margin straight with proximal blunt process bearing grasping spine and acute poison tooth followed by rounded notch subdistally; dactylus elongate, falcate; length ratio of 6 articles = 1.00 : 0.25 : 0.27 : 0.18 : 1.34 : 1.10.

Gill 3 (Fig. 4B) elongate, elliptical,  $0.63 \times$  pereonite 3.

Pereopod 3 (Fig. 4B) vestigial, uniarticulate,  $0.07 \times$  gill, with 4 simple and 2 penicillate setae.

Pereopod 4 (Fig. 4C) similar to pereopod 3, but slightly longer.

Pereopod 5 (Fig. 4D) well developed, slender, setose, 6-articulate,  $1.21 \times$  pereonite 5, inserted about 7/10 from the anterior end of pereonite 5; length ratio of 6 articles =  $1.00 : 0.21 : 0.74 : 0.87 : 0.94 : 0.68$ .

Pereopod 6 (Fig. 4E) well developed, setose, 6-articulate,  $2.49 \times$  pereonite 6,  $1.20 \times$  pereopod 5, attached to the posterodistal end of the pereonite 6; propodus subrectangular, palm defined by posterodistal blunt bump with grasping spine and seta; length ratio of 6 articles =  $1.00 : 0.28 : 0.76 : 0.84 : 1.40 : 1.00$ .

Pereopod 7 (Fig. 4F) similar and subequal to pereopod 6, length ratio of 6 articles =  $1.00 : 0.26 : 0.78 : 0.90 : 1.50 : 1.10$ .

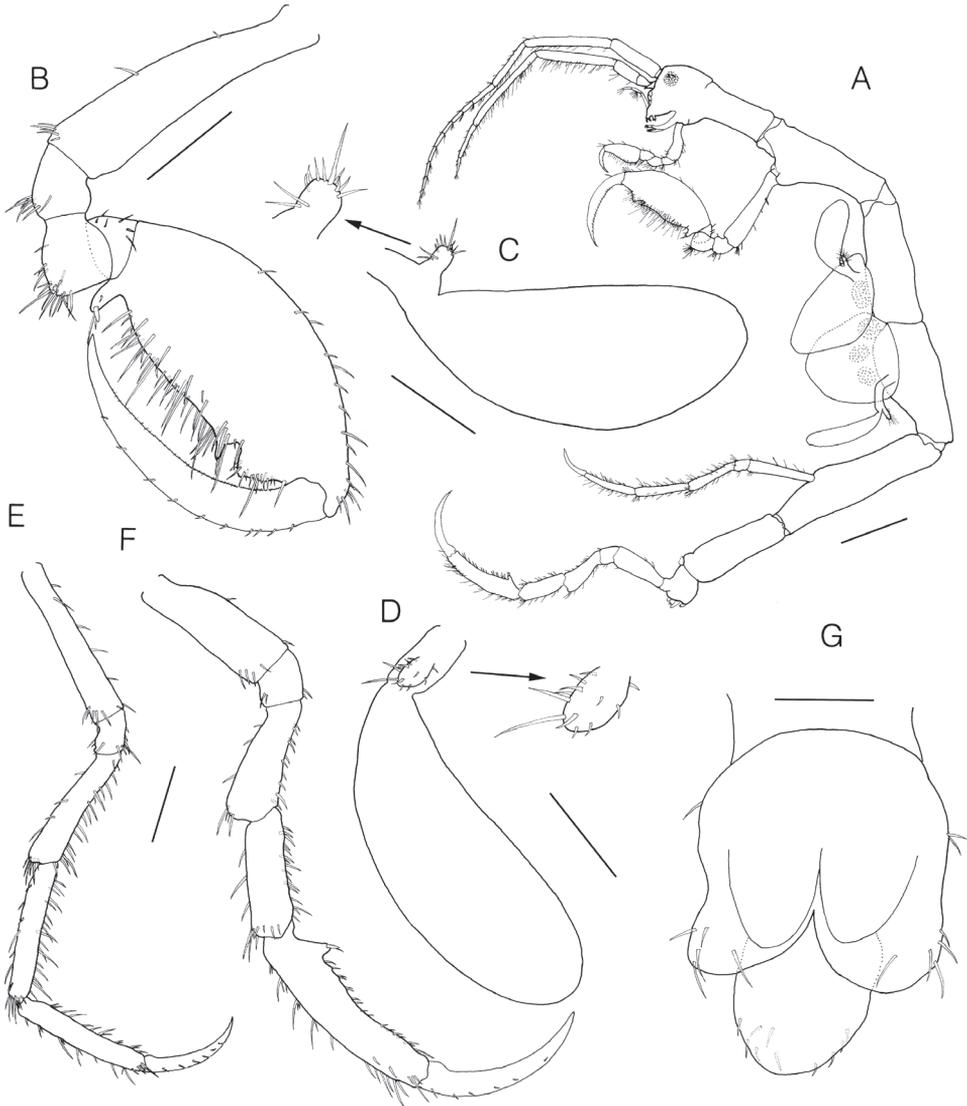
Penes (Fig. 4G) cylindrical in shape, situated medially, width  $0.50 \times$  length.

Abdomen (Fig. 4G, H) with a pair of appendages, a pair of lateral and single dorsal lobes; appendage uniarticulate, with 3 lateral, 1 apical setae, distal portion covered with patch of fine setules; lateral lobe with 4 simple setae apically; dorsal lobe rounded, with 7 simple setae dorsally.

**Paratype, female** (sexually dimorphic characters), NIBRIV0000309620.

Body (Fig. 5A) 11.7 mm long. Body form generally as in male including antennae 1–2, but pereonites 3–4 with rounded brood pouches. Gnathopod 2 (Fig. 5B) palm slightly curved convexly. Pereopods 3–7 (Fig. 5C–F) more setose than male. Abdomen (Fig. 5G) lacking appendages, lateral lobe wider than that of male.

**Remarks.** The genus *Monoliropus* belongs to the family Caprellidae, which has close affinities with *Metaprotella* Mayer, 1890 and *Tripotella* Arimoto, 1970 as it possesses the following characters: 1) antenna 2, peduncles without swimming seta, flagellum biarticulate; 2) mandibular palp bi- or triarticulate; 3) pereopods 3–4 reduced, uniarticulate; 4) in male, abdomen with uni- or biarticulate appendages. However, *Metaprotella* is distinguished from *Monoliropus* by setal formula  $1-x-y-1$  of the distal article of mandibular palp and fused pereonites 6–7. *Tripotella* is very similar to the genus *Monoliropus*, however, is discernible from *Monoliropus* by setal formula  $1-1-1$  of the distal article of the mandibular palp, uniarticulate pereopods 3–4, morphology of the gnathopod 2, and form of abdomen (Sivaprakasam 1977; Laubitz 1991; Guerra-García 2002). The species *Monoliropus agilis* has been redescribed by Guerra-García (2004), showing a setal formula of mandibular palp of  $1-1-1$ , and the abdomen very similar to that of the genus *Tripotella*. Therefore both genera could be re-established or synonymized in the future. The new species *Monoliropus leae* sp. n. is similar to *M. agilis* Mayer, 1903, *M. kazemii* Momtazi & Sari, 2013, and *Tripotella amica* Arimoto, 1970; however, is distinguished from its congeners based on the characters listed in Table 1 and the combination of the following features: 1) body medium sized, 9–11 mm (*vs.* small sized, 4 mm in *M. agilis*, 5–7 mm in *T. amica*); 2) maxilla 1, outer plate with six stout setal teeth (*vs.* five in *T. amica*, seven in *M. agilis* and *M. kazemii*); 3) mandibular palp, distal article with four simple setae (*vs.* three simple setae in *M. agilis* and *T. amica*); 4) gnathopod 1, propodus subrectangular (*vs.* subtriangular in *M. agilis*, *M. kazemii*, and *T. amica*); 5) gnathopod 1, dactylus with serrations on inner margin (*vs.* with serrations both margins in *T. amica*); 6) pereonites 2–3 with acute triangular



**Figure 5.** *Monoliropus leae* sp. n., paratype, female, 11.7 mm. **A** habitus, lateral view **B** gnathopod 2 **C** gill 3 and pereopod 3 **D** gill 4 and pereopod 4 **E** pereopod 5 **F** pereopod 6 **G** abdomen, ventral view. Scale bars: 1.0 mm (**A**), 0.4 mm (**B**) 0.3 mm (**E, F**), 0.2 mm (**C, D**), 0.1 mm (**G**).

processes anterolaterally (*vs.* without triangular processes in *M. agilis*, *M. kazemii*, and *T. amica*); 7) pereopods 3–4 short (*vs.* elongate in *M. agilis*, *M. kazemii*, and *T. amica*); 8) abdominal appendage uniarticulate (*vs.* biarticulate in *M. kazemii*).

**Etymology.** The specific name *leae* is in honor of Dr. Kyung-Sook Lee, who has contributed to knowledge of Korean caprellid Amphipoda.

**Distribution.** Bukhang Port, Jukgyo-dong, Mokpo-si, Jeollanam-do, Korea.

**Table 1.** Morphological characters of *Monoliropus leae* sp. n. and closely related species.

Characters	Species (male)			
	<i>Monoliropus agilis</i>	<i>Monoliropus kazemii</i>	<i>Tripotella amica</i>	<i>Monoliropus leae</i> sp. n.
Body length (mm)	4.0	8.5	5.4	6.3
Peronites 2–3, anterior processes	x	o	no referred	x
Right mandible, molar flake	o	x	no referred	o
Mandibular palp, distal article, # of setae	3	4	3	3
Maxilla 1, outer plate, # of setae	7	7	no referred	5 setae
Maxilliped, outer plate, distal margin	jagged	jagged	jagged	jagged
Gnathopod 1, propodus	subtriangular, width 0.61 × length	subtriangular, width 0.49 × length	no referred	subtriangular, width 0.80 × length
Gnathopod 1, dactylus serrations	inner margin	inner margin	no referred	both margins
Pereopods 3–4	elongate, 2.7–2.9 × width	elongate, 3.6–3.7 × width	elongate	elongate, 3.5 × width
Abdominal appendage, # of setae	uniarтикуlate, no seta	biarticulate, 5 setae	uniarтикуlate, 1 seta	uniarтикуlate, 1 seta
Abdomen, dorsal lobe, # of setae	2 terminal setae	2 terminal setae	no referred	2 terminal setae
Distribution	Phuket, Thailand (Guerra-García 2004)	Persian and Oman Gulf, Iran (Momtazi and Sari 2013)	Arabian Sea, Oman (Arimoto 1970)	Mbudya island, Tanzania (Guerra-García 2002)
				subrectangular, width 0.45 × length
				inner margin
				short, 1.3–1.9 × width
				uniarтикуlate, 4 setae
				7 dorsal setae
				Mokpo-si, Korea (Present study)

### Key to the species of *Monoliropus* (males)

- 1 Mandibular palp 2-articulate, with 1 single seta distally .....  
 ..... *M. hapipandi* Guerra-García, 2004
- Mandibular palp 3-articulate, with several setae distally ..... 2
- 2 Gnathopod 2, propodus without grasping spine and process on palmar margin .....  
 ..... *M. tener* Arimoto, 1968
- Gnathopod 2, propodus with grasping spine and process on palmar margin... 3
- 3 Pereopod 5, propodus with grasping spine..... 4
- Pereopod 5, propodus without grasping spine ..... 5
- 4 Gnathopod 2, propodus, palmar margin straight .....  
 ..... *M. kazemii* Momtazi & Sari, 2013
- Gnathopod 2, propodus, palmar margin concave...*M. falcimanus* Mayer, 1904
- 5 Abdominal appendage biarticulate..... *M. enodis* Rayol & Serejo, 2003
- Abdominal appendage uniarticulate..... 6
- 6 Gnathopod 2, propodus, palmar margin concave .....  
 ..... *M. concavimanus* Horton, 2008
- Gnathopod 2, propodus, palmar margin straight ..... 7
- 7 Gnathopod 1, propodus subtriangular; pereopods 3–4 elongate, length > 2.5  
 × width ..... *M. agilis* Mayer, 1903
- Gnathopod 1, propodus subrectangular; pereopods 3–4 short, length < 2.0 ×  
 width ..... *M. leae* sp. n.

### Acknowledgements

We cordially thank Seong-Soo Hong who contributed to finding the new species and we greatly appreciate the suggestions and comments given from anonymous reviewers that improved the manuscript. This work was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIBR No. 2013-02-001).

### References

- Arimoto I (1968) A new caprellid Amphipoda *Monoliropus tener* sp. n. collected from Tateyama Bay. Bulletin of the Biogeographical Society of Japan 24(8): 59–61.
- Arimoto I (1970) Two new genera and three new species of caprellids (Amphipoda: Caprellidea) from the Arabian Sea. Bulletin of the Biogeographical Society of Japan 24(11): 71–78.
- Arimoto I (1976) Taxonomic studies of caprellids (Crustacea, Amphipoda, Caprellidae) found in the Japanese and adjacent waters. Special Publications from the Seto marine Biological Laboratory, Kyoto University 3: 1–229.

- Guerra-García JM (2002) Redescription of five rare caprellids (Crustacea: Amphipoda: Caprellidae) collected from Tanzanian coasts. *Helgoland Marine Research* 55: 221–231. doi: 10.1007/s101520100083
- Guerra-García JM (2004) Littoral Caprellidea (Crustacea, Amphipoda) from Phuket, Thailand. *Steenstrupia* 28: 159–175.
- Horton T (2008) Amphipoda from marine caves of Hong Kong Island. *Journal of Natural History* 42(9): 825–854. doi: 10.1080/00222930701860124
- Laubitz DR (1991) Crustacea Amphipoda Caprellidea: caprellids from the western Pacific (New Caledonia, Indonesia and the Philippines). In: Crosnier A (Ed.) *Résultats des campagnes MUSOROSTOM*, vol. 9. *Mémoires du Muséum National d'Histoire Naturelle (A)* 152: 101–123.
- Mayer P (1890) Des Caprelliden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. *Fauna und Flora des Golfes von Neapel* 17: 1–157. doi: 10.5962/bhl.title.53624
- Mayer P (1903) Die Caprellidae der Siboga-Expedition. *Siboga-Expeditie* 34: 1–160. doi: 10.5962/bhl.title.53742
- Mayer P (1904) The Caprellidea collected by Professor Herdman at Ceylon in 1902. Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf Manaar 16: 223–227.
- Momtazi F, Sari A (2013) Intertidal caprellids (Crustacea: Amphipoda) of the Persian Gulf and the Gulf of Oman, with description of three new species. *Zootaxa* 3717(2): 195–223. doi: 10.11646/zootaxa.3717.2.5
- Rayol MC, Serejo CS (2003) A new species of *Monoliropus* Mayer, 1903 (Amphipoda, Caprellidea) from Guanabara Bay, RJ, Brazil. *Arquivos do Museu Nacional* 61(3): 165–170.
- Sivaprakasam TE (1977) The skeleton shrimps (Amphipoda: Caprellidea) of the Tamil Nadu and Kerala Coasts. *Journal of Marine Biological Association of India* 19: 78–96.
- WoRMS Editorial Board (2015) World Register of Marine Species. <http://www.marinespecies.org> [accessed 2015-04-30]



# Two new cave-dwelling species of the millipede genus *Paracortina* Wang & Zhang, 1993 from southern China (Diplopoda, Callipodida, Paracortinidae)

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## Abstract

Two new species of the millipede genus *Paracortina* Wang & Zhang, 1993 are described. Both are presumed troglophiles: *P. zhangi* **sp. n.** from a cave in Ceheng County, southwestern Guizhou Province and *P. yinae* **sp. n.** from a cave in Longlin County, western Guangxi Zhuang Autonomous Region. A distribution map and a key to all 12 *Paracortina* species are also provided.

## Keywords

*Paracortina*, new species, taxonomy, cave-dwelling, China

## Introduction

The family Paracortinidae was first established to comprise three genera: *Paracortina* Wang & Zhang, 1993, *Relictus* Wang & Zhang, 1993, *Altum* Wang & Zhang, 1993 (Wang and Zhang 1993). A fourth genus, *Angulifemur* Zhang, 1997, was added soon thereafter (Zhang 1997). All these genera are distributed in southern China only Yunnan and Sichuan provinces, as well as Tibet (Xizang Autonomous Region).

The family has since been reviewed and shown to have *Relictus* and *Altum* as junior synonyms of *Paracortina* (Stoev and Geoffroy 2004). The genus *Scotopetalum* Shear,

2000, which only included a single species from Vietnam, has been synonymized with *Paracortina* (Stoev and Geoffroy 2004). Although *Angulifemur* Zhang, 1997, with two species still remains treated as an independent genus, it is likely to also represent only a junior synonym of *Paracortina* (Stoev et al. 2008). In 2004, the first troglomorphic species *P. wangi* Stoev was described from south Yunnan, but it was subsequently synonymized with *A. unidigitis* Zhang, 1997 (Stoev et al. 2008).

As a result, *Angulifemur* consists of two species only from Mengzi, Yunnan of China. *Paracortina* is the largest genus in the family Paracortinidae including ten species and ranging from Tibet, Sichuan and Yunnan in southwestern China in the north of its distribution to Thanh Hoa and Hoa Binh provinces of northern Vietnam in the south (Stoev et al. 2008, Stoev and Enghoff 2011).

*A. tridigitis* Zhang, 1997, from Mengzi City, Yunnan, China.

*A. unidigitis* Zhang, 1997, from Mengzi City, Yunnan, China.

*P. carinata* Wang & Zhang, 1993, from Shangrila County (=Zhongdian County), Yunnan, China.

*P. chinensis* Stoev & Geoffroy, 2004, from Zhenxiong County, Yunnan, China.

*P. leptoclada* Wang & Zhang, 1993, from Shangrila County, Yunnan, China.

*P. multisegmentata* Stoev & Geoffroy, 2004, from Ngoc-Lac and Loc Thinh, Thanh Hoa, Vietnam.

*P. serrata* Wang & Zhang, 1993, from Deqin County, Yunnan, China.

*P. stimula* Wang & Zhang, 1993, from Shangrila County, Yunnan, China.

*P. thallina* Wang & Zhang, 1993, from Batang County, Sichuan, and Shangrila County, Yunnan, China.

*P. viriosa* Wang & Zhang, 1993, from Shangrila County, Yunnan, and Mangkang County, Tibet, China.

*P. voluta* Wang & Zhang, 1993, from Yajiang County, Sichuan, China.

*P. warreni* Shear, 2000, from Hong Mat, Hoa Binh, Vietnam.

Of these, four species have been considered as troglophiles: *A. tridigitis*, *A. unidigitis*, *P. chinensis*, and *P. warreni* (Stoev and Geoffroy 2004, Stoev et al. 2008). The present paper records two new paracortinid millipedes found in two caves, one in Guizhou Province, the other in Guangxi Zhuang Autonomous Region, both in southern China.

## Material and methods

All types are deposited in the zoological collection of the South China Agricultural University, Guangzhou, China (SCAU). All specimens used in this study were collected by hand in caves and preserved in 75% ethanol.

Observations and dissections were performed using a Leica DFC295 stereoscope. The line illustrations were executed with the help of a Leica MZ125 stereoscope and a *camera lucida* attached to the stereoscope. The photographs were taken with a Canon

EOS 40D camera, further processed using Adobe Photoshop CS5 computer software. The distribution map was created using MapInfo Professional 12.0 software.

The terminology used in the text is after Wang and Zhang (1993) and Stoev (2004).

## Taxonomic treatment

### *Paracortina zhangii* Liu & Tian, sp. n.

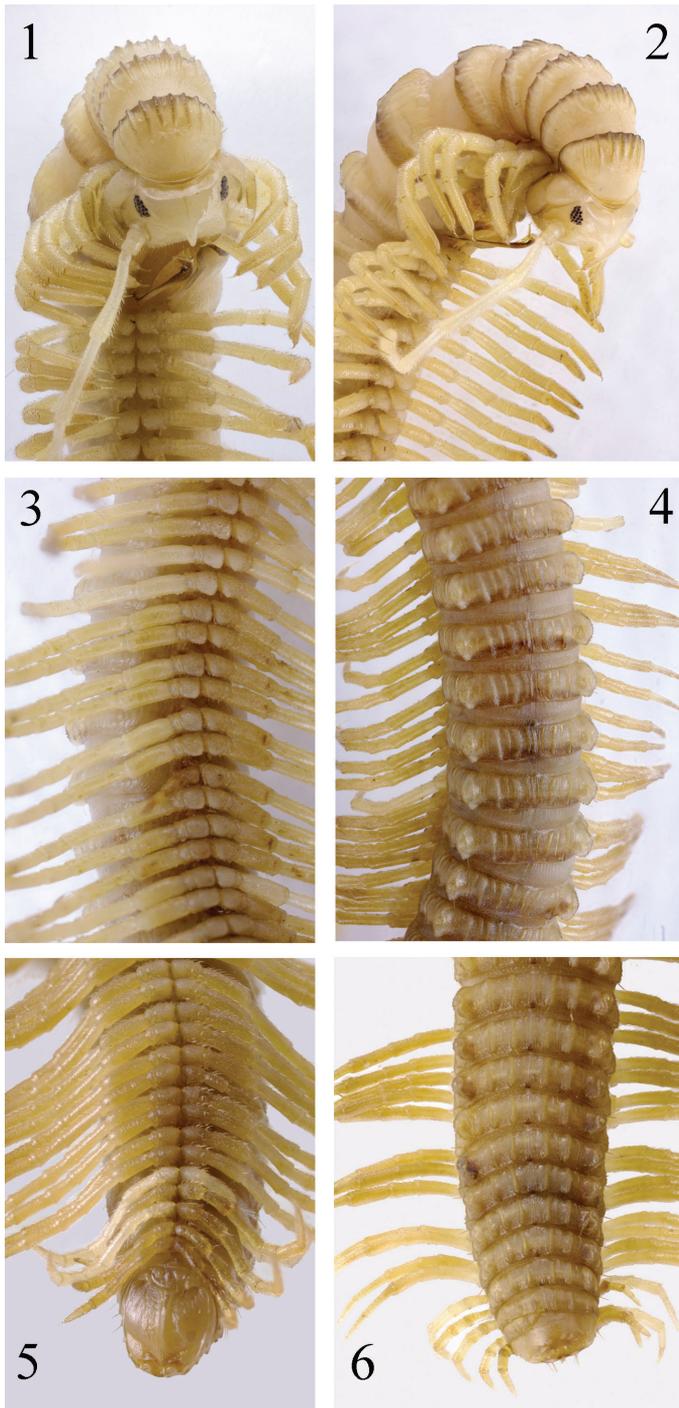
<http://zoobank.org/A1DB7B9A-F062-46C0-BAB4-5EA2CDC815FA>

Figs 1–22

**Material examined.** Holotype: adult male (SCAU), China, Guizhou, Qianxinan Zizhizhou, Ceheng County, Rongdu Village, Cave Qiaoxia Dong, 24°03.008N, 105°43.147E, 964 m, 26.XII.2012, leg. Mingyi Tian, Weixin Liu, Feifei Sun & Haomin Yin. Paratypes. 1 male, 3 females, 10 juveniles (SCAU), same locality, together with holotype.

**Description.** Length of adults of both sexes 46–55 mm, width of midbody segments 2.6–3.0 mm, body with 55–58 pleurotergites + telson. Holotype 46 mm long, 2.6 mm wide on midbody segment, maximum width on 6<sup>th</sup> pleurotergite 3.5 mm, body with 57 pleurotergites + telson. Body coloration light yellow-brownish, anterior part of body slightly lighter. Metazonae slightly darker than prozonae, posterior margin of pleurotergites brownish to dark brown, more infuscate on anterior pleurotergites (Figs 1–7). Head yellowish, epicranial suture distinct, with a large, median, beak-shaped process located between antennae in males, below it densely and finely setose and granulate (Figs 1–2). Edges of genae, posterior margin of the head, and bases of antennae marbled light brown-yellowish. Labrum dark brown. Ocellaria composed of ca. 16–23, dark grey ocelli arranged in four irregular longitudinal rows (Fig. 2). Tömös-váry's organs about 2–3 times larger than an ocellus, placed between ocellaria and base of antenna. Antennae light yellow, rather long and slender, extending behind posterior edge of pleurotergite 6 in males or pleurotergite 3(4) in females when stretched backwards; antennomere length ratios: 2=3>4=5>6>1>7, antennomeres 5 and 6 with a small distodorsal field of fine setae (Fig. 16). Legs light yellow to yellow-brownish, tarsi much darker (Figs 1–7).

Collum much narrower than head, pleurotergite 6 in males strongly enlarged (Fig. 2). Prozonae delicately alveolate-areolate; fine longitudinal striations in front of stricture between prozonae and metazonae. Crests on collum normal, extended forwards from about midlength (Figs 1–2). All crests on the metazonae well-developed, forming 5+5 primary crests, 5+5 secondary crests, and 12–18 lower crests down to ventral pleurotergal edge (Figs 4, 6). 3<sup>rd</sup> primary crest strongly enlarged. Ozopores starting with pleurotergite 6, present until penultimate pleurotergite, placed on tip of 3<sup>rd</sup> primary crest (Figs 2, 4, 7). 2+2 primary and 3+3 secondary crests between poriferous crests. Pleurotergal setae 5+5, located at edges of primary crests; setal pattern as in Table 1. Axial line rather distinct (Figs 4, 6).



**Figures 1–6.** *Paracortina zhangi* sp. n. holotype **1** anterior body, subventral view **2** anterior body, sublateral view **3** midbody, ventral view **4** midbody, dorsal view **5** posterior body, ventral view **6** posterior body, dorsal view.



**Figure 7.** *Paracortina zhangi* sp. n. female paratype.

Male leg-pairs 1 and 2 much shorter, leg-pair 3 slightly shorter than following legs (Figs 1–2). Midbody legs about 4 (male) or 3 times (female) as long as pleurotergite height. Prefemora to a lesser extent, postfemora and tibiae more strongly, but still finely micropapillate ventrally (Fig. 15). Tarsi 1–3 only 1-segmented, from leg 4 to ultimate pair 2-segmented in both sexes; male tarsal pads visible from leg-pairs 3 to 23. All legs ending with a rather slender, long and curved claw (Figs 1, 2, 15). Coxal sacs present from leg 3 to 23. Male coxa 2 with a small anterior process and a posterior



**Figures 8–10.** *Paracortina zhangii* sp. n. male paratype **8** leg-pair 7, anterior view **9** gonopods, dorsal view **10** gonopods, subventral view.

**Table 1.** Chaetotaxy of *P. zhangii* sp. n. and *P. yiniae* sp. n.

	Anterior setae	Posterior setae
Collum	5+5	-
Pleurotergites 2 to 4	5+5	-
Pleurotergite 5	d, a + a, d	e, c, b + b, c, e
Pleurotergite 6 to penultimate	-	5+5

gonopore, the latter placed on a small cone. Coxa 7 with a long, subfalcate and apically pointed posterior (**f**), and a rather strong, pear-shaped anterior process (**t**) (Fig. 8); **f** in situ protruding between the gonopods. Coxae of remaining legs normal. Epiproct simple, with about 10 tuberculations in irregular rows (Fig. 6). Hypoproct tripartite, medial sclerite largest, subrectangular, bearing two paramedian macrosetae; each lateral sclerite with a single macroseta. Anal valves smooth, each divided into a small

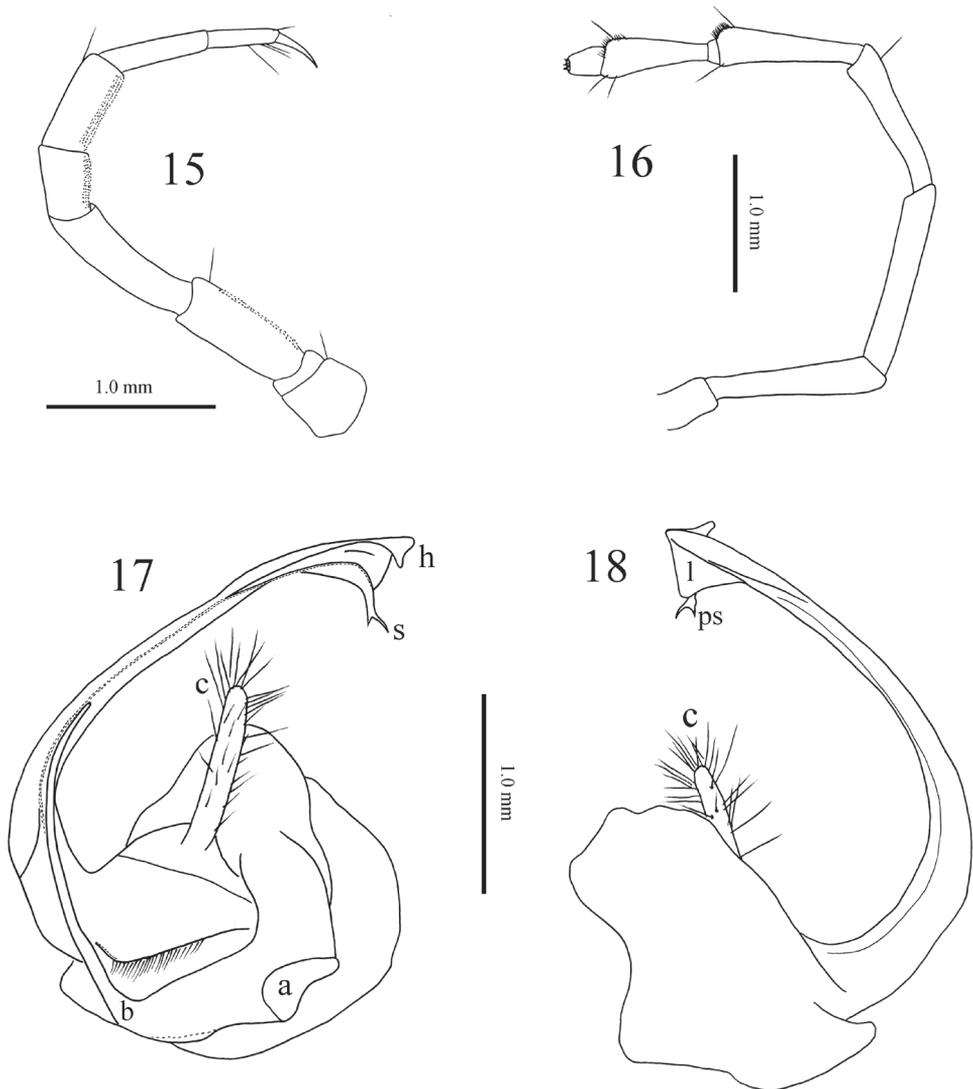


**Figures 11–14.** *Paracortina zhangi* sp. n. female paratype **11** leg-pair 1, anterior view **12** leg-pair 3, posterior view **13** leg-pair 2, anterior view **14** cyphopod, lateral view.

triangle and a large sclerite, both with a pair of macrosetae. Spinnerets comparatively thin and long, ending with a long macroseta (Fig. 5).

Gonopods (Figs 9–10, 17–18) yellow-brown to brown basally, seminal groove and telopodite black brown. Coxa with a large, curved, arch-shaped, anterior process (**a**) and a rather slender process (**b**), the latter a little more than half the length of telopodite. Prefemur with a large, clavate process (**c**) densely covered with long macrosetae. Femoroidal stem long, slender, rather clearly curved, directed cephalad. Telopodite's terminal part twisted, with a large median (**l**), and a small lateral lobe (**h**). Solenomere (**s**) bifid, parasolenomere (**ps**) much shorter; seminal groove ending on the longer branch.

**Female.** Pleurotergites 2 and 3 greatly enlarged. Leg-pairs 1 and 3 with tarsal pads (Figs 11–12). Coxa 3 with a rather small process (**m**). Prefemora 3 and 4 relatively

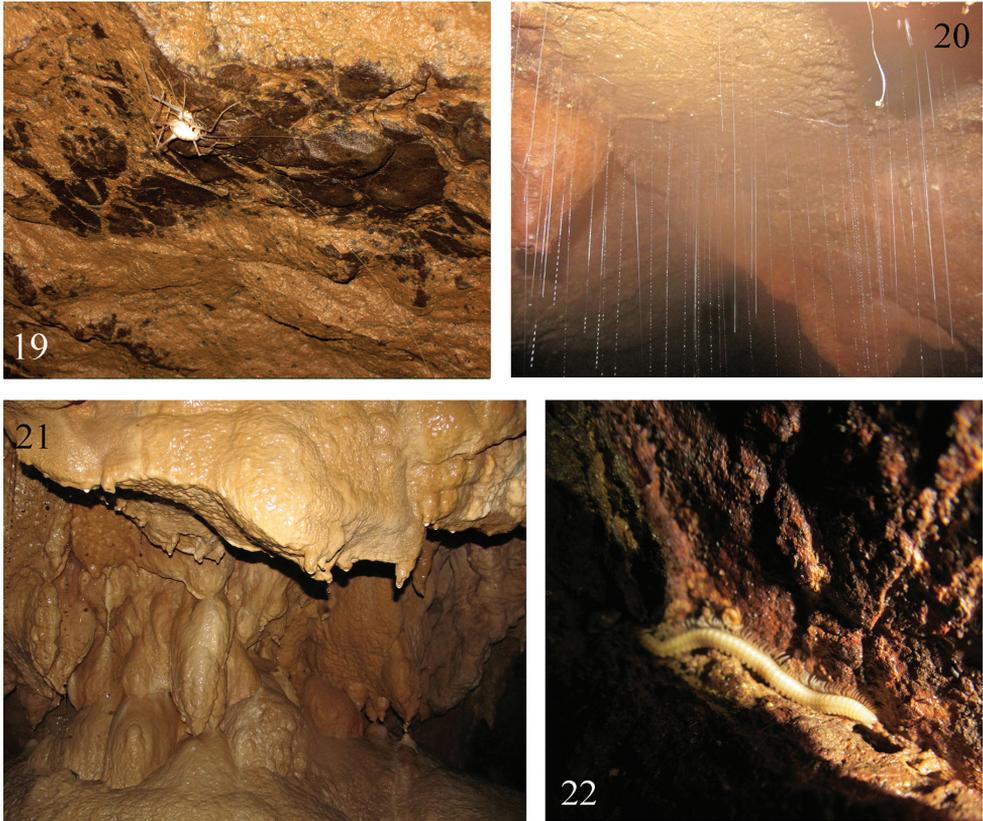


**Figures 15–18.** *Paracortina zhangii* sp. n. male paratype **15** midbody leg, anterior view **16** antenna, lateral view **17** right gonopod, mesal view **18** right gonopod, lateral view.

stout and clearly enlarged (Fig. 12). Leg-pair 2 (Fig. 13) rather strongly reduced down to a pairs of stout, apically shallowly biramous remnants in adult female (Fig. 7), normal in younger ones. Cyphopods small, densely setose, hidden in membranous sacs, divided laterally in the middle (Fig. 14). Coxae 7 normal, without processes.

**Etymology.** The species is dedicated to the memory of Mr. Chongzhou Zhang for his contribution to the systematics of Diplopoda in China.

**Remarks.** This species is distinguished from its congeners by the presence of 5+5 primary crests, 5+5 secondary crests on the metazonae, two processes on coxa 7 in



**Figures 19–22.** Cave Qiaoxia Dong 19–20 cave ceiling 21 cave deposits 22 *P. zhangi* sp. n. walking on a rock.

males, and in certain specific characters of the male gonopods, as well as in the small process on coxa 3, and reduced leg-pair 2 in females.

**Distribution.** China: Guizhou (Fig. 46).

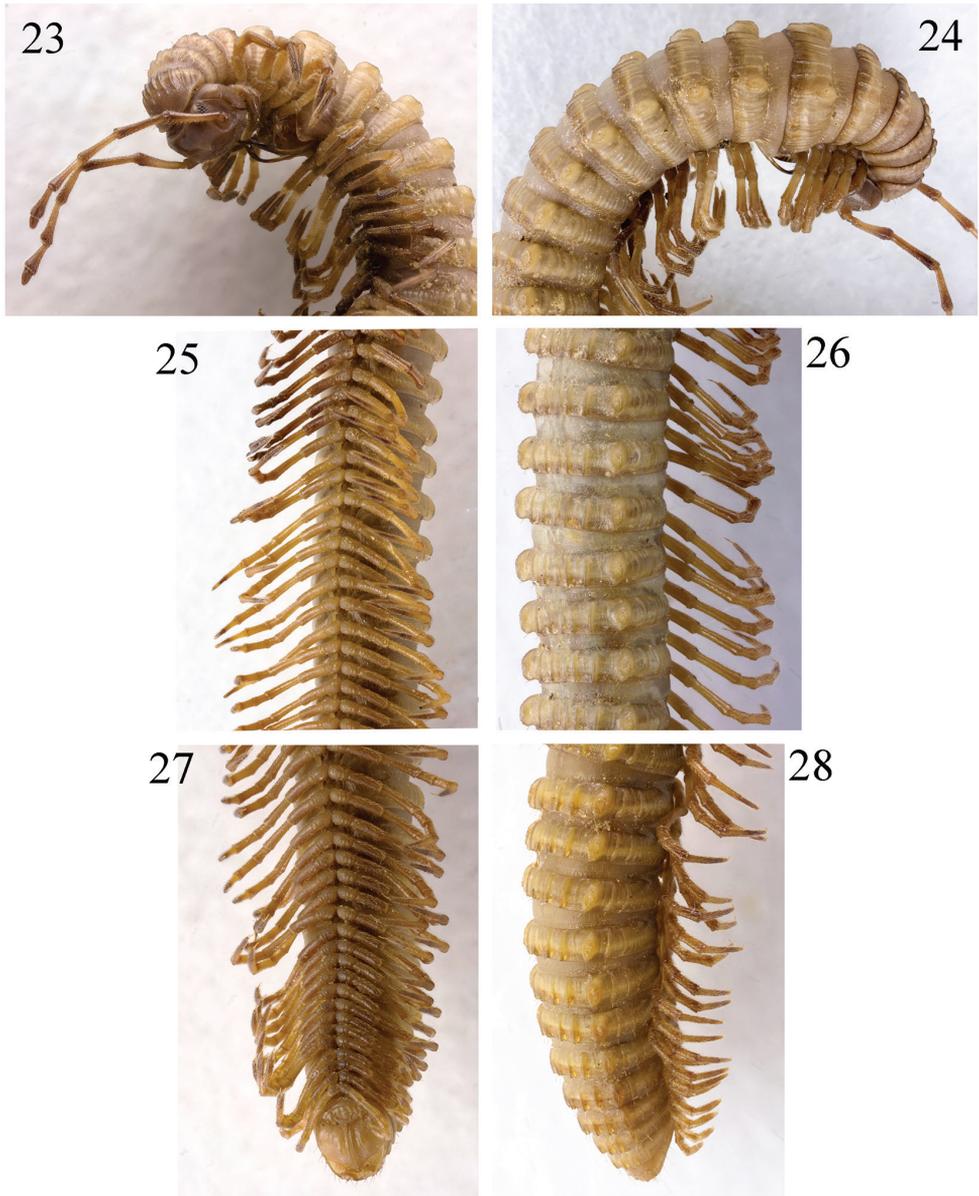
The entrance of cave Qiaoxia Dong (Figs 19–22) is located under a bridge in the village of Rongdu. The cave is about 200 meters long, 10 meters wide and 5 meters high. It is rather polluted from sewage water and rubbish. Other animals living in this cave are the ubiquitous diplopod, *Oxidus gracilis* C. L. Koch, 1847 (Polydesmida, Paradoxosomatidae), some ground beetles, crickets (Fig. 19), glowworms (Fig. 20), and spiders, etc.

***Paracortina yinae* Liu & Tian, sp. n.**

<http://zoobank.org/5F7E3FDD-A689-4F91-B2FE-5972754E0978>

Figs 23–45

**Material examined.** Holotype: adult male (SCAU), China, Guangxi, Baise City, Longlin County, Tianshengqiao Town, Yanchang Village, Cave I, 24.875732°N, 105.150143°E,



**Figures 23–28.** *Paracortina yinae* sp. n. holotype **23** anterior body, subventral view **24** anterior body, subdorsal view **25** midbody, ventral view **26** midbody, sublateral view **27** posterior body, ventral view **28** posterior body, lateral view.

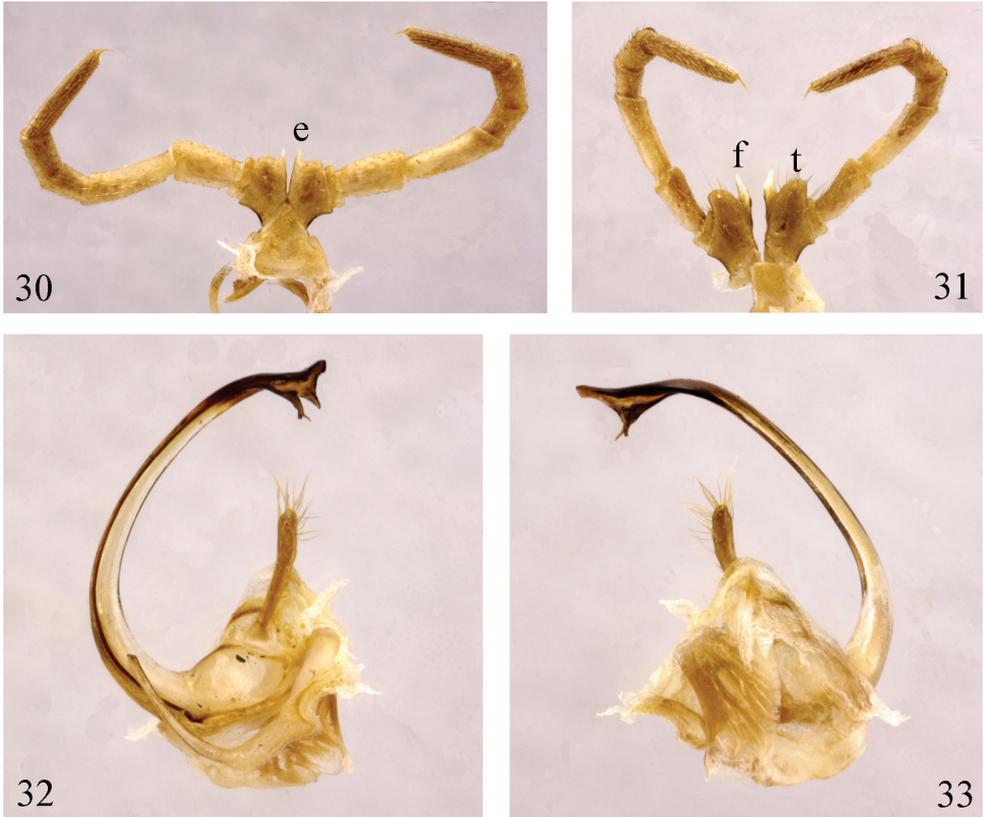
867 m, 12.VI.2014, leg. Mingyi Tian, Weixin Liu, Haomin Yin & Xiaozhu Luo. Paratypes. 2 males, 3 females, 2 juveniles (SCAU), same locality, together with holotype.

**Description.** Length of adult males 39–52 mm, of adult females 47–55 mm. Width of midbody segments in adult males 2.2–2.6 mm, in adult females 2.5–3.0 mm.



**Figure 29.** *Paracortina yinae* sp. n. female paratype.

Body with 53–61 pleurotergites + telson. Holotype 44.0 mm long, 2.5 mm wide on midbody segments, maximum width on 6<sup>th</sup> pleurotergite 2.5 mm, body with 54 pleurotergites + telson. Body coloration yellow-brownish. Metazonae slightly darker than prozonae, posterior margin of pleurotergites dark brown to brownish, more evidently so on the anterior pleurotergites (Figs 23–29). Head brownish to chocolate brown, epicranial suture distinct, with a slightly smaller, median, beak-shaped process located between antennae in males, surface below the vertex and genae densely beset with brown granules and fine setae (Fig. 23). Genae, labrum, the edge between the dorsal and the frontal face of head marbled dark brown. Ocellaria composed of ca. 21–32,



**Figures 30–33.** *Paracortina yinae* sp. n. male paratype **30** leg-pair 6, anterior view **31** leg-pair 7, anterior view **32** gonopods, mesal view **33** gonopods, lateral view.

dark grey ocelli arranged in four irregular longitudinal rows. Tömösváry's organs about 4 times larger than an ocellus, placed between ocellaria and base of antenna (Fig. 23). Antennae brownish, tip of each antennomere infuscate; very long, extending behind posterior edge of pleurotergite 6 (male) or 4 (female) when stretched backwards (Figs 23, 29), antennomere length ratios:  $2=3>4=5>6>1>7$ , antennomeres 5 and 6 with a small distodorsal field of fine setae (Fig. 39). Legs yellow-brownish to dark brownish, distal parts of femora much darker.

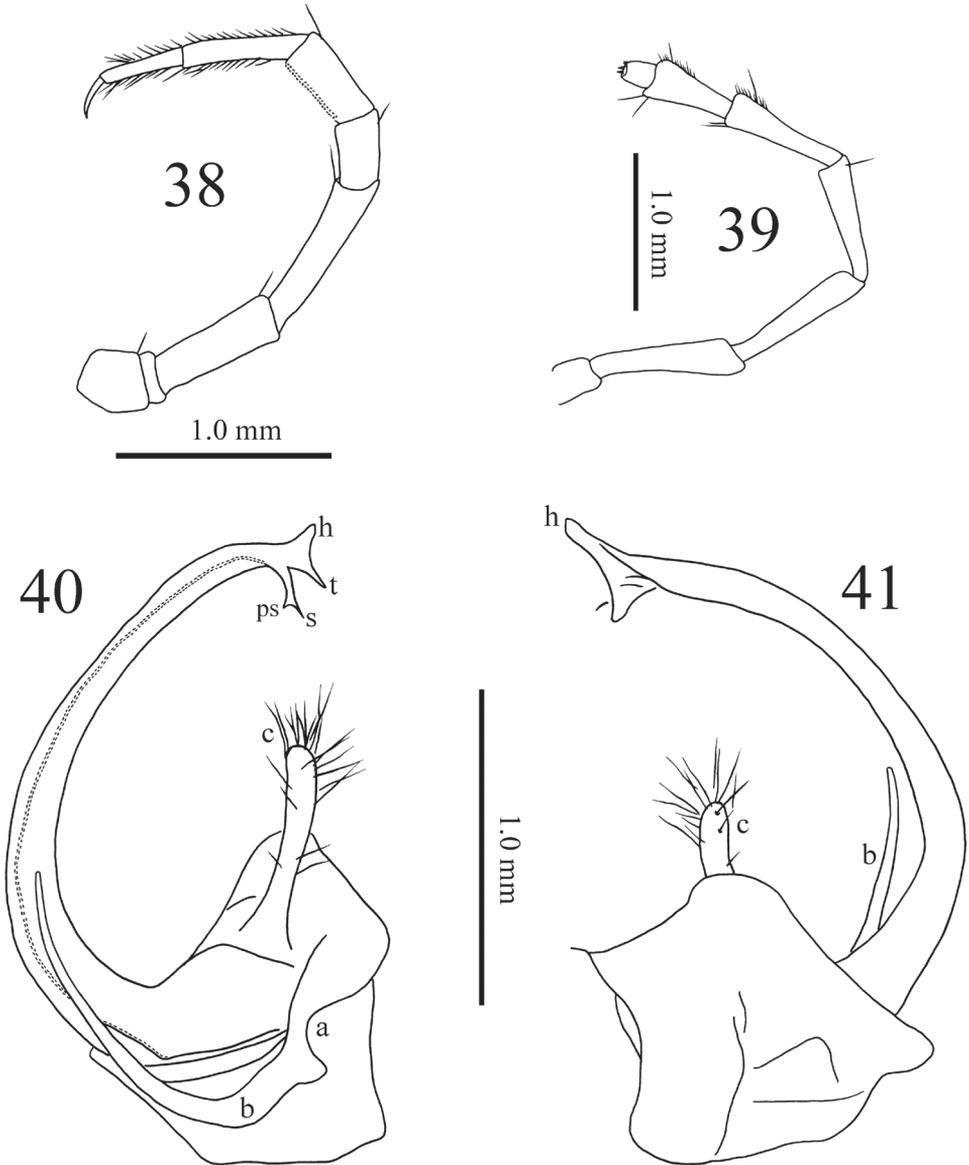
Collum much narrower than head, with two paramedian spots covered with brown granules, pleurotergite 6 in males strongly enlarged. Prozonae delicately alveolate-areolate; fine longitudinal striations in front of stricture between pro- and metazonae. Two first primary crests on collum relatively large. All crests on the metazonae, ozopores site, pleurotergal setae, and axial line as in *P. zhangi* sp. n. (Figs 24, 26, 28); setal pattern as in Table 1.

Male leg-pairs 1 and 2 much shorter, leg-pair 3 slightly shorter than following legs (Fig. 23). Midbody legs about 4 (male) or 3 times (female) as long as pleurotergal height, only tibia finely micropapillate ventrally (Fig. 38). Tarsi 1–3 only 1-segmented,



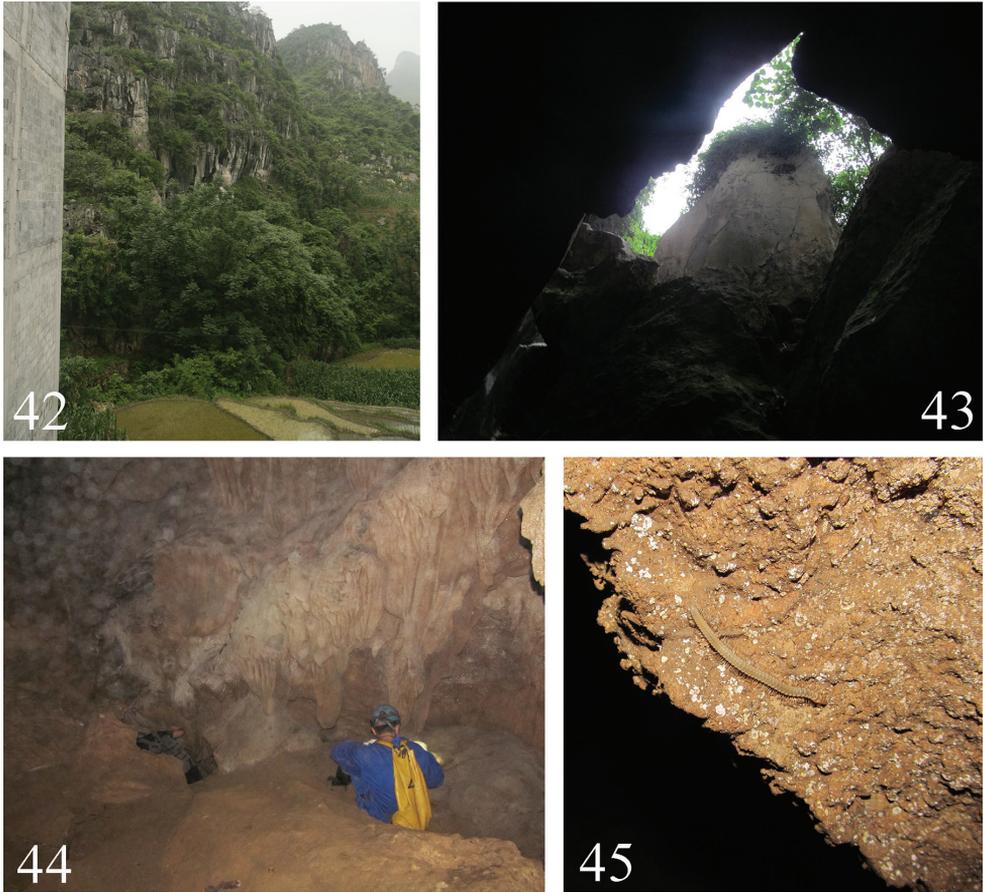
**Figures 34–37.** *Paracortina yinae* sp. n. female paratype **34** leg 1, anterior view **35** leg 3, posterior view **36** leg-pair 2 and cyphopod, anterior view **37** cyphopod, lateral view.

from 4 to ultimate pair 2-segmented; tarsal pads present from leg-pairs 3 to about 15. All legs ending with a rather slender, long and curved claw (Figs 1, 2, 15). Coxal sacs present from leg 3 to at least 25, but most abraded. Coxa 2 with a small anterior process and a posterior gonopore, the latter placed on a small cone. Coxa 6 with a small, pointed posterior process (e) (Fig. 30). Coxa 7 with a long, subfalcate and api-



**Figures 38–41.** *Paracortina yinae* sp. n. male paratype **38** midbody leg, anterior view **39** antenna, lateral view **40** right gonopod, mesal view **41** right gonopod, lateral view.

cally pointed posterior (**f**), and a very strong, rounded anterior process (**t**) (Fig. 31). Coxae of remaining legs normal. Epiproct simple, with 3+3 anterior and 8+8 posterior tuberculations in transverse rows. Hypoproct, anal valves and spinnerets as in *P. zhangi* sp. n. (Fig. 27).



**Figures 42–45.** Cave I **42** location **43** entrance **44** cave walls **45** *P. yinae* sp. n. walking on a rock.

Gonopods (Figs 32–33, 40–41) yellow-brown to brown basally, seminal groove and telopodite black brown. Coxa with an anterior process (**a**) and a rather slender process (**b**), the latter about half the length of telopodite. Prefemur with a large, clavate process (**c**), densely covered with long macrosetae apically. Femoroidal stem long, slender, rather strongly curved, directed cephalad. Telopodite's terminal part twisted, trifold, with a digitiform lateral (**h**), and a slender, apically pointed lobe (**t**). Solenomere (**s**) bifid, parasolenomere (**ps**) much shorter; seminal groove ending on the longer branch.

**Female.** A little larger than males, pleurotergites 2 and 3 strongly enlarged. Leg-pairs 1 and 3 with tarsal pads (Figs 34–35). Prefemur 3 evidently enlarged (Fig. 35). Leg-pair 2 (Fig. 36) rather strongly reduced down to a pairs of stout, apically deeply biramous remnants in adult females, normal in younger ones. Cyphopods small, densely setae, hidden in membranous sacs, partly extruded, laterally divided in the middle, the smaller part roundly concave apically (Figs 36–37). Coxae 6 and 7 normal, without processes.



**Figure 46.** Distribution map of *Paracortina* in China. **a** *P. voluta* **b** *P. thallina* **c** *P. viriosa* **d** *P. serrata* **e** *P. carinata* **f** *P. leptoclada* **g** *P. stimula* **h** *P. chinensis* **i** *P. zhangii* sp. n. **j** *P. yinae* sp. n.

**Etymology.** The species is named in honour of Miss Haomin Yin, an active collector in our team.

**Remarks.** The new species differs from its congeners by the presence of small, pointed, posterior processes (**e**) on coxae 6 and two pairs of processes on coxae 7 in males, as well as in certain specific characters of the male gonopods and reduced leg-pair 2 in females.

**Distribution.** China: Guangxi (Fig. 46).

Cave I (Figs 42–45) is situated at the foot of a karst mountain. It is a large cave, made up of a hall of several layers covered by numerous big rock boulders. We explored approximately 150 meters deep, but then had to withdraw because of a rushing underground river. Other animals also found in this cave are diplopods from the genera *Glyphiulus* (Spirostreptida, Cambalopsidae) and *Eutrichodesmus* (Polydesmida, Haplodesmidae), the blind trechine beetle *Satotrechus longlinensis* Deuve & Tian, 2011, and bats.

#### Key to species of the genus *Paracortina*

- 1        Gonopod prefemur with two processes covered with long macrosetae ..... 2
- Gonopod prefemur with only one process covered with long macrosetae.... 8

2	6+6 setae on pleurotergite 5 .....	3
–	5+5 setae on pleurotergite 5 .....	4
3	Head with a large median beak-shaped process located between antennae in males, 3+3 primary crests between poriferous crests.....	<i>P. thallina</i>
–	Head without such a process, 5+5 primary crests between poriferous crests ..	<i>P. stimula</i>
4	6+6 setae on pleurotergite 6 to penultimate .....	5
–	5+5 setae on pleurotergite 6 to penultimate .....	6
5	4+4 primary crests between poriferous crests; coxa 7 with two processes; gonopod prefemur with two processes clothed with dense long macrosetae apically .....	<i>P. leptoclada</i>
–	3+3 primary crests between poriferous crests; coxa 7 without processes, gonopod prefemur's nearby process smaller, with 8–9 strong macrosetae apically .....	<i>P. voluta</i>
6	Coxa 7 with two processes; gonopod prefemur's nearby process twisted, without setae.....	<i>P. serrata</i>
–	Coxa 7 without process; gonopod prefemur's nearby process apical with several apical setae .....	7
7	Collum with two large crests; gonopod telopodite's terminal part trifid .....	<i>P. viriosa</i>
–	Collum normal; gonopod telopodite's terminal part bifid.....	<i>P. carinata</i>
8	Body with 81–85 pleurotergites.....	<i>P. multisegmentata</i>
–	Body with 50–65 pleurotergites.....	9
9	Gonopod coxa without any process .....	<i>P. warreni</i>
–	Gonopod coxa with two processes .....	10
10	Gonopod coxa with a large, subtriangular, ovoid anterior process (a) and a small tooth (b).....	<i>P. chinensis</i>
–	Gonopod coxa with a large, arch-shaped, anterior process (a) and a rather long and slender process (b) (Figs 17, 30).....	11
11	Coxa 6 with a small, pointed, posterior process (e) (Fig. 30).....	<i>P. yinae</i> sp. n.
–	Coxa 6 normal, without process.....	<i>P. zhangi</i> sp. n.

## Acknowledgements

We express our cordial gratitude to two reviewers, Prof. Dr. Sergei I. Golovatch, Institute for Problems of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia, and Prof. Dr. Pavel Stoev, National Museum of Natural History, Sofia, Bulgaria, for their constructive suggestions and useful comments. Our thanks also go to members of our team in SCAU, for their various ways of assistance. This study was sponsored by the Specialized Research Fund for the Doctoral Program of Higher Education of China (Grant no. 20134404110026).

## References

- Deuve T, Tian MY (2011) Nouveaux Trechini et Tachyini des cavites souterraines de Chine meridionale (Coleoptera, Caraboidea). *Nouvelle Revue d'Entomologie* 27(2): 99–108.
- Shear WA (2000) A new genus and species of callipodidan millipede from Vietnam (Callipodida, Schizopetalidae). *Myriapodologica* 6(11): 95–100.
- Stoeb P (2004) The first troglomorphic species of the millipede genus *Paracortina* Wang & Zhang, 1993 from south Yunnan, China (Diplopoda: Callipodida: Paracortinidae). *Zootaxa* 441: 1–8. doi: 10.2476/asjaa.53.93
- Stoeb P, Enghoff H (2011) A review of the millipede genus *Sinocallipus* Zhang, 1993 (Diplopoda, Callipodida, Sinocallipodidae), with notes on gonopods monotomy vs. peripheral diversity in millipedes. *ZooKeys* 90: 13–34. doi: 10.3897/zookeys.90.1291
- Stoeb P, Geoffroy JJ (2004) Review of the millipede family Paracortinidae Wang & Zhang 1993 (Diplopoda: Callipodida). *Acta Arachnologica* 53(2): 93–103.
- Stoeb P, Sierwald P, Billey A (2008) An annotated world catalogue of the millipede order Callipodida (Arthropoda: Diplopoda). *Zootaxa* 1706: 1–50.
- Wang DQ, Zhang CZ (1993) A new family of millipeds (Diplopoda: Callipodida) from southwestern China. *Peking Natural History Museum* 53: 395–390.
- Zhang CZ (1997) Diplopoda from Yunnan Caves III. A new genus *Angulifemur*, including two new species of the cave-dwelling callipodid millipedes (Diplopoda, Callipodida, Paracortinidae). *Thesis Compilation of Tianjin Natural History Museum* 14: 1–5.

# A new genus and species of dalodesmid millipede from New South Wales, Australia (Diplopoda, Polydesmida, Dalodesmidae)

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## Abstract

*Cernethia inopinata* **gen. n., sp. n.** is described from highland New South Wales. Like other dalodesmids the new species has numerous sphaerotrichomes on the legs of adult males, but *C. inopinata* **sp. n.** shares several character states with Tasmanian species in the genera *Noteremus* Mesibov, 2009, *Paredrodesmus* Mesibov, 2003 and *Procophorella* Mesibov, 2003, which lack sphaerotrichomes and have not yet been assigned to family within the suborder Dalodesmoidea.

## Keywords

Diplopoda, Polydesmida, Dalodesmidae, New South Wales, Australia

## Introduction

When establishing the new genus *Noteremus* from Tasmania (Mesibov 2009), it was suggested that *Noteremus* and two other dalodesmoid Tasmanian genera, *Paredrodesmus* Mesibov, 2003 and *Procophorella* Mesibov, 2003, might form a natural group. Species in all three genera have a head+19 rings body plan, reduced paranota (absent in *Paredrodesmus*), the unusual pore formula 5+7-18, a trapezoidal array of spinnerets (ventral pair further apart than dorsal pair) and no sphaerotrichomes on the legs of adult males. The lack of sphaerotrichomes led to the placement of the three genera in the suborder Dalodesmoidea without a family assignment.

Here a new species from highland New South Wales is described, which shares the first four of those character states, but unexpectedly has sphaerotrichomes on the tarsus and tibia of most legs. The gonopod conformation is also distinctive, and the telopodite lacks the clusters of stout, rod-like setae found in the two named *Noteremus* species and five of the six named *Paredrodesmus* species.

The new species is placed in a new genus in Dalodesmidae. The relationships of the new genus, *Noteremus*, *Paredrodesmus* and *Procophorella* to each other and to more typical Australian Dalodesmidae remain a puzzle.

## Materials and methods

‘Male’ and ‘female’ in the text refer to adult (stadium 7) individuals. Body measurements were estimated with a Nikon SMZ800 binocular dissecting microscope using an eyepiece scale. Colour images were manually stacked using a Canon EOS 1000D digital SLR camera mounted on the Nikon SMZ800 fitted with a beam splitter, then processed with Zerene Stacker 1.04. Gonopods were cleared in 80% lactic acid and temporarily mounted in a 1:1 glycerol:water mixture for optical microscopy. Preliminary gonopod drawings were traced from prints of screenshots from the output of a 1.3 megapixel digital video eyepiece camera mounted in one ocular tube of a Tasco LMSMB binocular microscope. Images and drawings were prepared for publication using GIMP 2.8.

Locality details for specimen lots (also available online in Mesibov 2006–2015) are given with latitude and longitude converted to decimal degrees based on the WGS84 datum. My estimate of the uncertainty for a locality is the radius of a circle around the given position, in metres or kilometres. The ANIC georeferences come from the ANIC collection database.

Abbreviations: AM = Australian Museum, Sydney, Australia; ANIC = Australian National Insect Collection, Canberra, Australia; NSW = New South Wales, Australia.

## Results

**Order Polydesmida Pocock, 1887**

**Suborder Dalodesmidea Hoffman, 1980**

**Family Dalodesmidae Cook, 1896**

**Genus *Cernethia* Mesibov, gen. n.**

<http://zoobank.org/09602805-528E-411A-9C96-B2EB11037259>

**Type species.** *Cernethia inopinata* sp. n., by present designation.

**Other assigned species.** None.

**Diagnosis.** Superficially resembling *Atalopharetra* Mesibov, 2005, *Bromodesmus* Mesibov, 2004 and *Victoriombrus* Mesibov, 2004 in having reduced paranota

and an acrid defensive secretion. Distinguished from these three genera by having head+19 rings *vs.* head+20 rings body plan, and pore formula 5+7-18 *vs.* 5+7+9-19 in *Victoriombrus* and the normal pore formula in *Atalopharetra* and *Bromodesmus*. Similar to *Noteremus*, *Paredrodesmus* and *Procophorella* in head+19 rings, pore formula 5+7-18 and a trapezoidal array of spinnerets; distinguished from these three genera in having sphaerotrichomes on male legs.

**Description.** As for the type species.

**Name.** Anagram of 'Catherine', for the millipede specialist Catherine Car, collector of the type specimens; gender feminine.

***Cernethia inopinata* Mesibov, sp. n.**

<http://zoobank.org/C4B48F32-BB9A-4C24-9B84-BC363F4C75D0>

Figs 1–3, map Fig. 4

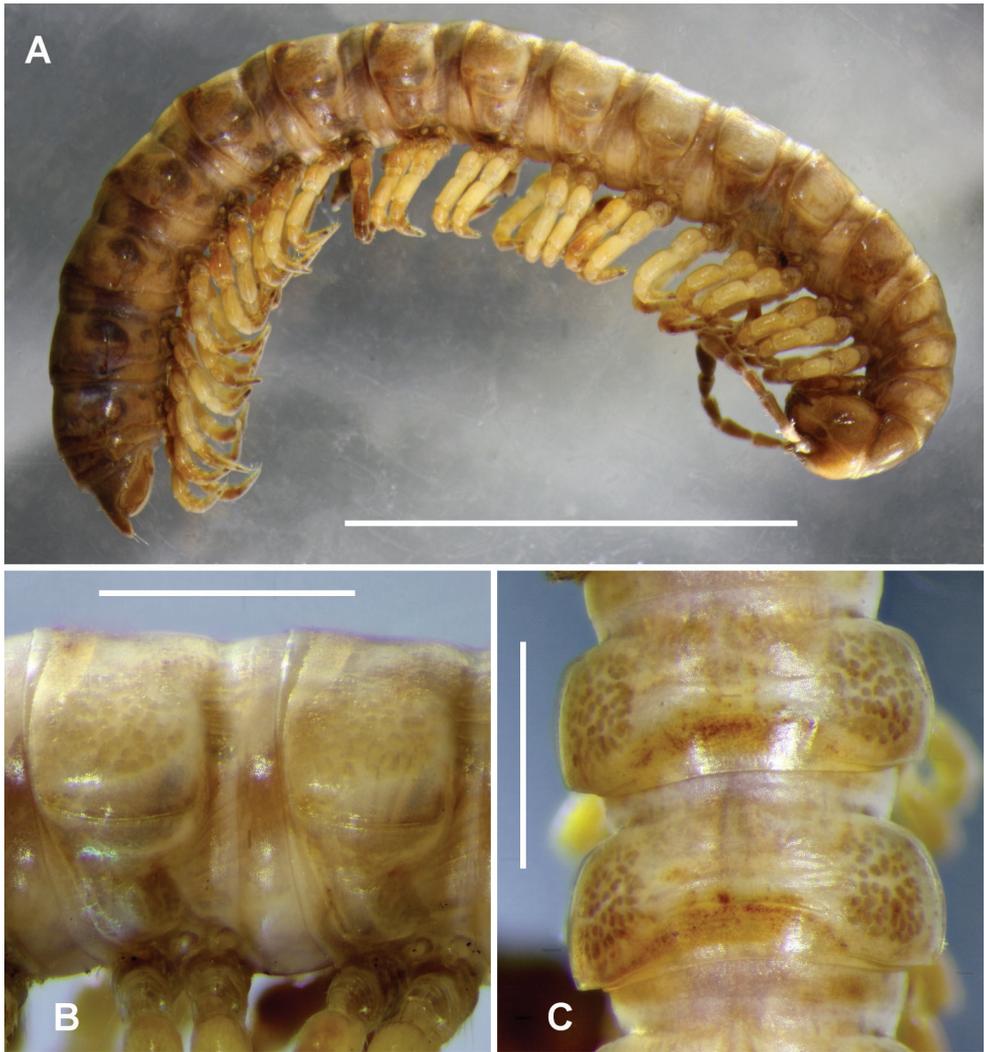
**Holotype.** Male, Glenbog State Forest near junction of Steeple Flat Road and Snowy Mountains Highway, ca. 10 km SE of Nimmitabel, NSW, -36.6128 149.3686 ±100 m, 1160 m a.s.l., 17 May 2006, C.A. Car, transect site T21, AM KS.124129 (ex AM KS.114908).

**Paratypes. AM:** 5 males, 7 females, 10 juveniles, details as for holotype, KS.114908; 2 males, 3 females, same details but 19 September 2006, KS.114909; 6 males (1 male missing head + rings 2-5), 2 females, 6 juveniles, same details but 29 March 2006, C.A. Car, KS.94875.

**Other material. AM:** 1 male, ca. 5 km SE of Nimmitabel at Bombala turnoff, NSW, -36.5806 149.3153 ±100 m, 1100 m a.s.l., 14 February 2007, C.A. Car, transect site T20, under bark of fallen log in wattle grove, KS.114919; 1 male, ca. 50 km W of Bega, Brown Mountain, Pipers Lookout, Monterey Road, NSW, -36.6203 149.4033 ±100 m, 1100 m a.s.l., 16 February 2007, C.A. Car, transect site T22, under bark scraps on ground, KS.114912; 3 stadium 6 juveniles, same details, KS.114913.

**ANIC:** 3 males, Brown Mountain, NSW, -36.6 149.3833 ±2 km, 5 January 1967, R.W. Taylor, ANIC berlesate no. 9, rainforest, 64-000344; 1 male, same locality but 9 December 1967, R. Taylor and J. Brooks, ANIC berlesate no. 41, leafmould, 64-000345; 5 males, 2 females, same details but ANIC berlesate no. 42, leafmould, 3000 feet, 64-000346; 2 males, same details but ANIC berlesate no. 42C, 64-000347; 1 male, Rutherford Creek, Brown Mountain, NSW, -36.6 149.4167 ±2 km, 9 January 1968, M. Upton, ANIC berlesate 55, rainforest, leafmould, 64-000348; 2 males, same locality but 15 January 1969, S.R. Curtis, ANIC berlesate no. 129, 64-000349; 8 males, same locality but 26 May 1970, R.W. Taylor and R. Bartell, ANIC berlesate 287, rainforest, 64-000350.

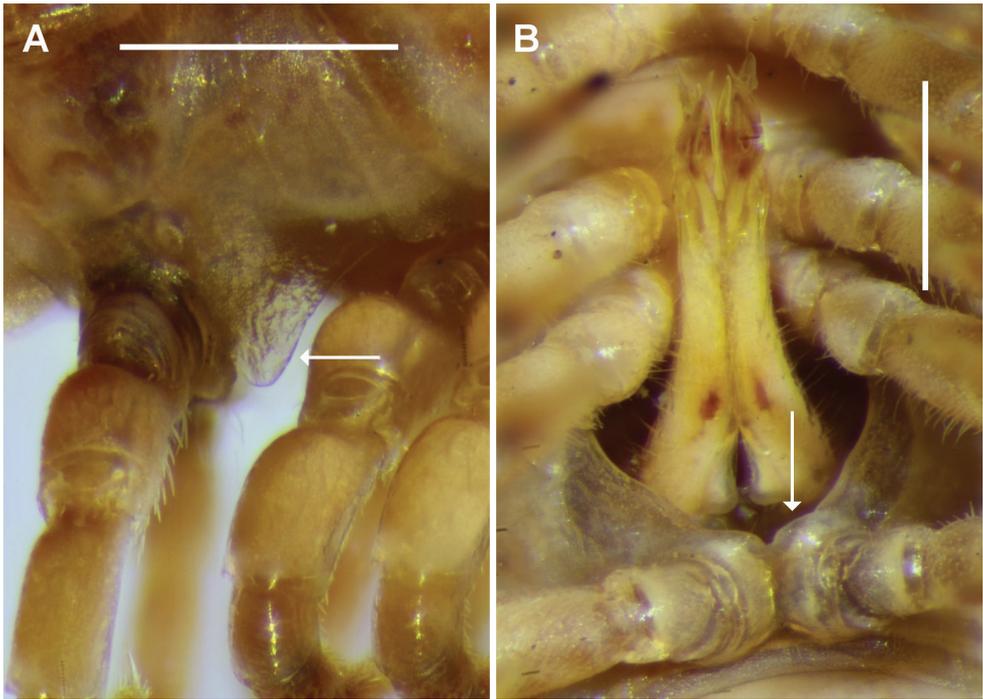
**Description.** Male and female adults with head+19 rings (Fig. 1A). Male/female approximate measurements: length 16/14 mm, maximum width across paranota 1.7/1.9 mm, maximum prozonite width 1.3/1.7 mm. In alcohol, well-coloured specimens yellowish brown with faintly reddish brown antennae, distal podomeres



**Figure 1.** *Cernethia inopinata* sp. n., male paratype ex AM KS.114908. **A** Habitus **B** Midbody rings, right lateral view **C** Midbody rings, dorsal view. Scale bars: 5 mm (**A**); 1 mm (**B**, **C**).

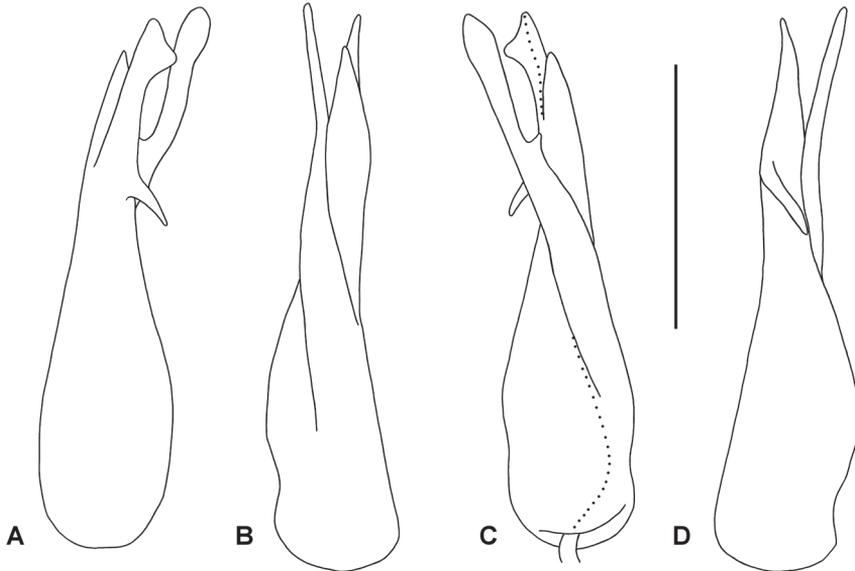
and lateral paranotal margins; some specimens with larger reddish-brown patches elsewhere, but patterning inconsistent.

Male with vertex of head bare, frons and clypeus sparsely setose; vertigial sulcus extending ventrally ca. halfway to line joining antennal socket centres; postantennal groove narrow, slightly impressed; antennal sockets separated by about 1.5× socket diameter. Antenna clavate, reaching dorsally to rear of tergite 2; relative antennomere lengths 6>3>2>(4=5), antennomere 6 widest. Collum half-moon-shaped in dorsal outline, anterior margin straight, posterior corner rounded. Relative overall ring widths collum<(head=2,3)<4<(5-15 equal)>16>17>18. Waist on diplosegments



**Figure 2.** *Cernethia inopinata* sp. n., male paratype ex AM KS.114908. **A** Aperture on ring 7, right lateral view; posterolateral rim marked with arrow **B** Gonopods in situ, ventral view; note sternite (arrow) overlapping rear of aperture. Scale bars: 0.5 mm.

shallow, without striations; prozonites and metazonites smooth; metazonites with three transverse rows of sparse, very short, fine setae, mainly missing; limbus with widely spaced, narrow, pointed elements. Ring 2 paranotum with lateral margin straight, lower than collum and ring 3 paranotal margin. Midbody paranota (Figs 1B, 1C) with anterior corners widely rounded, posterior corners narrowly rounded and not extending posteriorly; lateral margins more or less horizontal, at ca. 1/2 ring height. Paranota greatly reduced on rings 16 and 17, not detectable on 18. Midbody sternites moderately setose, longer than wide; impressions well developed, longitudinal deeper than transverse. Ozopore small, round, opening dorsolaterally at posterior corner of paranotum; pore formula 5+7-18. Spiracle openings small, round; on diplosegments with anterior spiracle dorsal to anterior leg and posterior spiracle midway between legs and dorsal to leg bases. Midbody legs short, relative podomere lengths (femur=tarsus)>prefemur>(postfemur=tibia). Prefemur dorsally swollen on anterior legs except 1 and 2; femur slightly swollen dorsally on anterior legs. Sphaerotrichomes on all legs except 1 and 2, more numerous anteriorly, mainly on tarsus and tibia, anteriorly also on postfemur; sphaerotrichomes with shafts tapering to fine point, on midbody legs directed at ca. 45° to long leg axis, shorter and more erect anteriorly. Brush setae unbranched, slightly tapered with blunt tips, on all legs except 1 and 2, anteriorly on

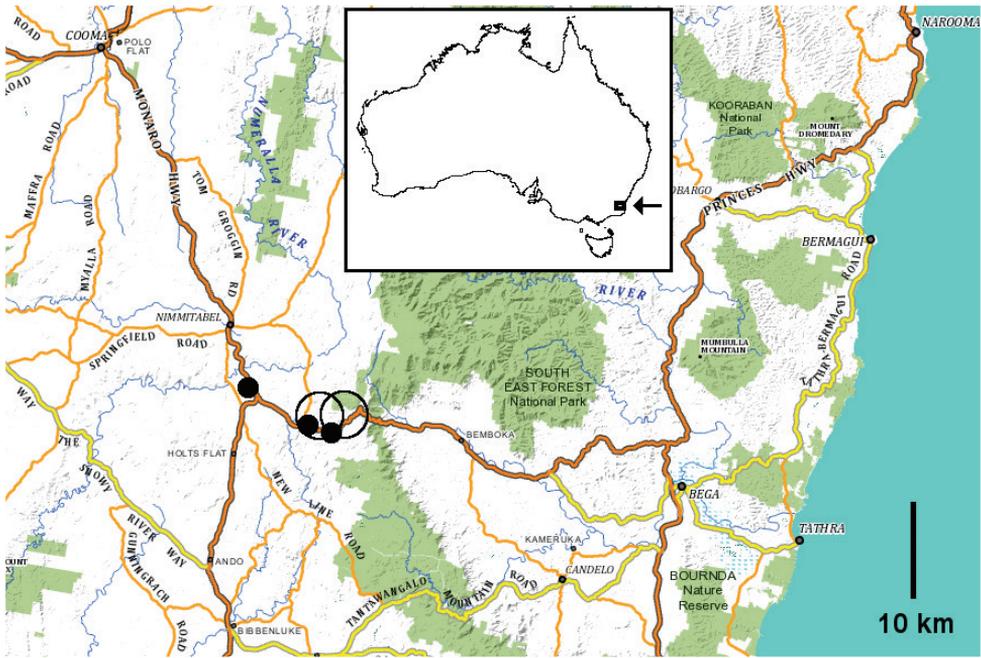


**Figure 3.** *Cernethia inopinata* sp. n., male paratype ex AM KS.114909. **A** lateral, **B** anterior, **C** medial and **D** posterior and slightly lateral views of right gonopod telopodite. Setation not shown; dotted line indicates course of prostatic groove. Scale bar: 0.5 mm.

coxa, prefemur, femur and postfemur, denser anteriorly. Pre-anal ring very sparsely setose; hypoproct paraboloid; epiproct extending well past anal valves, tip truncate and slightly emarginate; spinnerets in trapezoidal array, ventral spinnerets slightly further apart than dorsal.

Gonopore on short, truncate cone arising distomedially on leg 2 coxa. Leg 6 and 7 bases equally widely separated by shallow concavity, leg 5 bases more narrowly separated; small tab on sternite close to each leg 6 base. Aperture  $1/3$ - $1/2$  width of ring 7 prozonite, rim posterolaterally greatly extended ventrally (Fig. 2A), sternite between legs 9 overlapping posterior margin of aperture (Fig. 2B). Gonopod telopodites more or less straight (Fig. 2B), when retracted reaching space between leg 5 bases.

Gonocoxae short, truncated-conical, incompletely fused anteriorly in syncoxite, sparse setae on posterolateral and anteromedial surfaces. Cannula swollen at base, tapering abruptly and looping tightly to enter base of telopodite towards medial side. Telopodite (Figs 2B, 3) with cylindrical base, tapering from ca.  $1/4$  telopodite height, the main portion divided at ca.  $3/4$  telopodite height into two closely appressed processes: mediolaterally flattened solenomere with rounded tip and rounded subapical projection on posterior margin, and bluntly acuminate anteromedial process, slightly shorter than solenomere. Just basal to this telopodite division (i.e., just under  $3/4$  telopodite height), a small, finger-like, blunt process arising on posterolateral telopodite surface curving basally and posteromedially. Large, more or less flat process arising anteromedially, closely appressed to medial telopodite surface, directed distally and slightly posteriorly, curving slightly laterally to lie just medial and posterior to solenomere; apex laminar, slightly expanded with broadly rounded distal



**Figure 4.** Known localities of *Cernethia inopinata* sp. n. as of 22 June 2015; black dots are for accurately located AM samples, black circles are for approximately located ANIC samples. Base map from the Spatial Information Exchange, New South Wales Department of Finance and Services (<http://maps.six.nsw.gov.au/>; accessed 14 June 2015). Inset shows location of main map (arrow) on map of Australia.

margin, terminating at about solenomere height; small tooth on anterior edge of process at ca.  $2/3$  process length (ca.  $3/4$  telopodite height). Sparse, long setae on posterior telopodite surface from base to just basal to level of short, finger-like process. Prostatic groove running more or less straight to tip of solenomere, posterior to base of large medial process.

Female more robust than male but shorter, legs thinner and without swellings, paranota not as well developed. Epigynum  $1/3$ – $1/2$  ring 2 width, slightly raised medially; cyphopods not examined.

**Distribution.** So far known only from high-elevation, open eucalypt forest and rainforest in the southeastern corner of the Monaro Tablelands in New South Wales (Fig. 4). The climate in the *C. inopinata* sp. n. range is cool temperate but fairly dry, with a mean annual rainfall at nearby Nimmitabel (1075 m a.s.l.) of 687 mm, well-distributed through the year, and mean temperature minima and maxima of ca.  $-1.5$  °C and 8 °C in June and July and ca. 9 °C and 22 °C in January and February ([http://www.bom.gov.au/climate/averages/tables/cw\\_070067.shtml](http://www.bom.gov.au/climate/averages/tables/cw_070067.shtml); accessed 13 June 2015). Snow patches lie on the ground in the open forest in the winter months.

**Name.** Latin *inopinatus*, ‘unexpected’, for the unexpected presence of sphaerotrichomes (see Introduction).

**Remarks.** The gonopod in *C. inopinata* sp. n. resembles the gonopods of some species of *Gephyrodesmus* Jeekel, 1983 and *Orthorhachis* Jeekel, 1985 (Mesibov 2008)

in having two large, closely appressed branches at the end of a strongly tapering telopodite. In all species of *Orthorbachis* the major branching occurs at more than half the telopodite height, in *C. inopinata* sp. n. and all species of *Gephyrodesmus* at one-third or less the telopodite height. *Cernethia inopinata* sp. n. differs from *Gephyrodesmus* species in having an apically divided solenomere, as opposed to an undivided one. *Gephyrodesmus* and *Orthorbachis* species also differ from *C. inopinata* sp. n. in having a head+20 rings body plan, wide paranota and a square spinnerets array.

The type specimens of *C. inopinata* sp. n. were first examined in 2007, not long after they were collected. The samples smelled strongly at the time with an odour similar to that of the acrid defensive secretions of Tasmanian *Atalopharetra* and *Bromodesmus* species. The samples have had several changes of alcohol since 2007 and no longer have a strong odour.

## Acknowledgements

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## References

- Mesibov R (2006–2015) Millipedes of Australia [online catalogue]. <http://www.polydesmida.info/millipedesofaustralia/> [accessed 22 June 2015]
- Mesibov R (2009) A new millipede genus and a new species of *Asphalidesmus* Silvestri, 1910 (Diplopoda, Polydesmida, Dalodesmidea) from southern Tasmania, Australia. *ZooKeys* 7: 55–74. doi: 10.3897/zookeys.7.111