ZooKeys 673: 1–20 (2017)
doi: 10.3897/zookeys.673.12108
http://zookeys.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
ZooKeys
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A marvelous new glassfrog (Centrolenidae, Hyalinobatrachium) from Amazonian Ecuador

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Academic editor: *A. Herrel* | Received 4 February 2017 | Accepted 19 April 2017 | Published 12 May 2017

http://zoobank.org/F1221C2E-4243-4D4F-900C-21F5C2251F8B

Citation: Guayasamin JM, Cisneros-Heredia DF, Maynard RJ, Lynch RL, Culebras J, Hamilton PS (2017) A marvelous new glassfrog (Centrolenidae, Hyalinobatrachium) from Amazonian Ecuador. ZooKeys 673: 1–20. https://doi.org/10.3897/zookeys.673.12108

Abstract

Hyalinobatrachium is a behaviorally and morphologically conserved genus of Neotropical anurans, with several pending taxonomic problems. Using morphology, vocalizations, and DNA, a new species from the Amazonian lowlands of Ecuador is described and illustrated. The new species, *Hyalinobatrachium yaku* **sp. n.**, is differentiated from all other congenerics by having small, middorsal, dark green spots on the head and dorsum, a transparent pericardium, and a tonal call that lasts 0.27–0.4 s, with a dominant frequency of 5219.3–5329.6 Hz. Also, a mitochondrial phylogeny for the genus is presented that contains the new species, which is inferred as sister to *H. pellucidum*. Conservation threats to *H. yaku* **sp. n.** include habitat destruction and/or pollution mainly because of oil and mining activities.

Resumen

Hyalinobatrachium es un género de ranas Neotropicales con una morfología y comportamiento sumamente conservados, y con varios problemas taxonómicos no resueltos. Utilizando datos morfológicos, cantos y ADN, en el presente trabajo describimos una nueva especie de las tierras bajas de la Amazonía del Ecuador. La nueva especie, *Hyalinobatrachium yaku* **sp. n.**, se diferencia de todos sus congenéricos por tener una serie de puntos mediodorsales color verde oscuros en la cabeza y cuerpo, pericardio transparente, y un canto tonal con una duración de 0.27–0.4 s, con una frecuencia dominante 5219.3–5329.6 Hz. También presentamos una filogenia mitocondrial del género, la cual incluye la nueva especie y a su especie hermana, *H. pellucidum*. Las amenazas de conservación para *H. yaku* **sp. n.** incluyen principalmente la destrucción y/o contaminación del hábitat debido a actividades mineras y petroleras.

Keywords

Amazonia, Amphibia, Centrolenidae, *Hyalinobatrachium*, Ecuador, new species

Palabras claves

Amazonia, Amphibia, Centrolenidae, *Hyalinobatrachium*, Ecuador, nueva especie

Introduction

Among Neotropical frogs, the genus *Hyalinobatrachium* Ruiz-Carranza & Lynch, 1991 is one of the most distinguishable because of its morphological and behavioral traits. All species in this genus have a completely transparent ventral peritoneum, which means that organs are fully visible in ventral view. The reproductive behavior is also unusual, with males calling from the underside of leaves and providing parental care to egg clutches (Ruiz-Carranza and Lynch 1991, Cisneros-Heredia and McDiarmid 2007; Guayasamin et al. 2009; Delia et al. 2010).

Species identification within *Hyalinobatrachium* is complex because species tend to have a conserved morphology (Castroviejo-Fisher et al. 2011a, b), possibly related to their similar ecological constraints. Moreover, preserved specimens in the genus lose many of the color features that, in life, allow species identification. As a consequence, taxonomic discoveries usually require multiple sets of data, with vocalizations, DNA sequences, and accurate color descriptions being particularly revealing. Herein, we describe a new species of *Hyalinobatrachium* from the Amazonian lowlands of Ecuador; the new species is closely related to *H. pellucidum* (Lynch & Duellman, 1973), but is differentiated, mainly, by having a longer call and small, dark green spots on its head.

Material and methods

Species concept. Species are considered as segments of separately evolving metapopulation lineages, following the conceptual framework developed by Simpson (1951, 1961), Wiley (1978), and de Queiroz (2007).

Morphological data. Diagnosis and description follow Lynch and Duellman (1973) and Cisneros-Heredia and McDiarmid (2007). Webbing formula follows Savage and Heyer (1967), as modified by Guayasamin et al. (2006). Taxonomy follows the proposal by Guayasamin et al. (2009). We compared *Hyalinobatrachium* specimens housed at the following collections: Instituto de Ciencia Naturales, Universidad Nacional de Colombia, Bogotá, Colombia (ICN), University of Kansas, Museum of Natural History, Division of Herpetology, Lawrence, Kansas 66045, USA (KU), Museo de Historia Natural Gustavo Orcés, Escuela Politécnica Nacional, Quito, Ecuador (MEPN), Museo de Zoología, Universidad Tecnológica Indoamérica, Quito, Ecuador (MZUTI), Museo de Zoología, Pontificia Universidad Católica del Ecuador, Quito, Ecuador (QCAZ), National Museum of Natural History, Smithsonian Institution, Washington, D.C., USA (USNM), and Museo de Zoología, Universidad San Francisco de Quito, Quito, Ecuador (ZSFQ). Morphological measurements were taken with a digital caliper to the nearest 0.1 mm, as described in Guayasamin and Bonaccorso (2004). Sexual maturity was determined by the presence of vocal slits in males and convoluted oviducts in females.

Bioacoustics. Sound recordings were made with a TASCAM DR-05 Portable Digital Recorder. The calls were recorded in WAV format with a sampling rate of 44.1 kHz/second with 16 bits/sample. Measurements of acoustic variables were obtained as described in Hutter and Guayasamin (2012) and Dautel et al. (2011). Notes were divided into two classes—"pulsed" and "tonal"—based upon distinct waveforms on the rendered oscillogram. Pulsed (also termed peaked) notes are defined as having one or more clear amplitude peaks and amplitude modulation (i.e., visible increases and decreases in amplitude on the oscillogram throughout the call). In contrast, tonal notes are defined as having no clear amplitude peak. A call is defined as the sound produced in a single exhalation of air. Call data from Peruvian populations of *Hyalinobatrachium pellucidum* were obtained from Wen et al. (2012), recorded from individuals found in a stream (06°25'16.7"S, 76°17'28.5"W; 523 m a.s.l.) near San José, Departamento San Martín, Peru (Wen et al. 2012).

Fieldwork. The new species was found in three localities in the Amazonian lowlands of Ecuador: Timburi-Cocha Research Station, near San José de Payamino (0.4819°S, 77.2842°W, 294 m; province of Orellana); near Ahuano (1.0632°S, 77.5265°W, 360 m; province of Napo), and at the Kichwa community of Kallana (1.4696°S, 77.2783°W, 325 m; province of Pastaza). Records from San José de Payamino were collected during the following sampling periods: 30 May–09 June 2012 (11 investigators, 2 teams/night); 12–19 June 2012 (12 investigators, 2 teams/night); 03–11 June 2013 (11 investigators, 2 teams/night); 16–24 June (5 investigators, 1 team); 03 July–09 August 2013 (2 investigators, 1 team). Visual encounter surveys were conducted along transects of various lengths within primary forest, secondary and riparian forest, and along streams of various sizes during each sample period except for the last, where two people surveyed 20-m diameter plots within secondary forest for 30 minutes each (Maynard et al. 2016; RJM and PSH, unpubl. data). All surveys were conducted between 19:00–00:30 h. The record from the Arajuno River

is from a small stream within primary forest, obtained during fieldwork on 3–6 April, 1998 (5 researchers, surveys along stream conducted between 19:00–23:00 h). The third locality of the new species comes from a stream affluent of the Kallana River, obtained during fieldwork on 15 April, 2016 (2 investigators, surveys along stream conducted between 20:30–22:00 h).

Evolutionary relationships. We generated mitochondrial sequences (12S, 16S, ND1) for two individuals of the new species of *Hyalinobatrachium*. Extraction, amplification, and sequencing protocols are as described in Guayasamin et al. (2008). The obtained sequences were compared with those of all other available species of *Hyalinobatrachium*, downloaded from GenBank (https://www.ncbi.nlm.nih.gov/genbank/) and generated mostly by Guayasamin et al. (2008), Castroviejo-Fisher et al. (2014), and Twomey et al. (2014). Sequences were aligned using MAFFT v.7 (Multiple Alignment Program for Amino Acid or Nucleotide Sequences: http://mafft.cbrc.jp/alignment/software/), with the Q-INS-i strategy. MacClade 4.07 (Maddison and Maddison 2005) was used to visualize the alignment (no modifications were necessary). Phylogenetic analyses were performed under the ML criteria in GARLI 2.01 (Genetic Algorithm for Rapid Likelihood Inference; Zwickl 2006) for each mitochondrial gene and the concatenated sequences. GARLI uses a genetic algorithm that finds the tree topology, branch lengths, and model parameters that maximize lnL simultaneously (Zwickl 2006). Individual solutions were selected after 10,000 generations with no significant improvement in likelihood, with the significant topological improvement level set at 0.01; then, the final solution was selected when the total improvement in likelihood score was lower than 0.05, compared to the last solution obtained. Default values were used for other GARLI settings, as per recommendations of the developer (Zwickl 2006). Bootstrap support was assessed via 1000 pseudoreplicates under the same settings used in tree search.

Nomenclatural acts

The electronic edition of this article conforms to the requirements of the amended International Code of Zoological Nomenclature, and hence the new names contained herein are available under that Code from the electronic edition of this article. This published work and the nomenclatural acts it contains have been registered in ZooBank, the online registration system for the ICZN. The ZooBank LSIDs (Life Science Identifiers) can be resolved and the associated information viewed through any standard web browser by appending the LSID to the prefix "http://zoobank.org/". The LSID for this publication is: urn:lsid:zoobank.org:pub:F1221C2E-4243-4D4F-900C-21F5C2251F8B. The electronic edition of this work was published in a journal with an ISSN, and has been archived and is available from the following digital repositories: PubMed Central, LOCKSS.

Results

Systematics

***Hyalinobatrachium yaku* sp. n.**
http://zoobank.org/93A045E0-130D-4217-B20F-60CB55510B06
Suggested English name: Yaku Glassfrog
Suggested Spanish name: Rana de Cristal Yaku

Holotype. MZUTI 5001 (Fig. 1), adult male collected from a stream affluent of the Kallana river (1.4696°S, 77.2784°W, 325 m), nearby the Kichwa community of Kallana, province of Pastaza, Ecuador, collected by JC and Carlos Morochz on 15 April 2016.

Paratopotype. MZUTI 5002, adult male, same locality and collection data as holotype.

Paratypes. QCAZ 55628 (Fig. 1), adult male, QCAZ 53352, immature male, and QCAZ 53354, 56664, juveniles, all from Timburi-Cocha Research Station (0.4800°S, 77.2829°W, 300 m) near San José de Payamino, province of Orellana, Ecuador, collected by RJM, PSH, and RLL on June 2012. ZSFQ 02322, adult female from Ahuano (1.0632°S, 77.5265°W, 360 m), province of Napo, Ecuador, collected by DFCH and Jean-Marc Touzet on 5 April 1998.

Generic placement. The new species is placed in the genus *Hyalinobatrachium* (Ruiz-Carranza & Lynch, 1991, as modified by Guayasamin et al. 2009) on the basis of morphological and molecular data. The main diagnostic phenotypic traits of *Hyalinobatrachium* are: (1) ventral parietal peritoneum completely transparent; (2) digestive tract and bulbous liver covered by iridophores; (3) humeral spines absent; (4) white bones in life; and (5) males call from the undersides of leaves. All the aforementioned characteristics are shared by the new species. Additionally, analyses of three mitochondrial genes place the new species as a close relative of other *Hyalinobatrachium* species (Fig. 2); thus, generic placement in *Hyalinobatrachium* is unambiguous.

Diagnosis. The following combination of characters can distinguish *Hyalinobatrachium yaku* from other glassfrogs: (1) dentigerous process of the vomer lacking teeth; (2) snout truncate in dorsal and lateral views; (3) lower half of tympanic annulus visible; tympanic membrane clearly differentiated and with coloration similar to that of surrounding skin; (4) dorsal skin shagreen; (5) ventral skin areolate; cloacal area glandular, with one tubercular slightly enameled patch on each side of the cloaca, paired round tubercles below vent absent; (6) parietal peritoneum, pericardium, kidneys and urinary bladder transparent (lacking iridophores); hepatic, gastrointestinal, and testicular peritonea covered by iridophores; (7) liver bulbous; (8) humeral spines absent; (9) basal webbing between Fingers I and II, moderate webbing between external fingers; hand webbing formula: I 2 — 2 II 0^{+} — 3^{+} III 2^{-} — (1–2^{-}) IV; (10) foot webbing moderate; webbing formula: I (1–1^{+}) — (2–2^{-}) II (0^{+}–1) — (2^{+}–$2^{1/3}$) III 1 — $2^{1/3}$ IV $2^{1/3}$ — (1–$1^{1/3}$) V; (11) fingers and toes with thin lateral fringes; ulnar and tarsal folds present, but low and difficult to distinguish, with thin layer of iridophores

Figure 1. *Hyalinobatrachium yaku* sp. n. in life. Top row: adult male, MZUTI 5001, holotype, in dorsal and ventral view. Bottom row: adult male, paratype, QCAZ 55628.

that extends to ventrolateral edge of Finger IV and Toe V; (12) nuptial excrescence present as a small pad on Finger I (Type V), prepollex not enlarged; prepollical spine not projecting (spine not exposed); (13) when appressed, finger I longer than II; (14) diameter of eye 2.1 times wider than disc on Finger III; (15) coloration in life: dorsal surfaces apple green to yellowish green with small yellow spots and minute gray to black melanophores; posterior head and anterior half of the body with few small, well-defined dark green spots placed middorsally; bones white; (16) coloration in preservative: dorsal surfaces pale cream with minute lavender to black melanophores; (17) iris coloration in life: silver to yellow, with minute dark spots that are concentrated around pupil, giving impression of a diffuse ring; (18) melanophores present on Finger IV and Toes IV–V, absent on other fingers and toes; in life, hands and feet are cream with a light green hue, with tips of fingers and toes being yellowish green; (19) males call from the undersides of leaves; advertisement call consisting of a single tonal note; call duration note 0.27–0.4 s, dominant frequency 5219–5330 Hz, with no frequency modulation; (20) males attend egg clutches located on the underside of leaves overhanging streams, clutch size unknown; (21) SVL in adult males 20.8–22.3

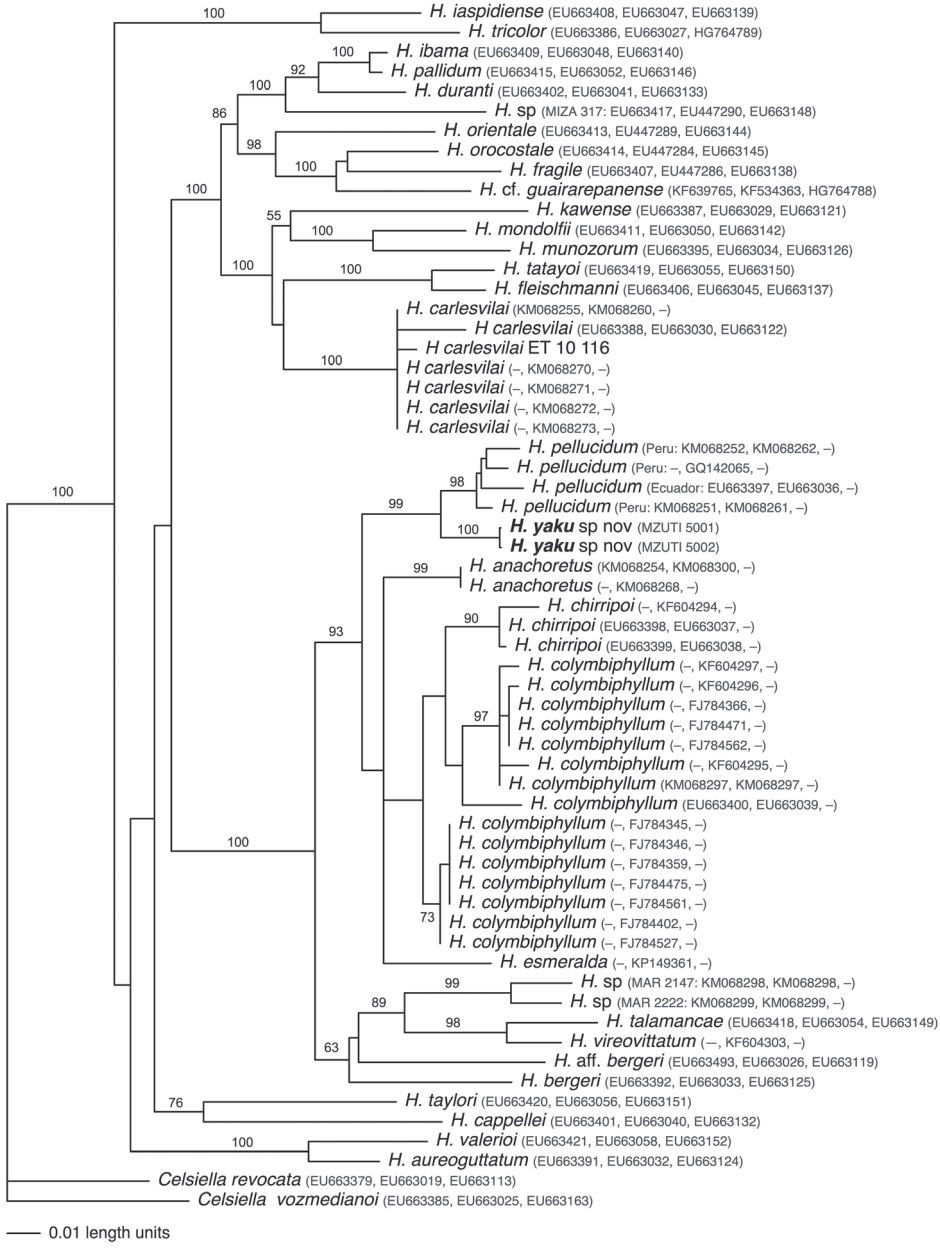

Figure 2. Phylogenetic relationships of *Hyalinobatrachium* inferred from combined mitochondrial genes (12S, 16S, ND1) under ML criterion. All sequences were downloaded from GenBank, except for those of the new species (Genbank codes: MF002063–MF002068). Genbank codes cited next to species names are in the following order: 12S, 16S, ND1. Associated locality data is available at Genbank, as well as in Guayasamin et al. (2008), Castroviejo-Fisher et al. (2014), and Twomey et al. (2014).

mm (n = 3), in adult female 21.1 mm (n = 1); (22) enameled glands absent from sides of head.

Comparisons with similar species. Many species of *Hyalinobatrachium* are difficult to diagnose using only morphological or chromatic characters (Castroviejo-Fisher et al. 2009; 2011); however the new species is diagnosable in life due to the presence of two unusual coloration traits: (i) the presence of middorsal dark green spots on the anterior half of the body (Fig. 1), and (ii) a completely exposed heart (parietal peritoneum and pericardium transparent). Only two other glassfrog species share, to some degree, these traits, the Central American *H. talamancae* and *H. vireovittatum*. However, phylogenetically, the new species is not closely related to *H. talamancae* nor *H. vireovittatum*. Also, the new species is easily distinguished by having a row of dark green middorsal spots (continuous middorsal line in *H. talamancae* and *H. vireovittatum*). Furthermore, they have a very disjunct distribution (*H. talamancae* and *H. vireovittatum* are found in Central America, whereas *H. yaku* inhabits the Amazonian lowlands). No Amazonian glassfrog has a dorsal pattern similar to the new species. *Hyalinobatrachium munozorum* and *H. ruedai* are sympatric with *H. yaku*, but they are distinguished by having white or mostly white pericardium (transparent in *H. yaku*), dorsal melanophores as punctuations of different sizes (uniform-sized in *H. yaku*), snout rounded in lateral view (truncate in *H. yaku*) and by lacking the row of dark green middorsal spots of *H. yaku*. *Hyalinobatrachium anachoretus* is morphologically similar to *H. yaku* but differs by lacking the midddorsal dark green spots, and by its call with a lower dominant frequency (4670–4800 Hz versus 5219.3–5329.6 in *H. yaku*). The most closely related species to *H. yaku* is *H. pellucidum* (Fig. 3); the two species differ by their call (Table 1) and dorsal color pattern (middorsal dark green spots present in *H. yaku* and absent in *H. pellucidum*; Figs 1, 3).

Description of the holotype. Adult male (MZUTI 5001) with SVL 20.8 mm. Head just wider than body; head width 37% of SVL; head width 1.07 times head length; head relatively short (Head length = 34% of SVL). Snout truncate in dorsal and lateral views. Loreal region slightly concave, nostrils slightly protuberant, elliptical; internarial region concave anterodorsally; canthus rostralis not well defined. Eyes small (eye diameter 12% of SVL), directed anterolaterally, eyes about 45° relative to midline. Tympanum with conspicuous dorsal inclination. Posterior half of tympanic annulus visible; tympanic membrane differentiated, pigmented as surrounding skin. Dentigerous processes on vomers lacking teeth, choanae large, circular; tongue oval, white in preservative, anterior 3/4 attached to mouth; vocal slits present, extending along floor of mouth lateral to tongue; enameled glands absent on sides of head. Ulnar fold present, but low and with very thin layer of iridophores. Relative length of fingers: I < II < IV < III; finger discs rounded, wider than toe discs; disc on Finger III 48% of eye diameter; basal finger webbing between Fingers I and II, moderate webbing between external fingers; hand webbing formula I 2 — 2 II 0^{+} — 3^{+} III 2^{-} — 2^{-} IV. Prepollex concealed; subarticular tubercles round, low; supernumerary tubercles absent, palmar tubercle round and small, thenar tubercle ovoid; nuptial excrescences present as a small pad on proximomedial edge of Finger I (Type V). Hind limbs slender, tibia length 59% of SVL; tarsal fold present,

Table 1. Comparison of relevant variables of the advertisement call of *Hyalinobatrachium yaku* sp. n. and two populations of *H. pellucidum*. Time is in seconds and frequency in Hertz.

Species, museum number, source	Number of individuals/ Numbers of calls	Call structure	# notes	Call duration (s)	Dominant frequency (hz)	Lower frequency (hz)	Upper frequency (hz)	Other frequencies (hz)
H. yaku, MZUTI 5001, this study	1/10	Tonal	1	0.27–0.4 (0.3 ± 0.03)	5219.3–5329.6 (5283.8 ± 35.0)	5207.3–5314.8 (5264.6 ± 34.6)	5236.5–5340.5 (5299.1 ± 34.1)	No
H. pellucidum, MEPN 14706, this study	1/6	Tonal	1	0.17–0.21 (0.18 ± 0.02)	5549.9–5667.9 (5608.4 ± 42.8)	5484.3–5575.1 (5539.4 ± 40.2)	5607.5–5691.1 (5649.5 ± 29.0)	11148.7–11303.3 (11218.9 ± 60.2)
H. pellucidum, MNCN 45393, uncollected individual, Wen et al. (2012)		Tonal	1	0.12–0.18 (0.15 ± 0.01)	4863.54–5408.68 Hz (5038.82 ± 190.15)	4533.0–5144.0 (4757.90 ± 191.24)	5112.0–5623.0 Hz (5284.48 ± 156.85)	No

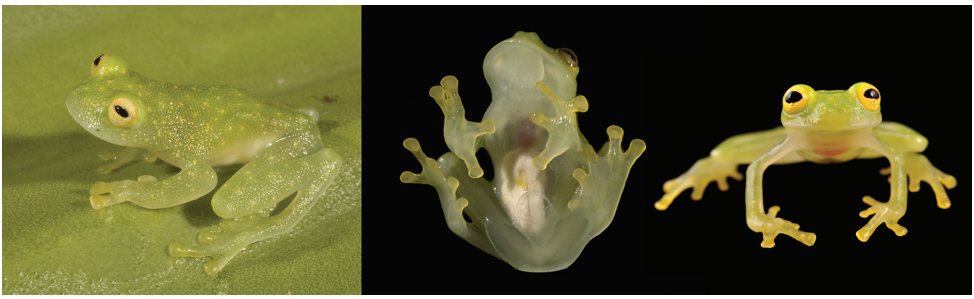

Figure 3. *Hyalinobatrachium pellucidum* in life. Left and center: QCAZ 4200. Right: QCAZ 41648. Photos by L. A. Coloma.

but low and with very thin layer of iridophores enameled; discs of toes small, round, inner metatarsal tubercle oval, small; outer metatarsal round, but very difficult to distinguish. Foot webbing moderate; webbing formula: I 1^{+} — 2 II 1 — 2^{+} III 1 — $2^{1/3}$ IV $2^{1/3}$ — $1^{1/3}$ V. In preservative, dorsal skin peppered with small dark melanophores; dorsal skin shagreen; skin on venter areolate; cloacal opening at level of upper thighs, cloacal ornamentation present as an enameled cloacal fold and small tubercles covered with thin layer of iridophores. Parietal peritoneum and pericardium transparent, urinary bladder lacking iridophores, liver and viscera covered by iridophores; liver bulbous.

Coloration in life. In adults, dorsum apple green to yellowish green with small yellow spots and minute gray to black melanophores; posterior head and anterior half of the body with few small, well-defined dark green spots placed middorsally; the anterior-most spot generally being the largest. Hands and feet are cream with a light green hue, with tips of fingers and toes being yellowish green; melanophores absent from fingers and toes, except Finger IV and Toes IV and V. Ventrally, parietal peritoneum and pericardium transparent, with red heart fully visible; visceral peritoneum of gall bladder and urinary bladder transparent; hepatic and visceral peritonea white. Ventral vein red. Iris silver to yellow, with minute dark spots that encircle the pupil, giving the impression of diffuse rings. Bones white.

Coloration in preservative. Dorsal surfaces cream dotted with minute dark lavender to black melanophores; venter uniform white; peritonea as in life. Iris white with lavender melanophores that become more numerous near the pupil. There are no traces of the characteristic middorsal dark green spots in preserved specimens.

Measurements. Measurements of the type series are shown in Table 2.

Variation. The other male from the type locality (MZUTI 5002) has more foot webbing (I 1 — 2^{-} II 0^{+} — 2^{+} III 1 — $2^{1/3}$ IV $2^{1/3}$ — 1 V) than the holotype. Juveniles have the same color pattern as adults, but the number and extent of the middorsal green dots varies, but they are usually smaller and less pronounced posteriorly (Fig. 4).

Vocalizations. The description is based on a series of ten calls emitted by the holotype and recorded by JC. The advertisement call of *Hyalinobatrachium yaku* is a single and high pitched tonal note (Fig. 5). Neither frequency nor amplitude modulation was observed. The call lasts 0.27–0.4 s (0.3 ± 0.03) and has an average call rate of 9.0

Table 2. Meristic variation of *Hyalinobatrachium yaku* sp. n. (in mm).

Character	MZUTI 5001 (holotype)	MZUTI 5002	QCAZ 55628	ZUSF 02322
Sex	male	male	male	female
SVL	20.8	21.2	22.3	21.1
Femur	11.9	11.7	11.3	12.3
Tibia	12.3	11.7	12.5	12.4
Foot	9.6	9.9	10.0	8.9
Head length	7.1	6.6	7.3	6.7
Head width	7.6	7.4	8.1	7.7
IOD	2.3	2.2	2.3	2.4
Upper eyelid	1.9	1.7	1.6	1.3
Internarinal distance	1.6	1.5	1.7	1.6
Eye diameter	2.5	2.3	2.4	1.6
Eye-to-snout distance	3.2	3.1	3.1	2.6
Tympanum diameter	1.0	0.9	0.9	0.9
Radioulna	4.3	4.4	4.4	4.3
Hand length	5.5	6.0	6.4	4.8
Finger I	4.3	4.4	4.0	3.9
Finger II	3.8	3.9	3.7	3.5
Disc Finger III	1.2	1.1	1.1	1.1
Disc Toe IV	1.0	0.9	0.9	0.9

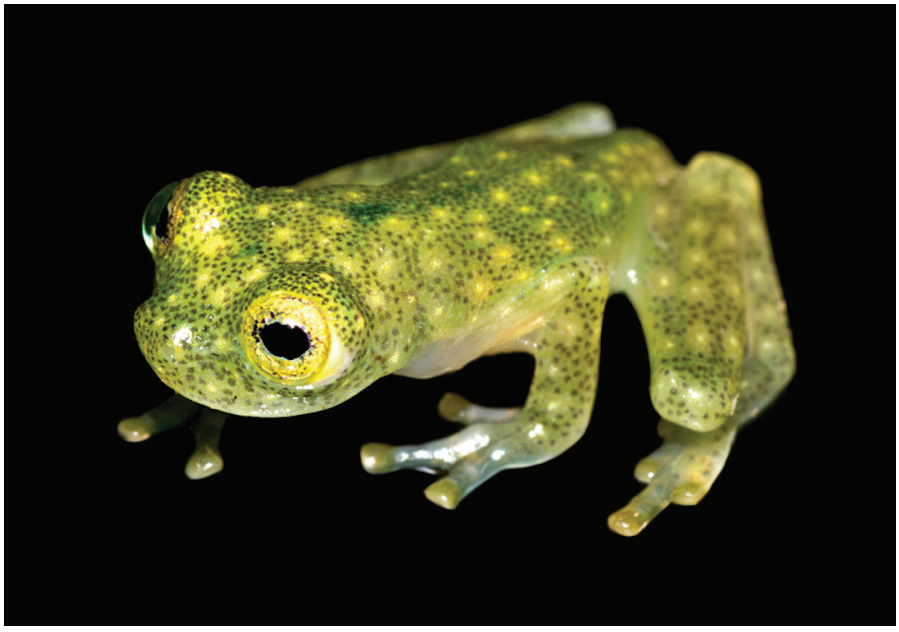

Figure 4. Juvenile of *Hyalinobatrachium yaku* in life, QCAZ 53354.

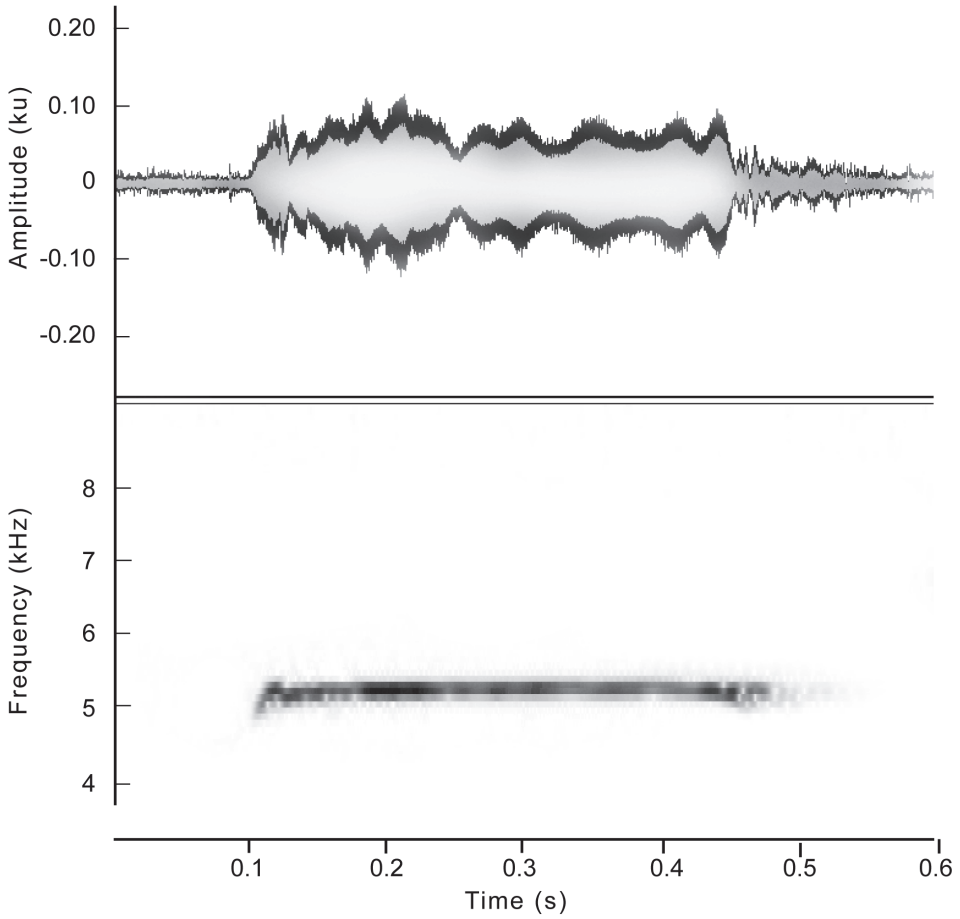

Figure 5. Call of *Hyalinobatrachium yaku* sp. n., holotype.

calls/minute. Time between calls varied from 5.3–8.9 s (7.1 ± 1.1). The dominant frequency, which is included in the fundamental frequency, ranges from 5219.3–5329.6 Hz (5283.8 ± 35.0). The frequency band has a lower frequency of 5207.3–5314.8 Hz (5264.6 ± 34.6) and an upper frequency of 5236.5–5340.5 Hz (5299.1 ± 34.1).

Ecology. At Kallana, the holotype and one paratype (MZUTI 5002) were found calling from the underside of leaves of riverine vegetation in pristine forest. The holotype was on the same leaf as two egg clutches, approximately 3 m above the stream. The paratype was also calling from the underside of a leaf nearly 6 m above water. The stream itself was slow-flowing, relatively narrow (approximately 3 m wide), and with depths no greater than 100 cm. Syntopic species at Kallana are: *Nymphargus mariae*, *Teratohyla midas*, *Agalychnis hulli*, *Phyllomedusa tomopterna*, *Hypsiboas calcaratus*, *H. geographicus*, *Osteocephalus fuscifacies*, *Pristimantis enigmaticus*, and *P. peruvianus*.

At Ahuano, the single individual was found on the underside of a leaf at 1 m above water in riverine vegetation along a small stream, tributary of the Arajuno River. The stream was slow-flowing, very narrow (approximately 1m wide), and shallow (approxi-

mately 40 cm deep). The area was covered by secondary forests. At Ahuano, *Hyalinobatrachium yaku* was found in syntopy with *Teratohyla midas* and *H. ruedai* (Cisneros-Heredia and McDiarmid 2006b).

Unlike individuals found at Kallana and Ahuano, individuals from San José de Payamino were found perched on leaves of small shrubs, ferns, and grasses (30–150 cm above ground) in disturbed secondary forest. All but one individual were found within a relatively small area near the Timburi Cocha Research Station bordering the Payamino River, with the additional individual found in slightly more mature secondary growth 50 m east of a dirt road situated approximately 1.5 km west of the research station (see Maynard et al. 2016). Additionally, all individuals recorded at San José de Payamino were found >30 m from any stream. Due to this unusual circumstance, syntopic species associated with *H. yaku* at San José de Payamino is rather extensive, as amphibian diversity in secondary forest at this site is high (Maynard et al. 2016). Syntopic glassfrog species include: *Cochranella resplendens*, *Hyalinobatrachium munozorum*, and *Teratohyla midas*. Other sympatric amphibian species include: *Allobates femoralis* (complex), *Hyloxalus sauli*, *Rhaebo ecuadorensis*, *Rhinella margaritifera*, *R. marina*, *Dendropsophus marmoratus*, *Hypsiboas boans*, *H. cinerascens*, *H. geographicus*, *H. punctatus*, *Nyctimantis rugiceps*, *Osteocephalus buckleyi*, *O. mutabor*, *Osteocephalus* sp., *Phyllomedusa tarsius*, *P. vaillantii*, *Scinax garbei*, *S. ruber*, *Hypodactylus nigrovittatus*, *Pristimantis acuminatus*, *P. altamazonicus*, *P. conspicillatus*, *P. croceoinguinis*, *P. delius*, *P. diadematus*, *P. kichwarum*, *P. lanthanites*, *P. librarius*, *P. variabilis*, *P.* aff. *martiae*, *Adenomera andreae*, *Engystomops petersi*, *Leptodactylus wagneri*, *Lithodytes lineatus*, *Chiasmocleis bassleri*, *Bolitoglossa peruviana.*

Distribution. *Hyalinobatrachium yaku* is only known from three localities on the Amazonian lowlands of Ecuador at elevations between 300–360 m. The two most-distant sites, Kallana in province of Pastaza, and San José de Payamino in province of Orellana, are approximately 110 km from one another, while Ahuano, province of Napo, is midway between them (Fig. 6). Given the geographic distance between the localities where the new species has been found, it is likely that *H. yaku* has a broader distribution, including areas in nearby Peru.

Evolutionary relationships. All inferred phylogenetic trees show that *Hyalinobatrachium yaku* and *H. pellucidum* are sister species (Fig. 2). Trees obtained for each mitochondrial gene trees are congruent with the tree shown in Figure 2.

Etymology. The specific epithet *yaku* is the Kichwa word for *water*. Water, in the form of streams, is fundamental for the reproductive biology of all glassfrogs. Water pollution, mainly through oil and mining activities, represents one of the biggest threats for Amazonian amphibians, as well as for numerous other water-dependent species.

Conservation status. Given that *Hyalinobatrachium* species are morphologically conserved and that many distinctive color traits are lost in preserved specimens (i.e., dorsal green spots), finding new records of *H. yaku* in herpetological collections is challenging. Also, many species of the genus are arboreal and difficult to find in nature, but this scarcity does not necessarily mean that the species have low abundances. Available information is insufficient to suggest an evaluation following IUCN criteria, thus we suggest that *H. yaku* is a Data Deficient species.

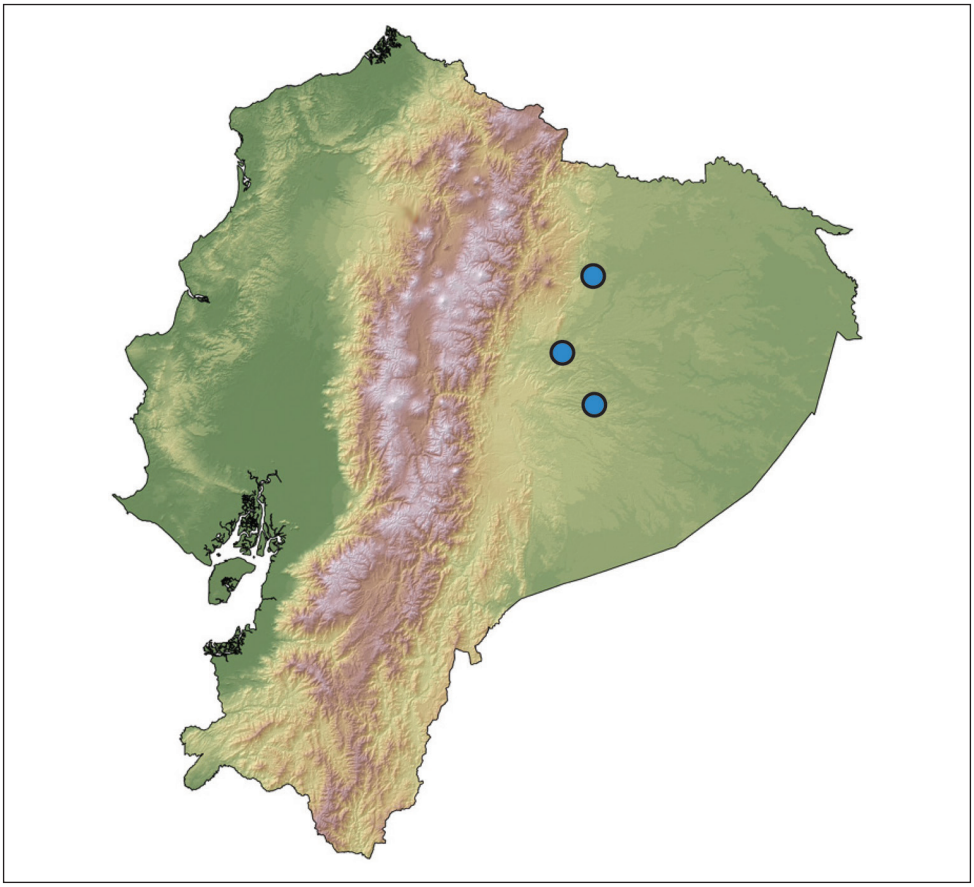

Figure 6. Distribution of *Hyalinobatrachium yaku* in Ecuador.

Discussion

Systematics

Although species delimitation within *Hyalinobatrachium* is often times complex (Castroviejo-Fisher et al. 2011a,b). The validity of *H. yaku* sp. n. is supported from all analyzed datasets (morphology, calls, DNA), allowing unambiguous separation from all congenerics, including its most related taxon, *H. pellucidum*. Our study also shows the importance of having a good record of coloration in life, especially in groups like glassfrogs where intraspecific coloration is relatively low (with the notable exception of *Espadarana prosoblepon*; see Savage 2002; Cisneros-Heredia and McDiarmid 2007; Arteaga et al. 2013). As mentioned above, the characteristic dark green spots present on the head and dorsum of *H. yaku* leave no trace in preserved specimens; thus, taxonomic work where only museum material is available may result in an underestimation of diversity. However, careful examination of some morphological and chromatic pattern together with the provenance of specimens could be useful to discriminate the identity of some specimens, in particular those in better preservation status. For example,

even though *Hyalinobatrachium yaku*, *H. pellucidum* and *H. anachoretus* are basically indistinguishable in preservation, when dorsal coloration has faded, identification of specimens is still possible because, as far as we know, the species are allopatric. While *H. yaku* occurs in the Lowland Amazonian forests of Ecuador below 400 m, *H. anachoretus* is only known from Cloud forests at Abra Patricia, northeastern Peru at 2001 m (Twomey et al. 2014), and *H. pellucidum* inhabits the Foothill, Low Montane, and Cloud forests on the eastern versant of Cordillera Oriental of the Andes of Ecuador and Peru, above 1300 m in northeastern Ecuador and above 1000 m in southeastern Ecuador and eastern Peru (although there are two localities down to 500 m in the Tarapoto area, northeastern Peru) and up to 1740 m (Lynch and Duellman 1973; Duellman and Schulte 1993; Cisneros-Heredia and McDiarmid 2006a,b, 2007; Castroviejo-Fisher et al. 2009; Twomey et al. 2014; cited as *Hyalinobatrachium* sp. from the Chinchipe River, SW Cordillera del Condor by Cisneros-Heredia et al. 2008). *Hyalinobatrachium yaku* is sympatric with *H. munozorum* and *H. ruedai*, but they are distinguished by characters that are fairly evident even in preserved specimens (pericardium coloration, dorsal melanophores pattern and snout form; see Diagnosis).

The inferred phylogeny confirms some pending taxonomic issues within *Hyalinobatrachium;* for example, only based on molecular data, there are at least four unconfirmed candidate species (see Murray and Schleifer 1994; Padial et al. 2010): *Hyalinobatrachium* sp. (MIZA 317) from Venezuela; *Hyalinobatrachium* sp. (MAR 2147, 2222) from Colombia; *Hyalinobatrachium* aff. *bergeri* (MTD 46305, MHNC 5577) from Peru; and a cryptic species within *H. colymbiphyllum* (Fig. 2). Also, it is very likely that more glassfrog species are yet to be found not just in unexplored areas of the Amazon basin, but also in rather well known areas, glassfrogs become highly arboreal and are difficult to find outside of the breeding season (e.g, Señaris and Ayarzaguena 2005; Castroviejo et al. 2009; Twomey et al. 2014). Additionally, the revision of taxa with large and/or discontinuous distributions will certainly reveal cryptic diversity (see Castroviejo-Fisher et al. 2011b; Gehara et al. 2014).

Conservation

Although the Amazon basin is globally recognized by its incredible biological and cultural diversity (Bass et al. 2010, Tarazona-Santos et al. 2001), current and future threats to conservation are conspicuous. For example, even though a high proportion of the Ecuadorian Amazon is already concessioned to several extractive activities (see Lessmann et al. 2016), the Government of Ecuador is planning to intensify oil extraction in the region (e.g., Ishpingo-Tambococha-Tiputini project, XI Ronda Petrolera). Aside from obvious concerns such as water pollution, extraction of natural resources increases the level of regional road development, which could threaten populations of *H. yaku* due to habitat degradation and isolation.

At San José de Payamino, the presence of a dirt road has been shown to negatively influence amphibian abundance and diversity, and alter assemblage composition (Maynard et al. 2016). All records of *H. yaku* at this site were > 1 km away from the

road edge. Glassfrogs presumably require continuous tracts of forest to interact with nearby populations, and roads potentially act as barriers to dispersal for transient individuals, such as those documented at San José de Payamino.

Considering the current scenario of development in the Ecuadorian Amazon, alternatives that contemplate both conservation and different levels of exploitation have been put forward by the scientific community (see Lessmann et al. 2016). These alternatives need to be seriously considered, especially when biodiversity research and conservation are clearly identified, at least in theory, as priorities for the Ecuadorian Government (Plan Nacional del Buen Vivir 2013–2017).

Author contributions

Manuscript writing was led by JMG, with substantial contributions by all authors. Ecological data were obtained by RJM, PSH, JC, RLL and DFCH. Molecular data were analyzed by JMG. Morphological descriptions, measurements, and species comparisons were made by JMG and DFCH.

Acknowledgments

J. Delia and E. Twomey provided comments that greatly improved this article. Research permits were issued by the Ministerio de Ambiente del Ecuador (MAE-DNB-CM-2015-0017, granted to Universidad Tecnológica Indoamérica). We thank UTI, KU, QCAZ, ICN, MEPN, and USNM for providing access to specimens housed at their collections. Thanks to Danilo Medina, Wilman Sánchez, Carlos Morozch, Javier Aznar, Jean-Marc Touzet, and Kallana community for their assistance and companionship in the field. Diego Batallas provided calls of *Hyalinobatrachium pellucidum* from Ecuador. Santiago Castroviejo-Fisher analyzed calls of *H. pellucidum* and *H. yaku*. Elisa Bonaccorso helped rendering the distribution map. This study was supported by the Universidad San Francisco de Quito (Equipamiento del Laboratorio de Biología Evolutiva, project ID 5467; Diversidad, ecología y conservación de las Ranas de Cristal de América del Sur, project ID 34; Ranas de Cristal: Taxonomía, Evolución y Conservación, project ID 5466; Taxonomía, Biogeografía y Conservación de Anfibios & Reptiles, project ID 48; and USFQ Collaboration Grant, Laboratorio de Zoología Terrestre), the Universidad Tecnológica Indoamérica Biodiversity Research Program, the Smithsonian Women's Committee, the 2002 Research Training Program, National Museum of Natural History, Smithsonian Institution, and the Programa "Becas de Excelencia", Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT).

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Appendix 1

Examined specimens

Hyalinobatrachium esmeralda: Colombia: Departamento de Boyacá, Municipio de Pajarito, Inspección Policía Corinto, finca 'El Descanso', quebrada 'La Limonita', 1600-1650 m, ICN 9592–94, 9596, 9602–03 (type series of *H. esmeralda*).

Hyalinobatrachium pellucidum: Ecuador: *Morona Santiago*: Nueva Alianza, Finca Santa Catalina (78.1335°W, 2.100°S, 1305 m), Límite del Parque Nacional Sangay, MEPN 14706. Quebrada del Río Napinaza (78.4070°W, 2.9266°S, 1100 m, QCAZ 42000. *Sucumbíos*: Río Azuela (0.1167 S, 77.6167 W; 1740 m), Quito–Lago Agrio road; KU 164691 (holotype), USNM 286708–10; Río Reventador, USNM 286711–12. *Morona Santiago*: km 6.6 on the Limón-Macas road (ca. 2.92816S, 78.344W; 1013 m), QCAZ 29438; 6 km N of Limon, QCAZ 25950. *Provincia de Zamora Chinchipe*: Cordillera del Cóndor, Miazi Alto (4.25044 S, 78.61356 W; 1282 m), QCAZ 41560–61, 41648.

Hyalinobatrachium munozorum: Ecuador: *Provincia de Sucumbíos*: Santa Cecilia (00°03'N, 76°58'W; 340 m), KU 118054 (holotype), 105251, 123225, 150620 (paratypes), 152488–89, 155493–96, 175504. *Provincia de Orellana*: Tiputini Biodiversity Station, ZSFQ DFCH-USFQ D105. Colombia: Departamento del Meta: Meta, ICN 5031-34, 39503. *Departamento de Amazonas*: Leticia, ICN (serie de campo JMR 4119).

Hyalinobatrachium ruedai: Colombia: *Departamento de Caquetá*: Parque Nacional Natural de Chiribiquete, ICN 40409 (holotype), ICN 40410-11, IND-AN 5448-52 (paratypes). Ecuador: *Provincia de Napo*: Tena, ZUSF DFCH-USFQ 0735. *Provincia de Pastaza*: Río Manderoyacu, Arajuno, MEPN 6427.

ZooKeys 673: 21–47 (2017)
doi: 10.3897/zookeys.673.13050
http://zookeys.pensoft.net

RESEARCH ARTICLE

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A new species of semiarboreal toad of the *Rhinella festae* group (Anura, Bufonidae) from the Cordillera Azul National Park, Peru

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Academic editor: *A. Herrel* | Received 5 April 2017 | Accepted 20 April 2017 | Published 12 May 2017

http://zoobank.org/2E8F1064-6624-45E1-A22F-A2C5F957BEE5

Citation: Cusi JC, Moravec J, Lehr E, Gvoždík V (2017) A new species of semiarboreal toad of the *Rhinella festae* group (Anura, Bufonidae) from the Cordillera Azul National Park, Peru. ZooKeys 673: 21–47. https://doi.org/10.3897/zookeys.673.13050

Abstract

A new semiarboreal species of the *Rhinella festae* group is described from montane forests of the Cordillera Azul National Park between 1245 and 1280 m a.s.l. in the Cordillera Oriental, San Martín region, northern Peru. The new species is morphologically and genetically compared with members of the *Rhinella acrolopha* group (former genus *Rhamphophryne*) and members of the *R. festae* group. The new species is characterized by its large size (female SVL 47.1–58.3 mm, n = 4), eight presacral vertebrae, fusion of the sacrum and coccyx, long protuberant snout, snout directed slightly anteroventral in lateral view, cranial crests moderately developed, absence of occipital crest, presence of tympanic membrane, dorsolateral rows of small conical tubercles extending from parotoid gland to groin, hands and feet with long digits, fingers basally webbed and toes moderately webbed. Phylogenetically it is a member of the *R. festae* group which is most closely related to *R. chavin* and *R. yanachaga* from Peru. Morphologically the new species shares similarities with *R. tenrec* and *R. truebae*, members of the *R. acrolopha* group from Colombia.

Keywords

Amphibia, phylogeny, *Rhinella acrolopha* group, *Rhinella lilyrodriguezae*, new species

Introduction

The family Bufonidae Gray, 1825 comprises a clade of neobatrachian anurans commonly known as "true toads" of approximately 600 species and more than 50 genera (Frost 2016). *Rhinella* Fitzinger, 1826 (former part of the genus *Bufo*) is one of the most diverse bufonid genera currently composed of 91 species and broadly distributed throughout the Neotropical region (Pramuk 2006, Frost et al. 2006, Pereyra et al. 2015, Frost 2016). In Peru, the family Bufonidae has 54 species assigned to seven genera (AmphibiaWeb 2017): *Amazophrynella* (4), *Atelopus* (18), *Nannophryne* (2), *Rhaebo* (3), *Rhinella* (25), *Truebella* (2). Six similarity-defined groups within the genus *Rhinella* in South America are traditionally recognized based on anatomical and external characters, as follows: *Rhinella acrolopha, R. crucifer*, *R. granulosa*, *R. margaritifera*, *R. marina*, *R. spinulosa* and *R. veraguensis* groups (Martin 1972, Duellman and Schulte 1992, Grant and Bolívar-G. 2014)

The former genus *Rhamphophryne* Trueb, 1971, now a part of *Rhinella*, comprised several species of bufonid toads distributed in South American tropical forests. Most of the diversity of this genus occurs in montane forests, with nine species in northern Colombia and eastern Panama (*R. acrolopha* Trueb, 1971; *R. lindae* Rivero & Castaño, 1990; *R. macrorhina* Trueb, 1971; *R. nicefori* Cochran & Goin, 1970; *R. paraguas* Grant & Bolívar-G., 2014; *R. rostrata* Noble, 1920; *R. ruizi* Grant, 2000 "1999"; *R. tenrec* Lynch & Renjifo, 1990; and *R. truebae* Lynch & Renjifo, 1990) and one species extending also to the upper Amazonian Basin of Ecuador (*R. festae* Peracca, 1904). From early on, the monophyly of the genus was not supported by Cannatella (1986) and Graybeal and Cannatella (1995). These authors noted that the only diagnostic feature of *Rhamphophryne* was the anteriorly ossified sphenethmoid forming a protuberant snout, which is variable in some species (*R. nicefori* and *R. rostrata*).

Recently, based on morphological and molecular data, the generic name *Rhamphophryne* was synonymized with *Rhinella* Fitzinger, 1826 by Chaparro et al. (2007) following results of Pauly et al. (2004), Frost et al. (2006) and Pramuk (2006). Grant and Bolívar-G. (2014) adopted the nomination *Rhinella acrolopha* group consisting of the species of the former genus *Rhamphophryne*, nevertheless, they did not formally propose delimitation of this species group. In a phylogenetic analysis based on the mitochondrial 16S rRNA gene of available species, Moravec et al. (2014) proposed a new species-group name, *Rhinella festae* group, for a clade of toads containing the following seven species: *R. chavin* (Lehr, Köhler, Aguilar & Ponce, 2001); *R. festae*; *R. macrorhina*; *R. manu* (Chaparro, Pramuk & Gluesenkamp, 2007); *R. nesiotes* (Duellman & Toft, 1979); *R. rostrata*; and *R. yanachaga* (Lehr, Pramuk, Hedges & Córdova, 2007). This monophylum is assumed to be integrated by certain species of the *R. acrolopha* group and some species of the *R. veraguensis* group (Pramuk 2006, Chaparro et al. 2007, Pramuk et al. 2008, Moravec et al. 2014, Grant and Bolívar-G. 2014). The *Rhinella veraguensis* group defined on morphological similarities by Duellman and Schulte (1992), modified by Padial et al. (2006) and Chaparro et al. (2007), is now recognized as a paraphyletic group. As a result, both *R. acrolopha* and *R. veraguensis*

groups are artificial groupings lacking synapomorphies that define each species group. It is evident that comparison of molecular data of other *Rhinella* species is necessary to precise species composition of the individual species groups within the genus *Rhinella*. For example, a close relationship between [*R. festae* + [*R. macrorhina* + *R. rostrata*]] and [*R. chavin* + [*R. manu* + *R. nesiotes*]] was uncovered by Pyron and Wiens (2011). Grant and Bolívar-G. (2014) pointed out that sequences of *R. macrorhina* and *R. rostrata* were not included into the genetic analysis made by Moravec et al. (2014). However, we argue that the GenBank samples of "*R. macrorhina*" and "*R. rostrata*" used in studies of Van Bocxlaer et al. (2010) and Pyron and Wiens (2011) are probably both *R. macrorhina* and must be carefully evaluated due to lower quality of DNA sequences (see Taxon sampling for more details). Herein, we follow Moravec et al. (2014) and assign the below-described new species into the *Rhinella festae* group.

The Cordillera Azul National Park (herein CAZNP) located in the Cordillera Oriental of the Andes, Loreto, San Martín, Huánuco and Ucayali regions, is one of the most diverse natural protected areas in northern Peru. CAZNP has an extension of more than 13,000 km^2 with an altitudinal range from 200 to 2400 m a.s.l. between the Huallaga and Ucayali rivers (INRENA 2006, Alverson et al. 2001). Rodríguez et al. (2001) conducted the first herpetological surveys of the CAZNP and recorded 58 species of amphibians and 24 species of reptiles from the basins of the rivers Pisqui and Pauya, Loreto. The recent discovery of new species of woodlizards (*Enyalioides azulae* Venegas, Torres-Carvajal, Durán & De Queiroz, 2013; and *E. binzayedi* Venegas, Torres-Carvajal, Durán & De Queiroz, 2013) and poison frogs (*Ranitomeya benedicta* Brown, Twomey, Pepper & Sanchez-Rodriguez, 2008; *R. summersi* Brown, Twomey, Pepper & Sanchez-Rodriguez, 2008; and *Ameerega yoshina* Brown and Twomey, 2009) within the CAZNP have increased the knowledge of the faunal diversity of this region. Most recently, Tasker and Twomey (2015) recorded 74 species of amphibians in the San Martín and Loreto regions of the CAZNP. As part of the aforementioned survey, Kaitlin Tasker and Juan C. Cusi conducted fieldworks in the surroundings of the Park Rangers Center N° 53 "Shapaja" at CAZNP, close to Tocache city in 2013, resulting in a discovery of a morphologically distinguishable *Rhinella* species, which was tentatively reported under the name *Rhinella* cf. *festae* by Tasker and Twomey (2015).

Here, a thorough comparison of this new bufonid from the Cordillera Azul National Park with other related *Rhinella* species is provided, its phylogenetic position based on DNA barcoding data elucidated, and the taxon formally described as a new species of the *Rhinella festae* group.

Methods

Fieldwork and deposition of specimens. Six specimens of the new species were collected inside the CAZNP (Fig. 1). All specimens were euthanized using an anesthetic 7.5% benzocaine gel on ventral surface of the individuals (McDiarmid 1994, Angulo

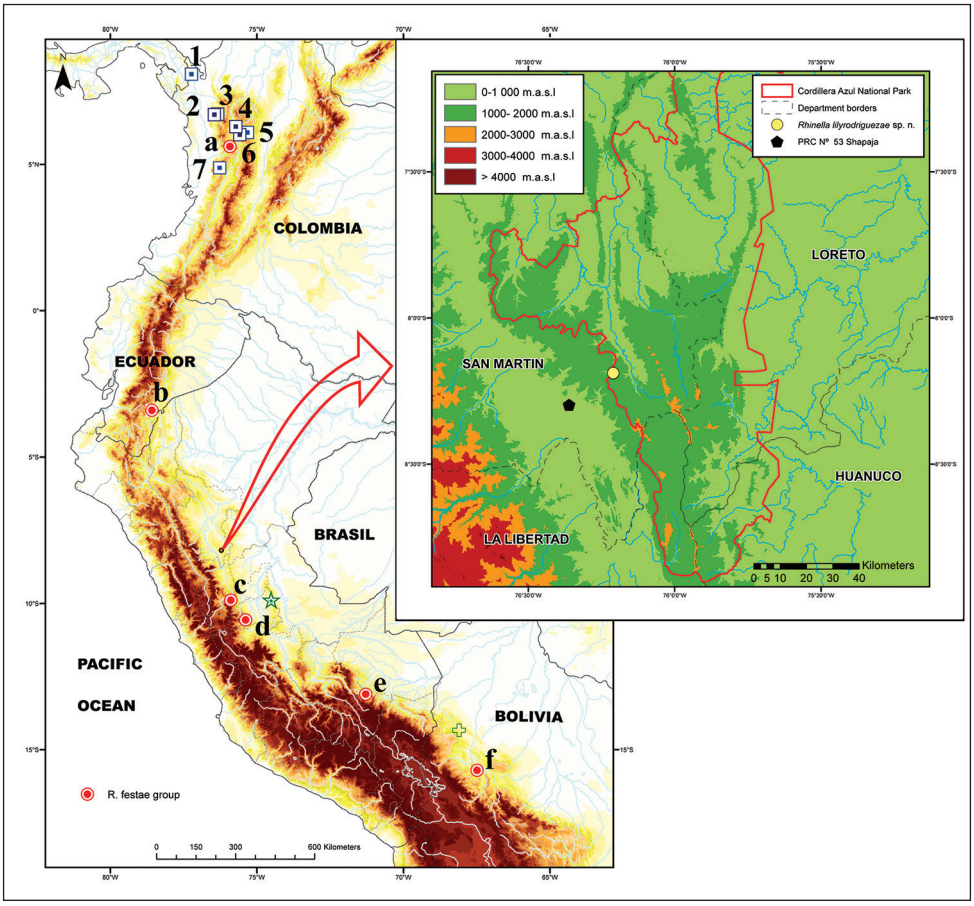

Figure 1. Map showing the type localities of *Rhinella lilyrodriguezae* sp. n. (●, yellow), selected species of the former genus *Rhamphophryne* (▣, blue; with numbers **1** *R. acrolopha* **2** *R. tenrec* **3** *R. lindae* **4** *R. nicefori* **5** *R. rostrata* **6** *R. ruizi* **7** *R. paraguas*), species of the *Rhinella festae* group (◉, red; with letters **a** *R. macrorhina* **b** *R. festae* **c** *R. chavin* **d** *R. yanachaga* **e** *R. manu*, f: *Rhinella* cf. *nesiotes*) and type localities of *Rhinella nesiotes* (★, green star) and *Rhinella tacana* (✚, cross, green). Abbreviation PRC: Park Rangers Center.

et al. 2006). Tissue samples (liver and muscle pieces) were removed prior to preservation and stored in 96% ethanol, while specimens were fixed using 10% formalin and stored in 70% ethanol. All specimens were deposited at the herpetological collection of the Museo de Historia Natural, Universidad Nacional Mayor de San Marcos (**MUSM**), Lima, Peru.

The specimens were compared with species previously assigned either to the *Rhinella festae* group or the *R. acrolopha* group (see Appendix) and original species descriptions. The coordinates of the type and reference localities of species of the *R. acrolopha* group were obtained using Global Gazetteer version 2.3 (http://www.fallingrain.com/

world/index.html). The geographic coordinates were based on the datum WGS84 and maps were designed using ArcGIS version 10.0.

Morphological characters. Morphometric measurements in millimeters (mm) were taken with a digital caliper Mitutoyo (nearest to 0.1 mm). Measurement abbreviations used throughout the text are:

SVL snout–vent length;
HW head width (at level of angle of jaw);
HL head length (from angle of jaw to tip of snout);
ED horizontal eye diameter;
IOD interorbital distance;
EW upper eyelid width;
EL eyelid length (upper eyelid length);
IND internarial distance;
E–N eye-nostril distance (straight line distance between anterior corner of orbit and posterior margin of external nares);
NSD nostril-snout distance;
SL snout length (between anterior corner of eye and tip of snout);
FL forearm length (between flexed elbow and proximal edge of palmar tubercle);
HNDL hand length (between proximal edge of palmar tubercle and tip of Finger III);
FEML femur length;
TL tibia length;
FOOTL foot length (distance from proximal margin of inner metatarsal tubercle to tip of Toe IV).

Fingers and toes are numbered preaxially to postaxially from I–IV and I–V, respectively. We determined comparative lengths of Toes III and V by adpressing both toes against Toe IV; lengths of fingers I and II were determined by adpressing the fingers against each other. Condition of the tympanum was assessed by visual examination under stereoscope. Specimens were sexed by examination of gonads and secondary sex characters. Ovarian eggs number and coloration were observed by dissection of a gravid female. The measurements of each egg were obtained of the maximum diameter, calculating the mean and standard deviation. Format of the description and diagnosis follows the standards of Trueb (1971), as modified by Grant (2000 "1999"), and Grant and Bolívar-G. (2014).

Webbing formula follows Savage and Heyer (1967), Myers and Duellman (1982) and Savage and Heyer (1997). X-ray radiographs were obtained using a Carestream DirectView Vita CR computerized radiography system (http://www.carestream.es/computed-radiography/vita-cr-systems.html; 44 kV, 32 mAs) and were taken of the dorsal surface of each specimen collected. Images were edited with Adobe Photoshops CS6 for MacBookPro. Coloration in life of specimens was described based on digital photographs and field notes.

Molecular phylogenetic analysis

Taxon sampling. Three specimens of the putative new species from the *Rhinella festae* group from the Cordillera Azul National Park were compared with the taxa from the dataset from Moravec et al. (2014), where the species group was established, supplemented by additional new material and sequences from GenBank. In particular, we included all taxa from the *R. festae* group available in GenBank for our genetic marker (16S rRNA), i.e. six taxa including one undescribed species "*Rhinella* sp. C" (Machado et al. 2016). We used only one sequence from two available of "*R. macrorhina*" and "*R. rostrata*" deposited in GenBank (Gluesenkamp *submitted 2001, unpublished*) due to their lower quality (based on comparison with other homologous sequences), and because they are most probably conspecific based on nucleotide sequences in overlapping DNA segments and information on origin of samples. Both samples were collected 0.5 km W of Medellin, Colombia by the same collector (P. Alberch), and are currently stored in the Museum of Vertebrate Zoology under the name "*Rhamphophryne macrorhina*" (voucher specimens/tissues: MVZ:Herp:231697/FC-13112; MVZ:Herp:150267/FC-13113). We therefore used only one sequence (AF375533) of "*R. rostrata*" and we name it *R. macrorhina* following David Cannatella's identification (2008-12-11; see http://arctos.database.museum/guid/MVZ:Herp:231697). The same sample (GenBank sequences) was earlier used by Van Bocxlaer et al. (2010) and Pyron and Wiens (2011), and thus, their "*R. rostrata*" and "*R. macrorhina*" both represent *R. macrorhina* and the divergence is probably caused by errors in nucleotide sequences due to their lower qualities. Genetic information for *R. rostrata*, which might now be extinct (Stuart et al., 2008), is thus unavailable. The GenBank "*R. nesiotes*" based on the specimen UTA 53310 we name *R.* cf. *nesiotes* due to the very distant origin of this sample (Bolivia: La Paz, Caranavi, Serranía de Bella Vista; Pramuk and Lehr 2005) from the known range of the species (Peru: Huánuco: Reserva Comunal El Sira). In addition to the main focus on the *R. festae* group, we also investigated genetic identities of 14 samples from the *R. margaritifera*, *R. veraguensis*, and *R. marina* groups (serving also as outgroups), with a particular interest in the affinities of specimens morphologically resembling recently described *R. yunga* from a new locality, Rio Huatziroki (Pui Pui Protected Forest, Junín, Peru). More detailed information on the new material, and all analyzed samples from the *R. festae* group, is given in Table 1.

Laboratory protocol and bioinformatics. A fragment of the mitochondrial 16S rRNA gene (~ 550 bp) was targeted. DNA extraction, PCR amplification and sequencing followed the methods described in Moravec et al. (2009, 2014). The computational analysis followed the procedure and methodological approach, including used software, of Moravec et al. (2014). The final dataset consisted of 63 samples. After adjustment of the sequence length according to available GenBank data and after deletion of ambiguously aligned positions, the final alignment consisted of 397 bp. The GTR+I+G model was selected as the best-fitting model of nucleotide evolution and employed for maximum likelihood and Bayesian phylogenetic inference.

Table 1. Species, sample localities, museum numbers and GenBank accession numbers for DNA sequences used in the phylogenetic analysis of all samples of the *Rhinella festae* group, and new material of the *R. margaritifera*, *R. veraguensis* and *R. marina* groups. For the species group affiliation see Fig. 2.

Species	Locality	Museum No.	GenBank Accession No.	Reference
			16S Cytb	
Rhinella lilyrodriguezae sp. n.	Peru: San Martín, Bellavista, Alto Biavo, Cordillera Azul National Park	MUSM 32205	KY912598	This study
Rhinella lilyrodriguezae sp. n.	Peru: San Martín, Bellavista, Alto Biavo, Cordillera Azul National Park	MUSM 32206	KY912599	This study
Rhinella lilyrodriguezae sp. n.	Peru: San Martín, Bellavista, Alto Biavo, Cordillera Azul National Park	MUSM 32211	KY912600	This study
Rhinella yanachaga	Peru: Pasco, Oxapampa, Cordillera Yanachaga: Quebrada Yanachada, 2900 m	FMNH 282819	KF992148	Moravec et al. 2014
Rhinella yanachaga	Peru: Pasco, Oxapampa, Cordillera Yanachaga: Quebrada Yanachada, 2900 m	MUSM 31100	KF992149	Moravec et al. 2014
Rhinella chavin	Peru: Palma Pampa	MTD 43789	DQ158441	Pramuk 2006
Rhinella sp. C (= *Rhinella sp. acrolopha* group *sensu* Grant and Bolívar-G 2014)	--	--	KT221613	Machado et al. 2016
Rhinella festae	Ecuador: Pastaza, Petrolera Garza	KU 217501	DQ158423	Pramuk 2006
Rhinella festae	Ecuador: Napo, Estacion Biologica Jatun Sacha	QCAZ 18203	KR012624	dos Santos et al. 2015
Rhinella macrorhina (before "*R. rostrata*" in GenBank)	Colombia, Antioquia, 0.5 km W (by road) Medellin†	MVZ:Herp:231697 (FC-13112)	AF375533	Gluesenkamp, unpublished
Rhinella macrorhina‡	Colombia, Antioquia, 0.5 km W (by road) Medellin†	MVZ:Herp:150267 (FC-13113)	AF375532	Gluesenkamp, unpublished
Rhinella cf. *nesiotes*	Bolivia: La Paz, Caranavi, Serranía de Bella Vista	UTA 53310	DQ158478	Pramuk 2006
Rhinella yunga	Peru: Junín, area of Rio Huatziroki, buffer zone of the Pui Pui Protected Forest, 1950 m	MUSM 31950	KY912601	This study
Rhinella yunga	Peru: Junín, area of Rio Huatziroki, buffer zone of the Pui Pui Protected Forest, 2230 m	MUSM 31966	KY912602	This study

Species	Locality	Museum No.	GenBank Accession No.	Reference
			16S Cytb	
Rhinella yunga	Peru: Junín, area of Rio Huatziroki, buffer zone of the Pui Pui Protected Forest, 2075 m	NMP6V 75552	KY912603	This study
Rhinella cf. *margaritifera*	Peru: Junín, Ayte, buffer zone of the Pui Pui Protected Forest, 2007 m	MUSM 32713	KY912604	This study
Rhinella cf. *margaritifera*	Peru: Junín, Ayte, buffer zone of the Pui Pui Protected Forest, 2007 m	MUSM 32715	KY912605	This study
Rhinella cf. *margaritifera*	Peru: Junín, Ayte, buffer zone of the Pui Pui Protected Forest, 2007 m	IWU 334	KY912606	This study
Rhinella cf. *margaritifera*	Peru: San Martín, Rioja, Pardo Miguel, Alto Mayo Protected Forest	MUSM 34237	KY912607	This study
Rhinella cf. *margaritifera*	Peru: San Martín, Rioja, Pardo Miguel, Alto Mayo Protected Forest	MUSM 34238	KY912608	This study
Rhinella cf. *margaritifera*	Bolivia: Polpebra	CBF 5800	KY912609	This study
Rhinella cf. *leptoscelis*	Peru: Junín, area of Rio Bravo, buffer zone of the Pui Pui Protected Forest, 1721 m	MUSM 32726	KY912610	This study
Rhinella cf. *leptoscelis*	Peru: Junín, area of Rio Bravo, buffer zone of the Pui Pui Protected Forest, 1721 m	PE 008A	KY912611	This study
Rhinella cf. *leptoscelis*	Peru: Junín, area of Rio Bravo, buffer zone of the Pui Pui Protected Forest, 1721 m	PE 008B	KY912612	This study
Rhinella cf. *leptoscelis*	Peru: Junín, area of Rio Bravo, buffer zone of the Pui Pui Protected Forest, 1721 m	PE 008C	KY912613	This study
Rhinella poeppigii	Perú: Junin, La Merced, Pampa del Carmen, old swimming pool	MUSM 32746	KY912614	This study

† Database: http://arctos.database.museum

‡ This sequence was not included into our analysis. See Taxon sampling.

Results

Phylogenetic analysis and systematics. The maximum likelihood (ML) analysis and Bayesian phylogenetic inference produced trees with the same topologies and strong support for the main clades. Our phylogenetic tree supported the *R. festae* group (Bayesian posterior probabilities 1.00/ML bootstrap 97) and the distinctiveness of the morphologically identified new species of *Rhinella* from the Cordillera Azul National Park. The new species was most closely related to a sister group composed of *R. yanachaga* and *R. chavin* (Fig. 2), both from mountains in central Peru. In the *R. margaritifera* group, our analysis also showed that three new samples of the recently described *R. yunga* (MUSM 31950, 31966, NMP6V 75552) from Rio Huatziroki, a buffer zone of the Protected Forest Pui Pui, Junín, Peru, are genetically identical to the type material (Fig. 2). In addition, our analysis inferred one new, yet unnamed lineage (a candidate species) of the *Rhinella margaritifera* species group from Ayte, Junín (Cordillera Central) and Alto Mayo, San Martín (Cordillera Oriental) in the Peruvian Amazonia. *Rhinella* cf. *margaritifera* from Bolpebra (Bolivia) is nested together with two samples from Peru and one Bolivian sample of *R.* cf. *paraguayensis*. Within the *R. veraguensis* group, four new samples of *R.* cf. *leptoscelis* (an adult specimen MUSM 32726 and conspecific torrenticolous tadpoles PE 008A, PE 008B, PE 008C) from Rio Bravo, Protected Forest Pui Pui, Junín, Peru proved to be closely related to two published sequences from Cordillera Yanachaga, Pasco, Peru (KF992153, KF992154).

***Rhinella lilyrodriguezae* sp. n.**
http://zoobank.org/8FD9CFFD-7311-42A5-85E2-2AB00CF4F7E7

Rhinella cf. *festae*: Tasker and Twomey 2015: Pag. 1, figs 7–9.

Suggested English name. Lily Rodriguez's Beaked Toad

Suggested Spanish name. Sapo picudo de Lily Rodríguez

Holotype. MUSM 32204 (field number KT 75, Figs 3–6). An adult gravid female collected *ca.* 20 km from Park Rangers Center N° 53 "Shapaja" of the Cordillera Azul National Park (08°11'15.1"S, 76°12'36.8"W, 1260 m), Alto Biavo District, Bellavista Province, San Martín Region, Peru, collected on 27 September 2013 by K. Tasker and J. C. Cusi.

Paratypes. Five individuals (Figs 7–8): an adult female MUSM 32206 (field number KT 76), two juveniles MUSM 32211 (field number KT 84), 32213 (field number KT 72) collected with the holotype; two adult females MUSM 32201 (field number KT 89), MUSM 32205 (field number KT 87), same locality as holotype, collected on 28 September 2013 by K. Tasker and J. C. Cusi.

Diagnosis. A large species of the *Rhinella festae* group confirmed by *16S* DNA barcoding. The new species can be diagnosed by the following combination of characters: (1) large size, SVL 47.1–58.3 mm in females (n = 4), males are unknown;

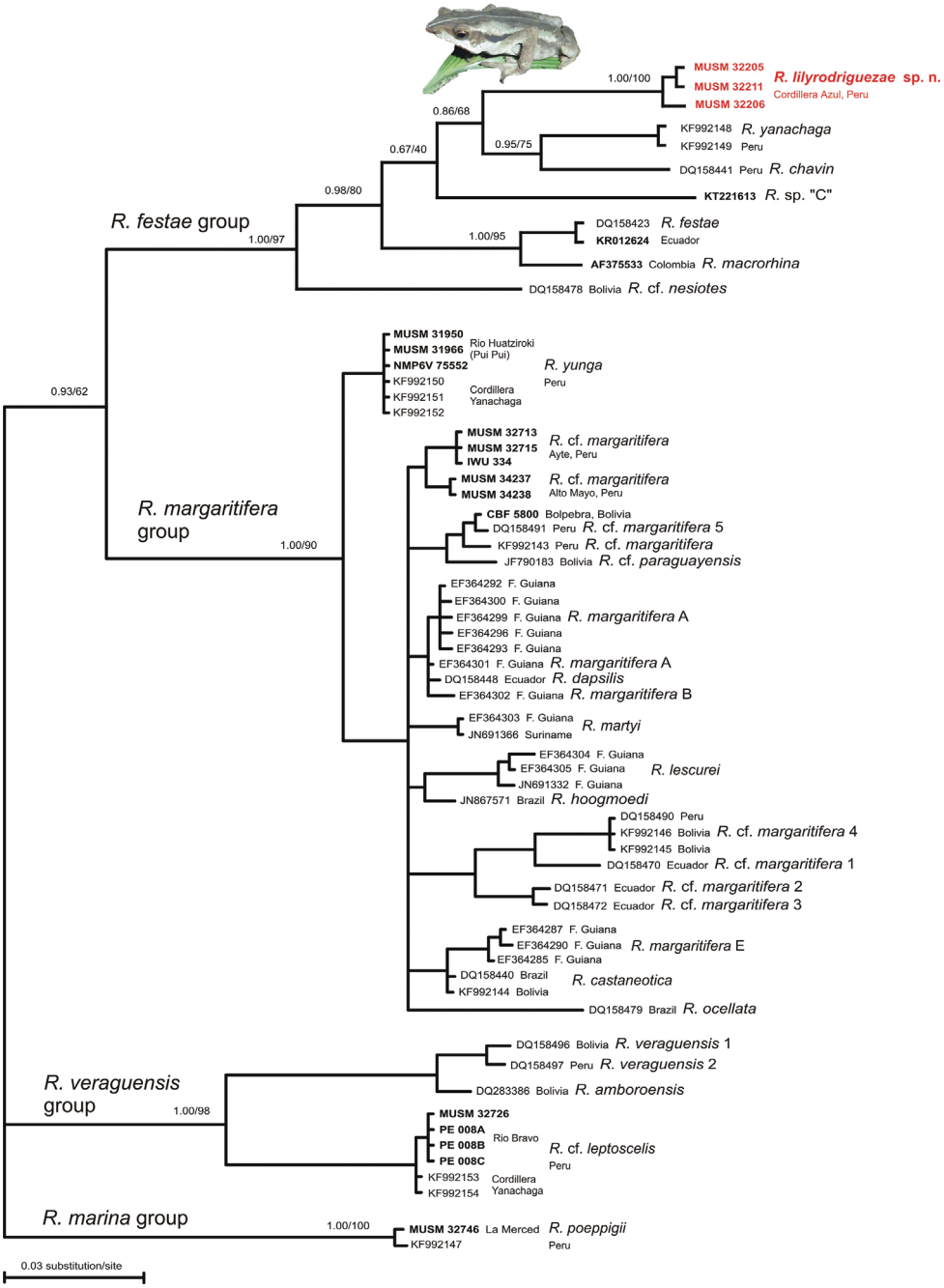

Figure 2. The Bayesian consensus tree resulting from analysis of the mitochondrial 16S rRNA gene dataset for South American *Rhinella* species based on the data from Moravec et al. (2014) with a special focus on the *R. festae* group. New samples are in bold. Bayesian posterior probabilities/maximum likelihood bootstrap values for the main clades (species groups) and within the *R. festae* group are indicated above each node. Three specimens of the new species collected in the Cordillera Azul National Park, Peru, are in red.

(2) eight presacral vertebrae; (3) sacral vertebrae fused with coccyx; (4) snout long, acuminate, pointed to rounded terminally in dorsal view; snout protuberant, directed slightly anteroventral in profile as a "shark snout"; (5) cranial crests moderately developed; (6) canthal, supraorbital, postorbital and supratympanic crests continuous, distinctly elevated in female, slightly elevated in juveniles; pretympanic crest present, occipital crest absent; (7) tympanic membrane present, tympanic annulus weakly defined; (8) mandibular angle not protruding; (9) parotoid glands moderately large, roughly triangular to rounded in outline, slightly swollen laterally, incorporated into lateral row of tubercles; (10) dorsolateral rows of small, conical tubercles extending from parotoid gland to groin; (11) hands and feet with long digits, fingers basally webbed and toes moderately webbed; (12) skin on dorsum smooth with scattered conical tubercles in females; (13) subarticular tubercles diffuse, round to ovoid; (14) supernumerary tubercles present, round but poorly developed; (15) cloacal sheath absent; (16) in life, dorsum light brown to greenish brown with irregular brown, dark brown or black markings; with or without grey white middorsal stripe; venter cream yellow to brownish grey with minute light cream spots; iris silvery greenish with irregular black mottling.

Comparisons with other species. The new species shares similarities with members of the *Rhinella festae* and *R. acrolopha* groups. Three species of the *R. acrolopha* group from Colombia and Panama (*R. truebae*, *R. lindae* and *R. tenrec*) are large-sized toads similarly to *R. lilyrodriguezae* sp. n. (maximum SVL 65.9 mm in *R. truebae*, 62.2 mm in *R. lindae*, 60.8 mm in *R. tenrec* and 58.3 mm in *R. lilyrodriguezae*). The new species is most similar morphologically to *R. truebae* and *R. tenrec*, but is distinguished by lacking the occipital crest (which is low in *R. truebae* and *R. tenrec*). *Rhinella lilyrodriguezae* sp. n. can also be distinguished from *R. tenrec* by having a sacrum fused with the coccyx, cranial crests moderately developed and tympanic membrane present (sacrum not fused with the coccyx, cranial crests poorly developed, tympanic membrane absent in *R. tenrec*); from *R. truebae* and *R. lindae* by having a dorsolateral row of small conical tubercles extending from parotoid gland to groin, hands basally webbed, and feet moderately webbed (dorsolateral fold formed by the tubercles fusion, hands and feet extensively webbed in *R. truebae* and *R. lindae*). *Rhinella lindae* possesses a snout slightly directed upwards (snout directed slightly anteroventral as "shark snout" in *R. lilyrodriguezae*).

Other species of the *Rhinella acrolopha* group are *R. acrolopha*, *R. nicefori*, *R. paraguas*, and *R. ruizi*. These species are differentiated from *R. lilyrodriguezae* sp. n. (characters in parentheses) by the absence of the tympanic membrane (present), hands and feet extensively webbed in *R. paraguas* and *R. ruizi,* and reduced webbing in *R. acrolopha* and *R. nicefori* (hands basally webbed and feet moderately webbed), sacrum not fused with the coccyx except in *R. paraguas* (fused), seven presacral vertebrae except in *R. paraguas* (eight) and the presence of occipital crest except in *R. paraguas* (absent). *Rhinella nicefori* and *R. ruizi* have hands and feet with short digits (long digits). *Rhinella paraguas* and *R. ruizi* have cranial crests very low (moderately developed). *Rhinella nicefori* has a dorsolateral row of enlarged tubercles extending from the posterior margin of the parotoid gland to a point about three-fourths the distance between the axilla

and groin (conical tubercles extending to groin). *Rhinella acrolopha* possesses a snout directed markedly anteroventrally (directed slightly anteroventral as "shark snout") and a dorsolateral row of depressed tubercles extending from the posterior margin of the parotoid gland posteriorly to a point about two-thirds distance between axilla and groin (conical tubercles extending from parotoid gland to groin).

The remaining species of the *R. acrolopha* and *R. festae* groups from Colombia and Ecuador (*R. festae*, *R. macrorhina* and *R. rostrata*) are distinguished from *R. lilyrodriguezae* sp. n. by lacking the tympanic membrane (present), by having hands and feet extensively webbed (hands basally webbed and feet moderately webbed), seven presacral vertebrae (except for *R. macrorhina* which has eight), snout directed markedly anteroventrally in *R. festae* and *R. macrorhina* and straight in *R. rostrata* (directed slightly anteroventral). *Rhinella festae* and *R. macrorhina* have occipital crest well developed (absent). *Rhinella macrorhina* is distinct in having a sacrum not fused with the coccyx (fused), and a dorsolateral row of small tubercles extending from posterior margin of parotoid gland posteriorly to a point about one-half distance between axilla and groin (tubercles extending from parotoid gland to groin). *Rhinella festae* possesses dorsolateral row of slightly enlarged, conical tubercles extending from posterior margin of skull to a point about three-fourths distance between axilla and groin (tubercles extending from parotoid gland to groin) and hands with short digits (long digits).

Peruvian species of the *R. festae* group (*R. chavin*, *R. manu*, *R. nesiotes* and *R. yanachaga*) are distinguished from *R. lilyrodriguezae* sp. n. by having smaller females (maximum SVL 21.4 mm in *R. manu*, 23.6 mm in *R. nesiotes*, 45.7 mm in *R. yanachaga*, except in *R. chavin* with 54.8 mm; vs. 58.3 mm in *R. lilyrodriguezae*) and by having webbing of hands and feet fleshy (membranous in *R. lilyrodriguezae*). *Rhinella chavin* possesses a snout rounded in lateral view (snout protuberant, directed slightly anteroventral as "shark snout"), large [about twice ED], ovoid parotoid glands (moderately large [about same size as ED] and triangular), dorsolateral row of large, nearly round elevated tubercles beginning above insertion of forelimb extending to inguinal region (small, conical tubercles extending from parotoid gland to groin), elevated, elongate glands on forearm, tibia and outer dorsal margin of the foot and hand (glands absent) and hands and feet with relatively short digits (long digits). *Rhinella nesiotes* has a snout rounded in lateral view (snout protuberant, directed slightly anteroventral as "shark snout"), lacks cranial crests (moderately developed), low ovoid parotoid glands (moderately large and triangular), lacks dorsolateral row of tubercles (present) and hands and feet with relatively short digits (long digits). *Rhinella manu* has a snout pointed in lateral view (snout protuberant, directed slightly anteroventral as "shark snout"), large [about twice ED], oblong parotoid glands to the point of being nearly spherical (moderately large [about same size as ED] and triangular) and inconspicuous cranial crests (moderately developed). *Rhinella yanachaga* is most similar to *R. lilyrodriguezae* sp. n. from cloud forests of central Peru, both have cranial crests, tympanic membrane distinct, moderately large [about same size as ED] parotoid glands, dorsolateral rows of small, conical tubercles extending from parotoid gland to groin, fingers and toes relatively long and long, slender extremities. Nevertheless, *R. yanachaga* differs from

R. lilyrodriguezae sp. n. by having a snout slightly protruding in lateral view (snout protuberant, directed slightly anteroventral as "shark snout"), well developed webbing on hands and feet (hands basally webbed, and feet moderately webbed), dorsal skin smooth without keratin-tipped tubercles in females (dorsum smooth with scattered conical tubercles in females) and dorsal coloration in life is dark brown with small, irregular, green spots and markings (dorsum light brown to greenish brown with irregular brown, dark brown or black markings).

Description of the holotype. Gravid female; body robust; SVL 58.3 mm; head triangular in dorsal view; head wider than long (HW 1.12 times HL), head width 30% of SVL; head length 27% of SVL; head narrower than body; snout acuminate, rounded terminally in dorsal view; not bulbous at tip; distance from the nostril to the tip of the snout (3.2 mm) is noticeably less than the distance from the nostril to the eye (5.8 mm), constituting 20% of head length; snout long, protuberant, directed slightly anteroventral as "shark snout" in profile (Fig. 3); snout with a ventral keel; canthus rostralis angular, rounded in lateral view; loreal region concave; nostrils small, rounded, not protruding, directed laterally, beyond anterior margin of lower jaw; internarial area concave; eye diameter equal to half the interorbital distance (ED/IOD = 0.5), ED noticeably shorter than E-D; canthal ridges angular evident; cephalic crests moderately developed; pre-, supra-, postorbital crests distinct, continuous; occipital crest absent; supratympanic crest evident, expanded laterally; pretympanic crests well defined; tympanic annulus weakly defined, superficial tympanic membrane present, not in contact with parotoid glands or postorbital crests; tympanum diameter smaller than eye diameter; parotoid glands moderately large (about same size as ED), roughly triangular in outline; upper eyelid covered with many, low, keratin-tipped tubercles; dorsal and lateral surfaces of head bearing many warts; forearms long, slender; forearm length 26% of SVL; dorsal surface of forelimbs spiculate, bearing densely scattered subconical tubercles; hand length 28% of SVL; hands with long fingers; relative lengths of fingers I < II < IV < III; finger tips rounded; fingers basally webbed, extended between fingers II–IV; Finger IV bears well-defined lateral fringes (Fig. 4A); palmar tubercle prominent, round, larger than oval thenar tubercle, about one half size of the palmar tubercle; subarticular tubercles diffuse, low, round to ovoid; supernumerary tubercles low, poorly developed, indistinct; hindlimbs long, slim; tibia length 40% of SVL; tibia longer than foot; dorsal surface of hindlimbs spiculate with subconical tubercles; foot length 39% of SVL; toes long; relative lengths of toes I < II < III < V < IV; toes tips rounded; toes moderately webbed, with the following formula: I $1–2^{-}$ II $1^{-}–2$ III $1–3^{+}$ IV $3^{+}–2$ V; free portions of all toes bear well-defined lateral fringes (Fig. 4B); tarsal fold absent; inner metatarsal tubercle large, slightly elliptical, weakly protuberant; outer metatarsal tubercle round, smaller than inner metatarsal tubercle, half the size of inner metatarsal tubercle; subarticular tubercles diffuse, low, round to ovoid; supernumerary tubercles indistinct, skin on dorsal surface of the body with numerous small, round, elevated tubercles, bearing single keratinized tip; flanks with lower density of tubercles than dorsum; dorsolateral row of small, conical tubercles extending from parotoid gland to groin, not forming a distinct dorsolateral fold; skin of venter and throat, chest and venter granular; cloacal

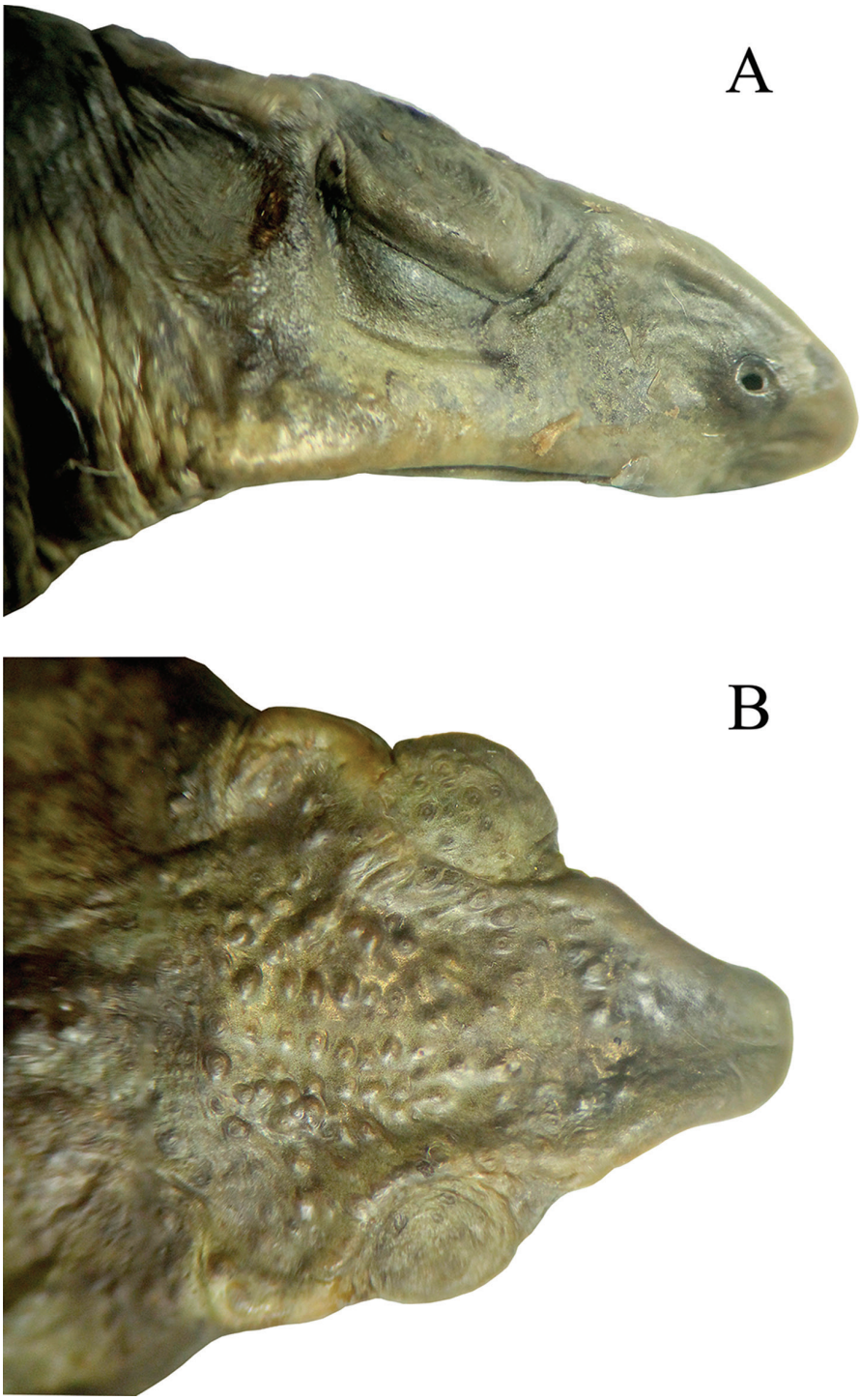

Figure 3. Holotype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32204, head length = 15.9 mm), **A** lateral, and **B** dorsal views of head. Photos by J. C. Cusi.

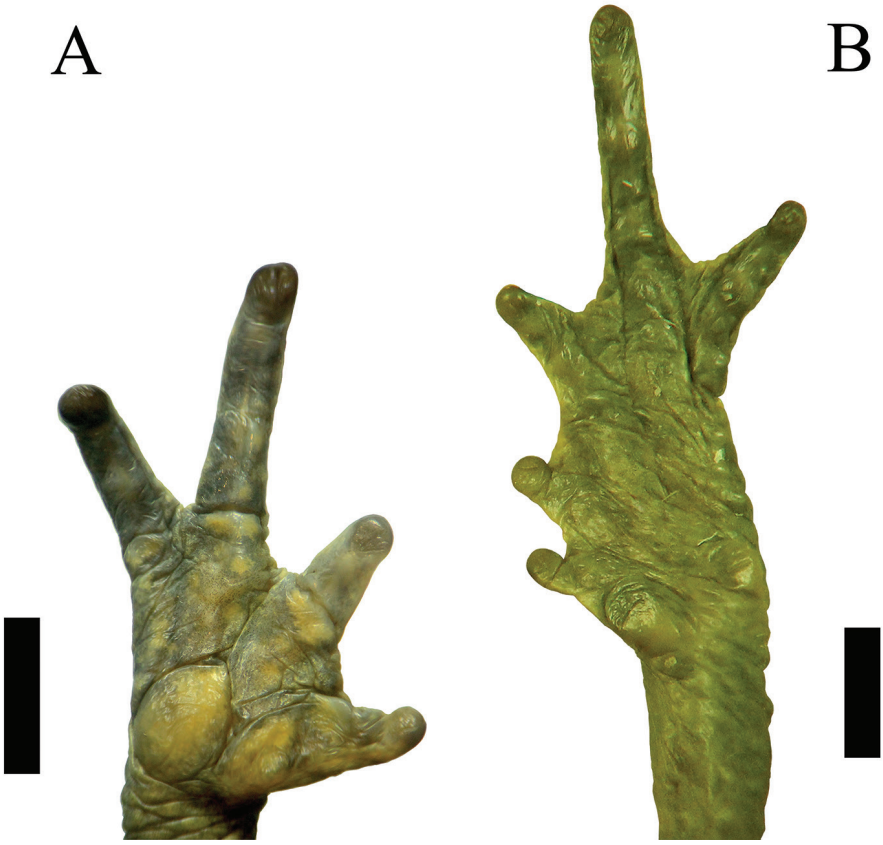

Figure 4. Holotype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32204), **A** palmar, and **B** plantar views of right hand and foot. Scale bar 5 mm. Photos by Juan C. Cusi.

opening directed posteriorly at the mid-level of the thighs); tongue narrow, about 2.5 times as long as wide, not notched posteriorly, posterior one half free; choanae small, ovoid, widely separated and partially concealed by palatal shelf of maxilla.

Measurements (in mm) of the holotype. SVL: 58.3; HW: 17.8; HL: 15.9; ED: 4.4; IOD: 9.3; EW: 3.9; EL: 6.4; IND: 4.3; E–N: 5.8; NSD: 3.2; SL: 9.1; FL: 15.4; HNDL: 16.3; FEML: 23.7; TL: 23.4; FOOTL: 22.6.

Coloration of the holotype in alcohol (Fig. 5). General dorsal coloration light brown; dorsum and hind limbs with small, irregular, dark brown spots and markings; flanks cream, with a discontinuous, well defined, broad, black ventrolateral band beginning behind tympanum and extending to inguinal region; dark grey transverse bars on shanks; tympanum brown; upper lip cream without bars or spots; dorsolateral row of tubercles reddish brown, sharply contrasting with the black discontinuous ventrolateral band; throat, chest and venter gray with minute light cream spots; ventral surfaces of thighs gray with minute dark grey spots; ventral surfaces of hands and feet dark gray; subarticular and supernumerary tubercles cream on hands.

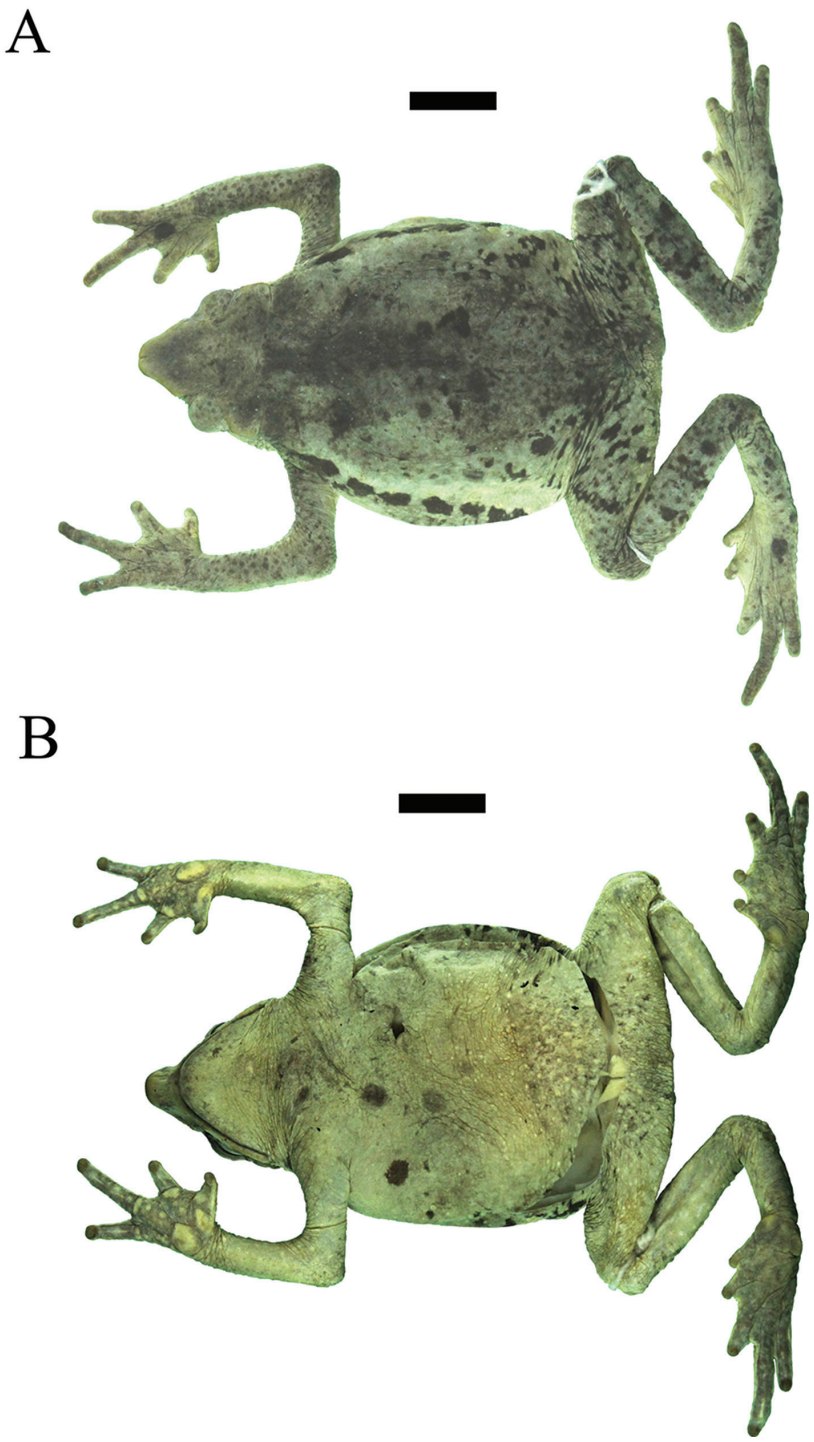

Figure 5. Holotype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32204) in alcohol, **A** dorsal, and **B** ventral views. Scale bar 10 mm. Photos by J. C. Cusi.

Coloration of holotype in life (Fig. 6). Diurnal coloration of dorsum and flanks dark brown; flanks with irregular, dark green dorsolateral blotches extending from behind the parotoid glands to sacral region; dorsolateral row of tubercles light brown; throat dark gray; chest and belly grey with minute light cream spots extending to the thighs; lower side of the belly cream yellow; iris silvery greenish with irregular black mottling.

Variation (Figs 7–9). Considerable variation between nocturnal and diurnal coloration was observed. The nocturnal coloration of an adult female (MUSM 32201, Fig. 7 A, B) was described as follows: dorsum light brown dorsally; whitish grey middorsal stripe extending from tip of the snout to cloaca; light cream parotoid glands; broad, whitish grey dorsolateral stripe on each side of flanks extending from behind the eyelids to groin; flanks with continuous, broad, black ventrolateral band extending from tympanic posterior region to groin; tip of the snout, eyes, eyelids, crown of head and tympanum light brown; upper lip, angle of the jaws and ventrolateral region of the flanks is whitish grey; dorsolateral row of tubercles reddish brown just above the black ventrolateral band; forelimbs and hands are brown, dorsum of the hands with whitish grey blotches in direction to the fingers; hindlimbs brown with transversal dark brown bars. The diurnal coloration of the same specimen (Fig. 7C, D): dorsum and flanks dark brown; gray middorsal stripe from tip of the snout to cloaca; parotoid glands cream brown; venter brownish grey marbled with cream; throat darker brown. An adult female (MUSM 32205; Fig. 8) lacked a middorsal stripe and had flanks with irregular dark grey spots at night. During the day, the same specimen was characterized by a dark green dorsolateral stripe on each side of body extending from parotoid gland to groin; venter brownish grey marbled with cream; irregular dark grey spots on thighs, lateral and lower side of the belly; white blotches on middle area of the belly. Two females (MUSM 32206, 32201) were of similar coloration as MUSM 32205.

The remaining paratypes show some variation in nocturnal color pattern. The overall dorsal coloration of the juveniles (MUSM 32211, 32213) is light grey with darker irregular markings forming a "dead-leaf pattern" from between eyes to cloacal region. Cranial crests are more prominent in adults than in juveniles. All specimens, except the holotype, have tip of snout acuminate in dorsal view. Radiographs show that all specimens have eight presacral vertebrae and a sacrococcygeal articulation (Fig. 9). For variation in measurements see Table 2.

Etymology. The specific epithet *lilyrodriguezae* is a noun in the genitive case and a patronym for Dr. Lily Rodriguez, for her contributions to the knowledge of the Peruvian amphibians and her initiatives that have promoted the creation of numerous natural protected areas in Peru, such as the Cordillera Azul National Park.

Distribution, ecology and conservation status. *Rhinella lilyrodriguezae* sp. n. is only known from the Shapaja sector within the CAZNP in northern Peru, at elevations between 1245 and 1280 m a.s.l. (Fig. 1). It was encountered in montane forest during the dry season. The type locality was accessed by a hike of 7 hours across a small trail from the Misterioso River (natural boundary between natural protected area and a forest concession dedicated to wood extraction). The species has nocturnal and semiarboreal mode of life (all individuals were found at night between 20:33 and 22:49

Figure 6. Holotype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32204, SVL = 58.3 mm) in life. **A** Latero-dorsal and **B** ventral views of the coloration during the day. Photos by K. Tasker.

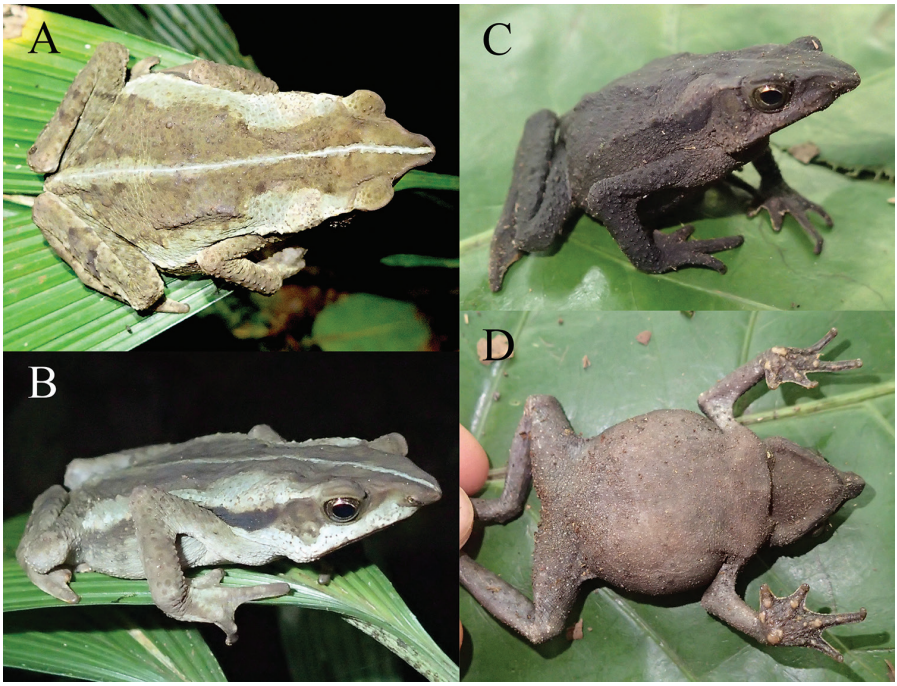

Figure 7. Paratype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32201, SVL = 57.5 mm) in life. **A** Dorsal and **B** laterodorsal views of the coloration at night **C** Laterodorsal and **D** ventral views of the coloration during the day. Photos by K. Tasker.

Table 2. Morphometric measurements in mm of the holotype and paratypes of *Rhinella lilyrodriguezae* sp. n. See text for abbreviations.

Measurements	Holotype	Paratypes				
	MUSM 32204	MUSM 32201	MUSM 32206	MUSM 32205	MUSM 32211	MUSM 32213
Sex	Female	Female	Female	Female	Juvenile	Juvenile
SVL	58.3	57.5	55.5	47.1	34.9	27.8
HW	17.8	18.0	17.2	11.4	11.6	9.4
HL	15.9	15.1	14.1	8.9	9.0	9.2
ED	4.4	4.3	4.3	4.2	3.7	3.2
IOD	9.3	8.8	8.8	8.4	5.6	4.9
EW	3.9	3.9	3.9	3.7	3.4	2.8
EL	6.4	6.8	6.0	6.2	3.9	3.2
IND	4.3	4.4	4.3	4.1	2.5	2.1
E-N	5.8	5.7	5.6	5.5	3.4	3.9
NSD	3.2	3.2	3.0	2.9	1.7	1.3
SL	9.1	9.0	8.7	8.1	5.8	4.9
FL	15.4	15.2	14.1	13.5	9.1	7.2
HNDL	16.3	16.4	15.1	13.7	8.7	6.5
FEML	23.7	23.5	22.0	20.3	13.2	11.7
TL	23.4	23.2	21.4	19.9	13.1	11.3
FOOTL	22.6	23.3	22.0	20.9	13.5	10.8

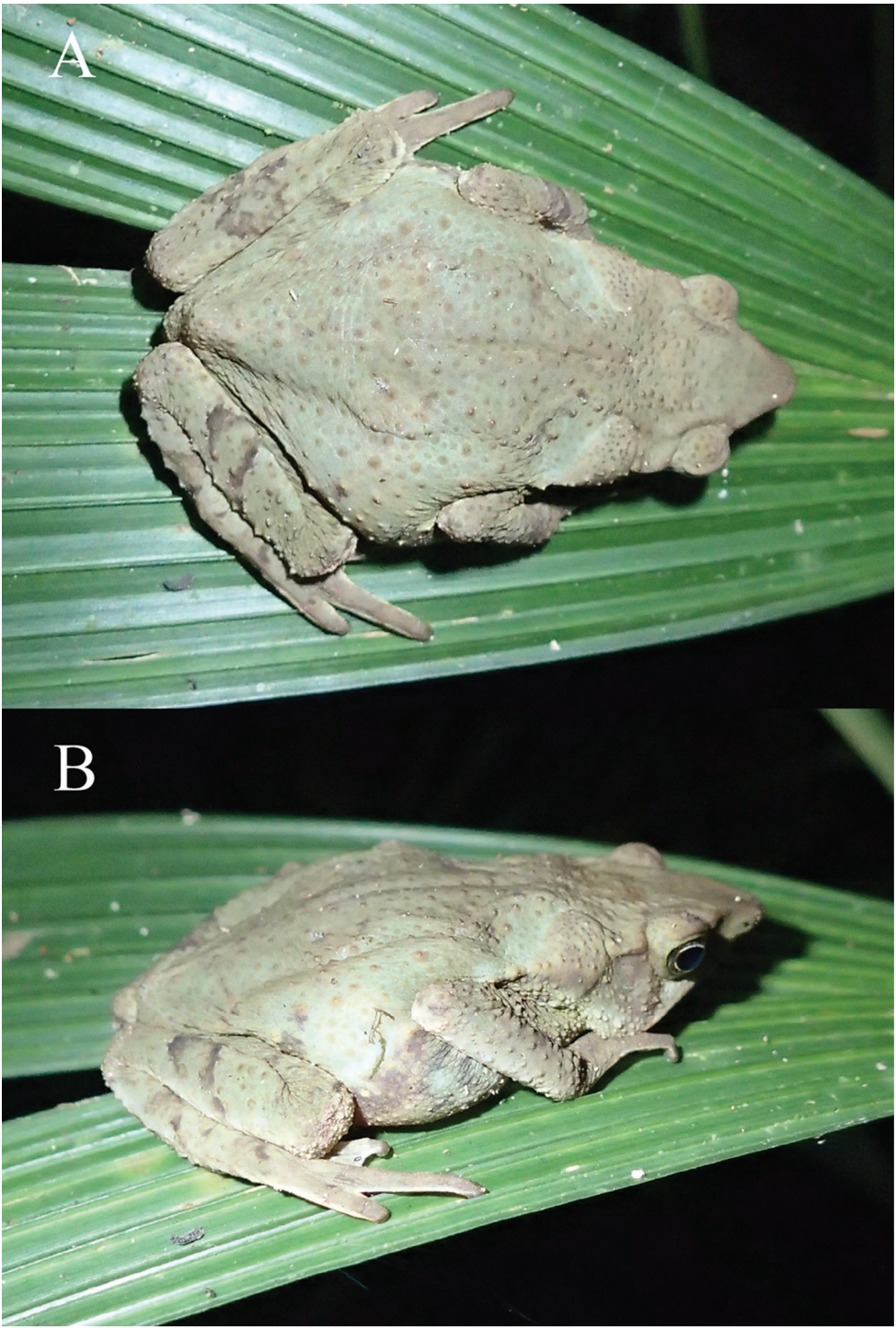

Figure 8. Paratype of *Rhinella lilyrodriguezae* sp. n. (MUSM 32205, SVL = 47.1 mm) in life. **A** Dorsal and **B** laterodorsal views of the coloration during the day. Photos by K. Tasker.

Figure 9. X-ray of the paratye *Rhinella lilyrodriguezae* sp. n. MUSM 32206. Photos by J. C. Cusi.

on leaves of bushes between 10 and 100 cm above the ground, along a small creek). A negative impact of logging, soil removal and noise pollution was observed around the localities of the new species. Subsistence game hunting and exaggerated fishing by local population are other factors threatening the local biodiversity.

One gravid female (MUSM 32204, SVL 58.3 mm, holotype) contained 185 ovarian eggs (left ovary: 95; right ovary: 90) with an average diameter of 2.8 ± 0.2 mm (3.2–2.7 mm, n = 20), which are pale cream yellow in preservative. The presence of numerous, large, pigmented eggs and association of the individuals with water bodies suggest endotrophic larvae (e.g., direct development or nonfeeding tadpoles that develop in water or moist soil; Peloso et al. 2014), as can be expected

in *R. manu*, *R. paraguas* and *R. tacana* (Grant and Bolívar-G. 2014, Catenazzi pers. comm.) The call of *Rhinella lilyrodriguezae* was not recorded. Other anuran species that occur in the area of the type locality include *Hyloscirtus* cf. *phyllognathus*, *Pristimantis peruvianus*, *P. ventrimarmoratus*, *Rulyrana* cf. *flavopunctata*, and *Osteocephalus mimeticus* (juveniles). We classify *Rhinella lilyrodriguezae* sp. n. as "Data Deficient" according to the IUCN red list criteria (IUCN 2016) based on the limited information on its geographic range.

Discussion

An early comprehensive revision of the former genus *Rhamphophryne* (= *Rhinella acrolopha* group) based on external morphology and osteology hypothesized multiple evolutionary histories and complex morphological variation within the genus (Trueb 1971). Knowledge of the phylogenetic relationships among most of the species of the *R. acrolopha* group remains largely unknown mainly due to few collected specimens (*R. truebae*, n = 1; *R. lindae*, n = 2; *R. nicefori* n = 5; *R. tenrec*, n = 11; Trueb 1971, Rivero and Castaño 1990, Lynch and Renjifo 1990), absence of available genetic material, and the fact that several species seem to be seriously threatened (e.g., *R. rostrata* is possibly extinct in the wild, Bolívar and Lynch 2004, Stuart et al. 2008).

Our 16S rRNA analysis supports the monophyly of the *Rhinella festae* clade of Moravec et al. (2014) and confirms the inclusion of species previously assigned to this group. Furthermore, our analysis adds *R. lilyrodriguezae* sp. n. and *Rhinella* sp. C to the *R. festae* group. Although we did not include *R. manu* in our tree (due to the unavailability of 16S rRNA sequence data), its incorporation into the *R. festae* group is highly likely; as already showed by Chaparro et al. (2007) in one clade comprised by [[*R. festae* + *R. chavin*] + [*R. manu* + *R. nesiotes*]] using combined mitochondrial and nuclear DNA data. On the other hand, the species *R. rostrata* and *R. nesiotes* are tentatively removed from the *festae* group (sensu Moravec et al. 2014) due to absence of available genetic material that confirms their inclusion into this group. The specimen UTA 53310 "*R. nesiotes*" from Serranía de Bella Vista, Bolivia used by Pramuk (2006), Chaparro et al. (2007), Pramuk et al. (2008) and Moravec et al. (2014), is now identified as *Rhinella* cf. *nesiotes* to occur at about 1000 km south of the type locality of *Rhinella nesiotes*, which inhabits in an isolated mountain ridge between the Pachitea and Ucayali rivers, Central Peru. This identification is justified on the basis of geographic distance, the scarce knowledge of the distribution range of the species and the occurrence of species morphologically similar in the Bolivian area as *R. tacana*, possibly confused with it (Fig. 1). In absence of molecular data, we cannot assign *Rhinella nesiotes*, known from four specimens collected at Serranía El Sira in Peru, to any recognized groups. Furthermore, a morphological examination of Bolivian material and comparison with Peruvian specimens of *R. nesiotes* is required. Thus, according to our current knowledge, the *Rhinella festae* group contains the following eight species: *R. chavin*, *R. festae*, *R. lilyrodriguezae* sp. n., *R. macrorhina*,

R. manu, *R. yanachaga*, *R.* cf. *nesiotes* and *Rhinella* sp. C. The recently described *R. tacana* extended from Serranía Eslabon, northern Bolivia to Urubamba River Basin, southern Peru (Padial et al. 2006, Chávez et al. 2013) is morphologically most similar to *R. manu*, and is expected to be part of the *festae* group. The *Rhinella festae* group represents a morphologically and genetically diverse group of toads broadly distributed in the region of eastern slopes of the Cordillera Occidental from Colombia, upper Amazon Basin and lower Andean slopes of Ecuador and eastern slopes of the Cordillera Oriental from Peru and Bolivia. Our phylogenetic analysis supports the unique position of *R. lilyrodriguezae* sp. n., which is distributed in montane forests of the Cordillera Oriental, San Martín, northern Peru. *Rhinella lilyrodriguezae* sp. n. is a semiarboreal species because it was observed climbing on leaves and branches (approximately 1 m above ground) close to lotic aquatic bodies of medium-size and moderate water flow, and dwelling on the ground during the day. All species of the *R. festae* and *R. acrolopha* groups display diverse types of habitat use. Some species are semiarboreal (*R. chavin*, *R. lilyrodriguezae* sp. n., *R. nesiotes*, *R. paraguas*) or arboreal (*R. manu*, *R. yanachaga*), others are terrestrial (*R. festae*, *R. macrorhina*, *R. rostrata*). Most members of both groups inhabit rainforests and montane forests at elevations between 1200 m and 3600 m, except for *R. tenrec* occurring in the Chocó lowlands, and *R. festae* inhabiting the Amazonian lowlands.

Finally, the monophyly of the *Rhinella festae* clade as proposed by Moravec et al. (2014) is further supported by our present data, and species composition is modified by inclusion of additional taxa previously assigned to the *R. acrolopha* group (i.e. *R. macrorhina* and *Rhinella* sp. C), as supported by high morphological similarity and molecular affinity. However, additional molecular data are required for any conclusive observations. Our study constitutes a starting point for understanding the diversification within this radiation. Additional morphological and molecular evidence from a larger number of taxa is needed to reach a better knowledge of the evolution, systematics and biogeography of this interesting South American lineage of bufonid anurans.

Acknowledegments

We are grateful to A. Catenazzi and anonymous reviewers for their comments that improved our manuscript J. C. Cusi is sincerely grateful to K. Tasker for funding the fieldwork and for the opportunity to participate in the research within the natural protected area. We thank Tatiana Pequeño and Jorge Martinez at CIMA (Investigación y Manejo de Areas Naturales: Cordillera Azul) for providing access, permits and information on localities in the Cordillera Azul National Park. We are grateful to J. Córdova for granting access at the Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Lima, Peru (MUSM). Radiographs were provided by S. Zevallos at ECODVet Veterinarian (http://www.ecodvet.com). The work of JM and VG was financially supported by the Ministry of Culture of the Czech Republic (DKRVO 2014/14, 2015/15, 2016/15 and 2017/15, National Museum Prague, 00023272).

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Appendix

Specimens examined

Rhinella chavin (9 specimens). PERU: HUÁNUCO, Pachitea, Chaglla, Palma Pampa, 20 km southeast of Chaglla, 3010 m: MUSM 20028 (holotype), MUSM 18439–18446.

Rhinella manu (8 specimens). PERU: CUSCO: Paucartambo, Kosñipata: MUSM 21129, 27931, 30385; Rocotal: MUSM 26282, 27932; Mirador Tres Cruces: MUSM 27929, 27933; San Pedro: MUSM 27930.

Rhinella nesiotes (4 specimens). PERU: HUANUCO, Puerto Inca, Yuyapichis, Comunidad El Sira: MUSM 29386, 29387, 29390, 29404.

Rhinella yanachaga (4 specimens). PERU: PASCO: Oxapampa, Oxapampa, Yanachaga-Chemillén National Park (PNYCH), W side of the Cordillera Yanachaga near Río San Alberto, 2600 m: MUSM 19994 (holotype); village San Alberto: MUSM 33309-33310; Buffer zone of the PNYCH: MUSM 33520.

ZooKeys 673: 49–104 (2017)
doi: 10.3897/zookeys.673.12422
http://zookeys.pensoft.net

CHECKLIST

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A checklist of land snails from the west coast islands of Sabah, Borneo (Mollusca, Gastropoda)

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Academic editor: *M. Haase* | Received 25 February 2017 | Accepted 25 April 2017 | Published 12 May 2017

http://zoobank.org/567A576D-1D15-4C27-A4D6-AFBA5C7C796B

Citation: Phung C-C, Yu FTY, Liew T-S (2017) A checklist of land snails from the west coast islands of Sabah, Borneo (Mollusca, Gastropoda). ZooKeys 673: 49–104. https://doi.org/10.3897/zookeys.673.12422

Abstract

Sabah, situated in one of the world's biodiversity hotspots, has the largest number of islands in Malaysia with more than 500 of various sizes and degrees of isolation. However, information on the islands' biodiversity is limited. This study provides an up-to-date checklist of land snail species found on 24 west coast islands in Sabah. A total of 67 species (nearly 20% of the total number of land snail species in the state) representing 37 genera and 19 families is enumerated based on systematic field surveys of 133 sampling plots, BORNEENSIS database records and species checklists published between 2000 and 2016. The number of species on the islands ranges from four to 29. Labuan Island has the highest number of species (29), followed by Tiga Island (25), Mantanani Besar Island (24) and Gaya Island (23). However, the populations of some land snail species may have declined as several previously recorded species on the islands were not found in a recent systematic field sampling. This checklist is provided as a baseline inventory for future island land snail studies and to better inform biodiversity conservation plans of marine parks and other islands on the Sabah west coast.

Keywords

Endemic species, island biodiversity, Labuan, Malaysia, marine parks, Sundaland

Introduction

The island of Borneo is recognised as one of the mega biodiversity hotspots in the world (Myers et al. 2000). Sabah, a state in Malaysia and formerly known as British North Borneo, is situated on the northwestern part of the island. Documentation of the biodiversity in Sabah began in the 19th century with explorations by European naturalists in this region. One of the first comprehensive checklists of land snails was published by Issel (1874) who documented an estimated 100 species from Borneo. In the subsequent decades, explorations and collections of land snails in Sabah were conducted mainly by British naturalists such as A. Everett and H. Cuming. Their explorations resulted in several published reports and descriptions of a number of new species (Pfeiffer 1852, 1863; Godwin-Austen 1891; Smith 1894). In the 20th century, information on Sabah land snails was mainly contributed by Jaap J. Vermeulen through taxonomic revisions of several land snail genera (Vermeulen 1991, 1993, 1994, 1996, 1999). In the 21st century, knowledge on Sabah land snails expanded greatly with the publication of detailed taxonomic revisions of certain land snail groups (Liew et al. 2009; Vermeulen et al. 2015), inventories of Borneo land snails (Schilthuizen and Vermeulen 2003; Schilthuizen et al. 2011; Uchida 2013) and ecological studies (Schilthuizen and Rutjes 2001; Schilthuizen et al. 2002, 2003a, 2003b, 2005; Liew et al. 2008, 2010). To date, the number of land snail species documented in Sabah is approximately 350.

Many of these studies were conducted in ecosystems on the Sabah mainland, covering mountains (Liew et al. 2010), tropical lowland rainforests (Schilthuizen and Rutjes 2001; Schilthuizen et al. 2002; Liew et al. 2008; Uchida et al. 2013) and limestone outcrops (Schilthuizen et al. 2003a, 2003b, 2005; Schilthuizen and Vermeulen 2000). To date, there have been very few systematic surveys on the land snail diversity in the island ecosystem. In the 19th century, several new species from Labuan Island, Tiga Island and Usukan Island on the west coast of Sabah were described (Pfeiffer 1863; Adams 1865; Issel 1874; Godwin-Austen 1889; Godwin-Austen 1891; Fulton 1896). It was only a century later that land snail biodiversity studies were conducted on islands such as the Mantanani Island group on the west coast, Balambangan Island and Banggi Island on the north coast, and Bohey Dulang Island, Tetagan Island, Bod Gaya Island, Sebangkat Island, Maiga Island, Mantabuan Island, Pulau Sibuan and Selakan Island on the east coast (Liew et al. 2008; Schilthuizen et al. 2011, 2013).

Despite these efforts, knowledge on land snail biodiversity on the islands remains inadequate as previous studies covered less than 3% of the estimated 500 islands in Sabah (JUPEM 2005). Of these number, 45 islands located on the west coast of Sabah should be prioritised for a land snail survey since (1) they are close to major cities in Sabah and therefore subjected to more intensive tourism activities and economic development, (2) 11 of these 45 have been gazetted as marine parks, and basic biodiversity knowledge is thus vital for park management, and (3) there is already a land snail species at risk of extinction -*Plectostoma decrespignyi*- from Labuan Island, and this indicates that island land snails are very vulnerable to human activities (Schilthuizen and Vermeulen 2004b).

In view of these, a systematic sampling for land snails on 24 west coast islands was conducted and the data compiled together with land snail inventory data from literature and previously collected specimens deposited in the BORNEENSIS collection at Universiti Malaysia Sabah. Although only about half of the total number of islands on this part of Sabah were involved, the selection included the entire geographical extent of islands off the west coast of Sabah (see Figure 1). The aim of this paper is to provide a comprehensive and updated checklist of land snails by consolidating data from literature and database, including photographs of all species, in order to present a baseline species inventory for future island land snail studies. Interpretation of species diversity pattern in term of island biogeography will be discussed in upcoming analytical papers.

Materials and methods

Site of study

The Malay language term for 'island'- *pulau* - will henceforth be used as many of the formally gazetted island names are in the local language. Land snails from 24 islands located off the Sabah west coast were investigated (see Figure 1). The sizes of these islands range from 0.005 km² (Pulau Peduk) to 87 km² (Pulau Labuan) (see Table 1). The distance between these islands and the mainland ranges from 0.25 km to 60 km. Eleven of the selected islands are in the three gazetted parks, namely Tunku Abdul Rahman Park, Pulau Tiga Park and Labuan Marine Park.

Land snail sampling and sorting

Field work was carried out between December 2015 and November 2016 with standard sampling conducted within a 20m × 20m plot (Schilthuizen et al. 2013). The number of plots varied from two to 14 depending on island size. Direct search for living land snails in their habitats such as vegetation, decaying logs and leaf litter on forest floor at each plot was carried out by two person-hours. Land snails encountered opportunistically along these trails were also collected. In addition, 5 liters of leaf litter and top soil were collected at each plot. The soil samples were then oven-dried for three days and subjected to a series of sieves. The empty shells were subsequently sorted out from the soil samples under a dissecting microscope.

Land snail identification and accession

All the specimens were preserved and identified to species level based on shell characteristics by referring to the manuscript of *Field Guide to Land Snails of Sabah* (Ver-

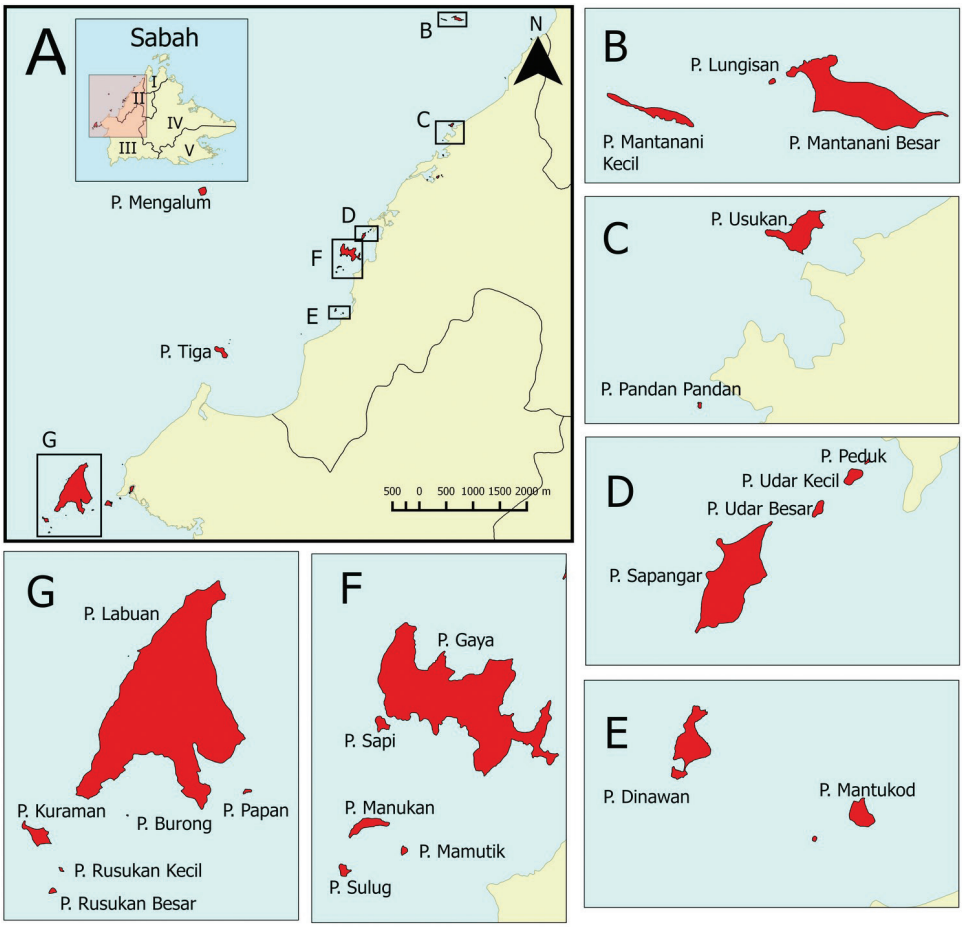

Figure 1. The 24 islands located off the Sabah west coast sampled for this study. **A** Sabah overview map with five divisions shown, namely (I) Kudat division, (II) West Coast division, (III) Interior division, (IV) Sandakan division, (V) Tawau division; Pulau Mengalum and Pulau Tiga shown in enlarged Sabah west coast **B** Mantanani island group **C** Pulau Usukan and Pulau Pandan Pandan **D** Sapangar Bay island group **E** Pulau Dinawan and Pulau Mantukod **F** Tunku Abdul Rahman Park **G** Pulau Labuan, Pulau Papan, Pulau Burong and Labuan Marine Park, which includes Pulau Kuraman, Pulau Rusukan Kecil and Pulau Rusukan Besar.

meulen et al. in prep), Vermeulen et al. (2015), literature with original species descriptions, and the BORNEENSIS collection at the Institute for Tropical Biology and Conservation at Universiti Malaysia Sabah. After identification, specimens were then catalogued in the database, labelled and stored in the BORNEENSIS collection.

Species checklist compilation

This checklist enumerates the land snail fauna sampled and recorded from the west coast islands between 2000 and 2016 based on literature, BORNEENSIS collections

Table 1. Coordinates, areas (km²), numbers of standard plots, and numbers of existing records from BORNEENSIS for the 24 sampled islands.

Pulau (*Island*)	Latitude (°)	Longitude (°)	Area (km²)	Number of standard plots	Number of existing records from BORNEENSIS
1. Pulau Burong	5.2376	115.1910	0.0108	1	7
2. Pulau Dinawan	5.8471	115.9906	0.2603	5	51
3. Pulau Gaya	6.0175	116.0315	14.5061	15	176
4. Pulau Kuraman	5.2245	115.1315	1.5834	6	108
5. Pulau Labuan	5.3110	115.2191	90.6642	11	147
6. Pulau Lungisan	6.7152	116.3359	0.0132	6	11
7. Pulau Mamutik	5.9665	116.0136	0.0563	3	46
8. Pulau Mantanani Besar	6.7119	116.3529	2.0554	9	76
9. Pulau Mantanani Kecil	6.7092	116.3129	0.2738	7	27
10. Pulau Mantukod	5.8378	116.0129	0.0965	3	13
11. Pulau Manukan	5.9752	116.0012	0.4196	8	52
12. Pulau Mengalum	6.2001	115.5967	5.1640	7	112
13. Pulau Pandan Pandan	6.3508	116.3087	0.0144	2	7
14. Pulau Papan	5.2537	115.2706	0.1291	4	43
15. Pulau Peduk	6.0873	116.0963	0.0049	2	11
16. Pulau Rusukan Besar	5.1873	115.1413	0.1529	4	78
17. Pulau Rusukan Kecil	5.2015	115.1470	0.0626	3	39
18. Pulau Sapi	6.0095	116.0060	0.1856	2	18
19. Pulau Sapangar	6.0675	116.0738	1.3225	7	76
20. Pulau Sulug	5.9598	115.9932	0.1250	3	25
21. Pulau Tiga	5.7234	115.6522	7.1638	11	257
22. Pulau Udar Besar	6.0794	116.0881	0.0386	3	18
23. Pulau Udar Kecil	6.0848	116.0939	0.0642	3	21
24. Pulau Usukan	6.3963	116.3349	0.8787	8	188

and recent systematic samplings (Table 1). Taxonomy classification of the species in this checklist followed the system used in the recent systematic paper on Sabah land snails (Vermeulen et al. 2015). The checklist comprised information about the type locality of the species, examined materials with accession number, species distribution in Sabah and general remarks for the species. For morphospecies that could not be assigned to an existing taxonomic name, a provisional species name was given (for example, sp. 1). Photographic images comprising four views of the representative specimen (i.e. apertural, lateral, dorsal and ventral views) for each species were presented.

Type localities

The type locality of each species was written in the format of "country: state: district–location" if their exact location were known. For those without the exact location specified, a general description of the location (e.g. "Borneo") was mentioned. "Not stated" was given to species with no locality indicated in their original description. For provisional species name, type locality was indicated as "not applicable".

Examined materials

For each species, the accession number of referenced specimens from the west coast islands was listed out. The abbreviation "BOR/MOL" indicated specimens from the BORNEENSIS collection while "V" referred to the private collection of Jaap J. Vermeulen of Leiden in the Netherlands. "Not seen" was mentioned for materials based solely on literature that could not be examined.

Distribution in Sabah

The distribution of each species on the Sabah islands and mainland was compiled from the BORNEENSIS collection which currently houses more than 12,000 records. The distribution of each species was indicated in the format of "*Island*: [West]; [North]; [East]. *Mainland*:" Islands in Sabah were grouped into three categories: [West] for islands located within the West Coast Division and Interior Division; [North] for those located within Kudat Division, and [East] for ones situated within the Sandakan Division and Tawau Division. The distribution of the species on the mainland was according to five divisions: West Coast Division, Kudat Division, Sandakan Division, Tawau Division and Interior Division (Figure 1A).

Remarks

Additional information such as species status as either endemic or introduced to Sabah or Borneo was stated for species well supported by literature. Conversely, those with no information from the literature were not mentioned. Other relevant notes for the species were also provided.

Results and discussion

The checklist reported a total of 67 land snail species belonging to 37 genera and 19 families, of which 18 species were Caenogastropoda, four Neritimorpha and 45 Pulmonata (See supplementary file 1). The family Ariophantidae was the most species-rich family found on west coast islands, with eleven species (17.6%) recorded. This was followed by the family Cyclophoridae (nine species, 13.2%) and family Euconulidae (six species, 8.8%). Microsnails (size less than 5mm) accounted for about 47% of the total number of species. Among the 67 species, 19 were endemic, and six were introduced species. Species that were widespread across west coast islands included *Kaliella scandens* 20 islands, *Pythia chrysostoma* 20 islands, *Leptopoma pellucidum* 18 islands, *Paropeas achatinaceum* 18 islands, *Allopeas gracile* 18 islands, and *Ptychopatula orcula* 18 islands. Among these species, *Leptopoma pellucidum* was the only Caenogastropod found widespread across the west coast islands.

Surprisingly, this study revealed a high number of species that were unique to one particular island. 23 land snail species were found only on one of the 24 west coast islands included in this study. These were *Elasmias globulosum*, *Acmella striata*, *Japonia balabacensis*, *Platyraphe bongaoensis*, and *Plectostoma jucundum* (Pulau Mantanani Besar); *Charopa* sp. "lissobasis", *Everettia* sp. , *Microcystina* sp. 2, and *Kaliella barrakporensis* (Pulau Labuan); *Ganesella tigaensis*, *Pterocyclos tenuilabiatus*, *Georissa scalinella* and *Georissa saulae* (Pulau Tiga); *Ditropopsis imadatei*, *Ditropopsis koperbergi* and *Pterocyclos amabilis* (Pulau Gaya); *Acmella polita* and *Arinia* sp. (Pulau Rusukan Besar); *Diplommatina recta* and *Videna metcalfei* (Pulau Mengalum); *Charopa* sp. "jugalis" (Pulau Sapangar); *Microcystina* sp. 1 (Pulau Peduk); and *Truncatella marginata* (Pulau Burong). From all the listed species above, nine were island endemics as these species had not been reported from mainland Sabah previously (i.e. *Platyraphe bongaoensis*, *Japonia balabacensis*, *Everettia* sp., *Microcystina* sp. 1, *Microcystina* sp. 2, *Ganesella tigaensis*, *Elasmias globulosum*, *Diplommatina recta*, and *Plectostoma jucundum*). Most of these species were recorded from Pulau Labuan, Mantanani group, and also from all the gazetted marine parks: Pulau Tiga Marine Park, Tunku Abdul Rahman Park and Labuan Marine Park, indicating that marine parks as vital habitats for unique species of land snails.

Among the 24 west coast islands, Pulau Labuan had the highest species richness (see supplementary file 1) and the highest number of species unique to the island. This could probably be due to its larger size compared to other islands. The second largest island on the west coast, Pulau Gaya, ranked fourth in species richness. Pulau Tiga and Pulau Mantanani Besar also recorded remarkable species richness, with 25 species from Pulau Tiga and 24 from Pulau Mantanani Besar. These two islands differed from other west coast islands in having limestone outcrops (in Pulau Mantanani Besar) and mud volcanoes (in Pulau Tiga), which potentially housed more diverse habitats leading to the existence of more land snail species.

Nevertheless, many species from Pulau Labuan in the 19th century (Pfeiffer 1863; Adams 1865; Godwin-Austen 1891; Fulton 1896) were not found in this study. This included *Dyakia hugonis* (Pfeiffer, 1863), *Pterocyclos labuanensis* (Pfeiffer, 1863), *Geotrochus labuanensis* (Pfeiffer, 1863), *Ganesella subflava* (Godwin-Austen, 1891), *Trachia pudica* (Godwin-Austen, 1891), and *Nanina* (*Xesta*) *decrespignyi* (Higgins, 1868). On the other hand, three species were added to the previous land snail list of the Mantanani Island group by Schilthuizen et al. (2013) – *Elasmias manilense*, *Macrochlamys tersa*, and *Nesopupa moreleti*. However, four other species were not encountered during recent surveys–*Japonia balabacensis*, *Gastrocopta recondita*, *Elasmias globulosum* and *Microcystina microrhynchus*. In addition, four species, including some Borneo-endemic species found in Pulau Tiga during 2000 and 2003 were not encountered again during recent surveys –*Georissa saulae*, *Georissa scalinella*, *Geotrochus conicoides* and *Pterocyclos tenuilabiatus*.

The decline of land snail species (especially endemics) on the west coast islands could be attributed to two reasons. First, the field sampling period coincided partly with El Nino which had caused six months of drought in Sabah between January 2016 and June 2016 and might have negatively influenced sampling effectiveness. Second, forested habitats on many islands have vanished due to rapid urban development and

tourism activities, particularly in Pulau Labuan (Mohamad and Samion 2016). Many of the species from Pulau Labuan were described or recorded from limestone outcrops in the south-eastern part of the island, all of which had since been quarried away for the construction of Labuan Airport in the 1960s. Hence, there was a high possibility that limestone-restricted species from Pulau Labuan could have been extinct in local.

However, six introduced land snail species were encountered across the 24 west coast islands –*Subulina octona*, *Achatina fulica*, *Huttonella bicolor*, *Macrochlamys indica*, *Quantula striata* and *Bradybaena similaris*. A large quantity of *Macrochlamys indica* and *Quantula striata* were found only on Pulau Labuan and Pulau Papan with *Quantula striata* a new record for Sabah land snails. The impact of the invasion by these introduced species on island land snail communities remains unknown. Therefore, future research should focus on the effects of introduced species on native species.

Although only 24 out of the 500 islands in Sabah were included, this study has managed to document nearly 20% of the total land snail species in Sabah. West coast islands are significant as habitats for land snails, particularly for several endemic species. In view of this, islands within the Labuan Marine Park, Pulau Tiga Park, Tunku Abdul Rahman Park, Pulau Labuan and Mantanani Island group should be prioritised for land snail conservation. Particular attention should also be accorded to island endemic species such as *Plectostoma jucundum* (endemic to Pulau Mantanani Besar) and *Ganesella tigaensis* (endemic to Pulau Tiga). Biodiversity conservation plans are therefore advocated not only for marine parks, but also for other west coast islands in Sabah.

Species checklist

Clade: CAENOGASTROPODA Cox
FAMILY ASSIMINEIDAE

***Acmella striata* Vermeulen, Liew & Schilthuizen, 2015**
Figure 2A

Type locality. "Malaysia: Sabah: Kudat–Balambangan Island, South end, Batu Sireh" (Vermeulen et al. 2015)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3726, BOR/MOL 7173.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar; [North] Pulau Balambangan. *Mainland*: Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Acmella polita* Von Moellendorff, 1887**
Figure 2B

Type locality. "Philippine: Luzon–Montalban near Manilla" (Von Moellendorff, 1887)

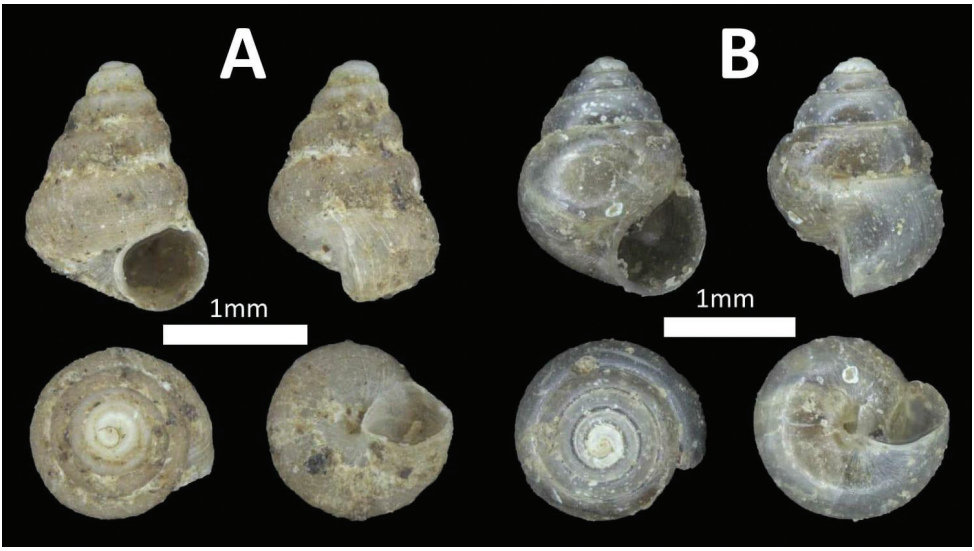

Figure 2. Family Assimineidae. **A** *Acmella striata* (BOR/MOL 7173) **B** *Acmella polita* (BOR/MOL 12243).

Examined materials. *Pulau Rusukan Besar*: BOR/MOL 12237, BOR/MOL 12243.

Distribution in Sabah. *Island*: [West] Pulau Rusukan Besar. *Mainland*: Interior Division, Sandakan Division and Tawau Division.

Remarks. Widespread in Sabah. First record on an offshore island.

FAMILY CYCLOPHORIDAE

***Pterocyclos tenuilabiatus* (Metcalfe, 1851)**
Figure 3A

Type locality. "Borneo" (Metcalfe, 1851)

Examined materials. *Pulau Tiga*: BOR/MOL 105.

Distribution in Sabah. *Island*: [West] Pulau Tiga. *Mainland*: West Coast Division, Interior Division, Sandakan Division and Tawau Division.

Remarks. Endemic to Borneo. The examined sample was collected in 2000 and not found in the current surveys.

***Pterocyclos amabilis* Fulton, 1905**
Figure 3B

Type locality. "N. Borneo" (Fulton, 1905)

Examined materials. *Pulau Gaya*: BOR/MOL 8850, BOR/MOL 11118.

Distribution in Sabah. *Island*: [West] Pulau Gaya. *Mainland*: West Coast Division and Interior Division.

Remarks. Endemic to Sabah.

***Leptopoma pellucidum* (Grateloup, 1840)**
Figure 3C

Type locality. "Philippines: Manilla" (Grateloup, 1839)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 1562, BOR/MOL 1573, BOR/MOL 3723, BOR/MOL 3724, BOR/MOL 6008, BOR/MOL 6009, BOR/MOL 6011, BOR/MOL 6012, BOR/MOL 6013, BOR/MOL 6699, BOR/MOL 6700, BOR/MOL 6701, BOR/MOL 6702, BOR/MOL 6704, BOR/MOL 7187. *Pulau Mantanani Kecil*: BOR/MOL 3727, BOR/MOL 3728, BOR/MOL 3787. *Pulau Mengalum*: BOR/MOL 6064, BOR/MOL 6065, BOR/MOL 6066, BOR/MOL 6162, BOR/MOL 6168, BOR/MOL 6178, BOR/MOL 8733, BOR/MOL 8737, BOR/MOL 8738, *Pulau Tiga*: BOR/MOL 8817, BOR/MOL 9720, BOR/MOL 9722, BOR/MOL 9726, BOR/MOL 9727, BOR/MOL 9728. *Pulau Gaya*: BOR/MOL 6301, BOR/MOL 6303, BOR/MOL 8816, BOR/MOL 8851, BOR/MOL 9444, BOR/MOL 9445, BOR/MOL 9446, BOR/MOL 9447, BOR/MOL 9449, BOR/MOL 9450, BOR/MOL 9451. *Pulau Sapangar*: BOR/MOL 6784, BOR/MOL 6786, BOR/MOL 6791, BOR/MOL 6792, BOR/MOL 6794, BOR/MOL 6796, BOR/MOL 6777, BOR/MOL 6780, BOR/MOL 6782, BOR/MOL 12000, BOR/MOL 12006, BOR/MOL 12013, BOR/MOL 12014, BOR/MOL 12015. *Pulau Udar Besar*: BOR/MOL 6802, BOR/MOL 6803, BOR/MOL 6804. *Pulau Udar Kecil*: BOR/MOL 7151, BOR/MOL 7152, BOR/MOL 7153, BOR/MOL 7154, BOR/MOL 7155, BOR/MOL 7156, BOR/MOL 10379. *Pulau Sapi*: BOR/MOL 6668, BOR/MOL 6669, BOR/MOL 6670, BOR/MOL 7933, BOR/MOL 8523, BOR/MOL 8524. *Pulau Mamutik*: BOR/MOL 6691, BOR/MOL 6693, BOR/MOL 6694, BOR/MOL 6695, BOR/MOL 6764, BOR/MOL 6767, BOR/MOL 10000, BOR/MOL 10009. *Pulau Manukan*: BOR/MOL 6744, BOR/MOL 6745, BOR/MOL 6746, BOR/MOL 6747, BOR/MOL 6749, BOR/MOL 6752, BOR/MOL 6755. *Pulau Sulug*: BOR/MOL 6769, BOR/MOL 6770, BOR/MOL 6771, BOR/MOL 7932, BOR/MOL 10338, BOR/MOL 10346. *Pulau Usukan*: BOR/MOL 7886, BOR/MOL 7887, BOR/MOL 7888, BOR/MOL 7881, BOR/MOL 7882, BOR/MOL 12024, BOR/MOL 12025, BOR/MOL 12027, BOR/MOL 12039, BOR/MOL 12040, BOR/MOL 12475. *Pulau Labuan*: BOR/MOL 7913, BOR/MOL 7917, BOR/MOL 7904, BOR/MOL 7906, BOR/MOL 7907, BOR/MOL 7910, BOR/MOL 8590, BOR/MOL 8795, BOR/MOL 12168, BOR/MOL 12184. *Pulau Dinawan*: BOR/MOL 7678, BOR/MOL 7679, BOR/MOL 7680, BOR/MOL 7681, BOR/MOL 7683, BOR/MOL 7693, BOR/MOL 7694, BOR/MOL 8909. *Pulau Rusukan Kecil*: BOR/MOL 8552, BOR/MOL 8555, BOR/MOL 8556, BOR/MOL 8557, BOR/MOL 8558, BOR/MOL 8605, BOR/MOL 8539, BOR/MOL 8540, BOR/MOL 8541, BOR/MOL 8542, BOR/MOL 8543, BOR/MOL 8544, BOR/MOL 8545,

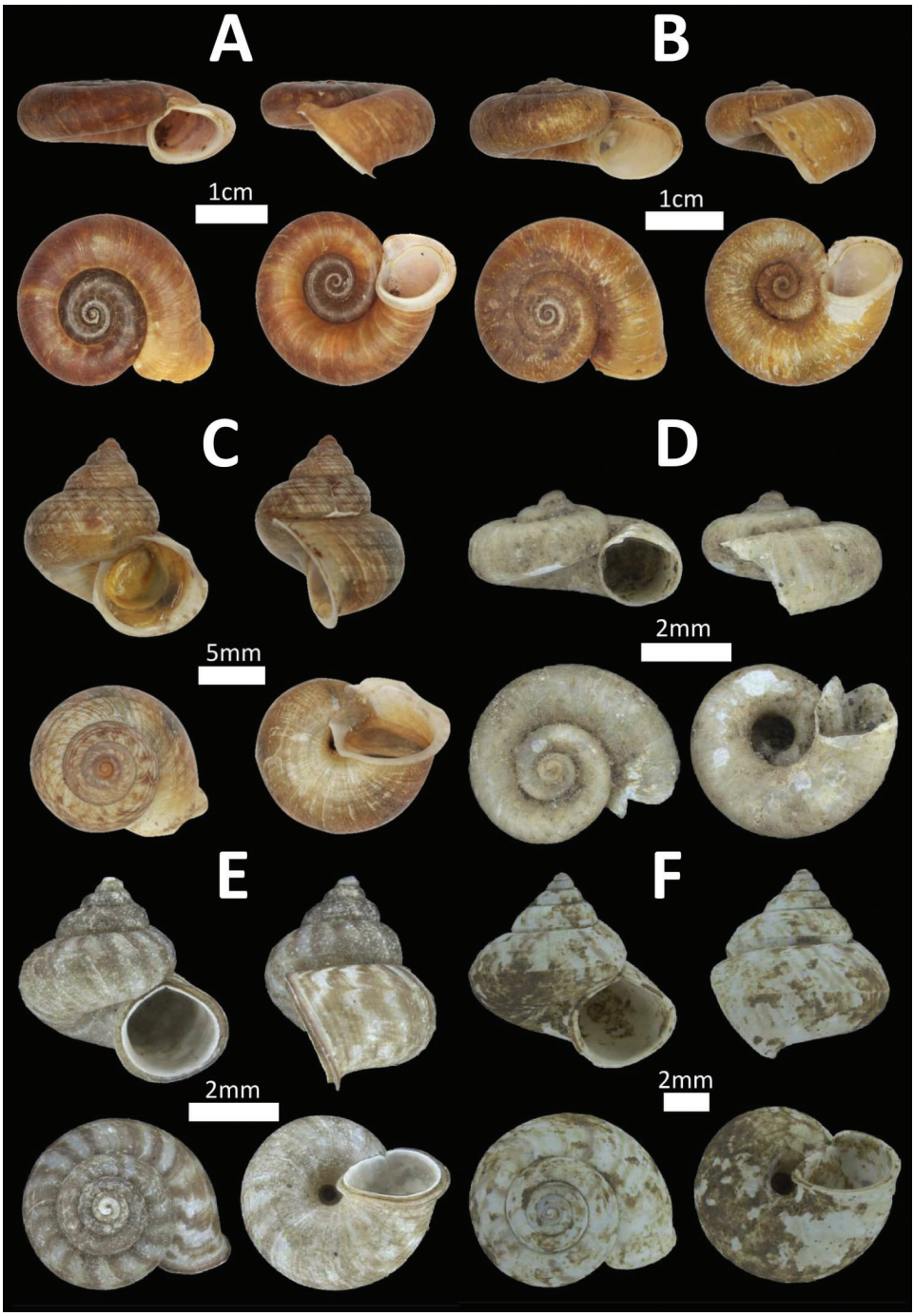

Figure 3. Family Cyclophoridae. **A** *Pterocyclos tenuilabiatus* (BOR/MOL 105) **B** *Pterocyclos amabilis* (BOR/MOL 8850) **C** *Leptopoma pellucidum* (BOR/MOL 6780) **D** *Platyraphe bongaoensis* (BOR/MOL 7185)*Broken aperture **E** *Japonia triliratal kinabaluensis* species complex (BOR/MOL 12267) **F** *Japonia balabacensis* (BOR/MOL 3725).

BOR/MOL 8546, BOR/MOL 8550. *Pulau Rusukan Besar*: BOR/MOL 8559, BOR/MOL 8560, BOR/MOL 8574, BOR/MOL 8575, BOR/MOL 8576, BOR/MOL 8583, BOR/MOL 8584, BOR/MOL 8585, BOR/MOL 8588, BOR/MOL 8589, BOR/MOL 12234, BOR/MOL 12247, BOR/MOL 12265, BOR/MOL 12271. *Pulau Kuraman*: BOR/MOL 8614, BOR/MOL 8621, BOR/MOL 8622, BOR/MOL 8626, BOR/MOL 8631, BOR/MOL 8635, BOR/MOL 8638, BOR/MOL BOR/MOL 12099, BOR/MOL 12108, BOR/MOL 12120, BOR/MOL 12134, BOR/MOL 12144.

Distribution in Sabah. *Island*: [West] Tunku Abdul Rahman Park, Pulau Mengalum, Pulau Tiga, Pulau Sapangar, Pulau Udar Kecil, Pulau Udar Besar, Pulau Usukan, Pulau Labuan, Labuan Marine Park; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division and Tawau Division.

Remarks. Widespread in Sabah.

Platyraphe bongaoensis (E.A. Smith, 1894)

Figure 3D

Type locality. "Philippines: Sulu Archipelago: Tawi-Tawi–Bongao island" (E.A. Smith, 1894).

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3722, BOR/MOL 7169, BOR/MOL 7185, BOR/MOL 7201.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar; [North] Pulau Balambangan. *Mainland*: No record.

Remarks. Only found in Pulau Mantanani Besar and Pulau Balambangan, which are close to the Palawan archipelago in the Philippines.

Japonia trilirata/kinabaluensis species complex

Figure 3E

Type locality. *Japonia kinabaluensis* "Malaysia: Sabah: Ranau–Mt. Kinabalu" (Smith, 1895); *Japonia trilirata* "Malaysia: Sabah: Labuan" (Pfeiffer, 1852)

Examined materials. *Pulau Tiga*: BOR/MOL 201, BOR/MOL 202, BOR/MOL 2758, BOR/MOL 8518, BOR/MOL 6606, BOR/MOL 6595, BOR/MOL 8425, BOR/MOL 8431, BOR/MOL 11079, BOR/MOL 11087, BOR/MOL 11091, BOR/MOL 11093, BOR/MOL 11107, BOR/MOL 11109, BOR/MOL 11110. *Pulau Gaya*: BOR/MOL 8461, BOR/MOL 8475, BOR/MOL 8477, BOR/MOL 8449, BOR/MOL 8495, BOR/MOL 8502, BOR/MOL 9448, BOR/MOL 10988, BOR/MOL 10359, BOR/MOL 10369. *Pulau Rusukan Besar*: BOR/MOL 8577, BOR/MOL 8578, BOR/MOL 8579, BOR/MOL 8586, BOR/MOL 12227, BOR/MOL 12242, BOR/MOL 12246, BOR/MOL 12255, BOR/MOL 12260, BOR/MOL 12266, BOR/MOL 12267, BOR/MOL 12270. *Pulau Kuraman*: BOR/MOL 8615, BOR/MOL 8632, BOR/MOL 8636,

BOR/MOL 8639, BOR/MOL 8644, BOR/MOL 8647, BOR/MOL 8656, BOR/MOL 12103, BOR/MOL 12105, BOR/MOL 12114, BOR/MOL 12126, BOR/MOL 12136, BOR/MOL 12139, BOR/MOL 12145. *Pulau Dinawan*: BOR/MOL 8922, BOR/MOL 8905, BOR/MOL 8915, BOR/MOL 8917. *Pulau Sapangar*: BOR/MOL 11991, BOR/MOL 11997, BOR/MOL 12011. *Pulau Labuan*: BOR/MOL 12194.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Gaya, Pulau Rusukan Besar, Pulau Kuraman, Pulau Dinawan, Pulau Sapangar, Pulau Labuan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Sebangkat, Pulau Selakan, Pulau Tetagan. *Mainland:* West Coast Division, Interior Division, Sandakan Division and Tawau Division.

Remarks. Widespread in Sabah. The difference between *Japonia kinabaluensis* (E.A. Smith, 1895) and *Japonia trilirata* (Pfeiffer, 1852) is ambiguous as the shell shape and size of the two species are highly variable and intermediate shell forms have been found. Therefore, we considered *J. kinabaluensis* and *J. trilirata* as *Japonia trilirata*/*kinabaluensis* species complex.

Japonia balabacensis **(E.A. Smith, 1895)**

Figure 3F

Type locality. "Philippines: Palawan–Balabac Island" (E.A. Smith, 1895)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3725.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar; [North] Pulau Banggi, Pulau Balambangan. *Mainland*: No record.

Remarks. Only found in Pulau Mantanani Besar, Pulau Balambangan and Pulau Banggi, which are close to the Palawan archipelago in the Philippines.

Japonia keppeli **(Godwin-Austen, 1889)**

Figure 4A

Type locality. "Malaysia: Sarawak: Miri–Batu Niah N.P" (Godwin-Austen, 1889)

Examined materials. *Pulau Gaya*: BOR/MOL 6681, BOR/MOL 6683, BOR/MOL 8466, BOR/MOL 8481, BOR/MOL 8489, BOR/MOL 8494, BOR/MOL 8501, BOR/MOL 10363, BOR/MOL 10368. *Pulau Sapi*: BOR/MOL 10027, BOR/MOL 10293. *Pulau Manukan*: BOR/MOL 10298, BOR/MOL 10302, BOR/MOL 10303, BOR/MOL 10307, BOR/MOL 10316, BOR/MOL 10318, BOR/MOL 10324. *Pulau Sulug*: BOR/MOL 10330, BOR/MOL 10332, BOR/MOL 10333, BOR/MOL 10339, BOR/MOL 10345.

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Sapi, Pulau Manukan, Pulau Sulug. *Mainland*: Interior Division.

Remarks. Endemic to Borneo.

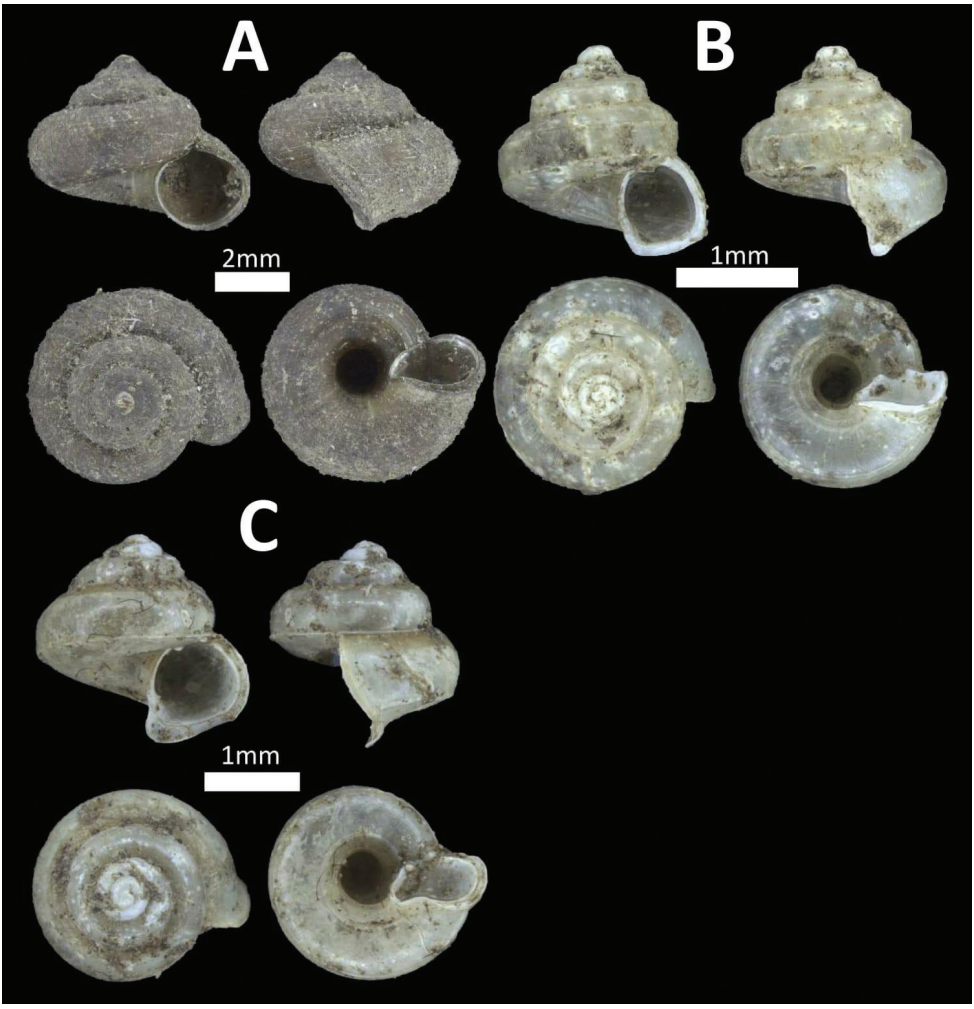

Figure 4. Family Cyclophoridae. **A** *Japonia keppeli* (BOR/MOL 10027) **B** *Ditropopsis koperbergi* (BOR/MOL 8455) **C** *Ditropopsis imadatei* (BOR/MOL 10358).

Ditropopsis koperbergi (Zilch, 1955)

Figure 4B

Type locality. "Indonesia: Kalimantan: Landak" (Zilch, 1955)

Examined materials. *Pulau Gaya*: BOR/MOL 8455, BOR/MOL 8446.

Distribution in Sabah. *Island*: [West] Pulau Gaya. *Mainland*: Interior Division, West Coast Division and Sandakan Division.

Remarks. Endemic to Borneo.

Ditropopsis imadatei **(Habe, 1965)**
Figure 4C

Type locality. "Brunei: Bandar Seri Begawan" (Habe, 1965)
Examined materials. *Pulau Gaya*: BOR/MOL 8460, BOR/MOL 10358.
Distribution in Sabah. *Island*: [West] Pulau Gaya. *Mainland*: Interior Division.
Remarks. Endemic to Borneo.

FAMILY DIPLOMMATINIDAE

Diplommatina recta **E.A. Smith, 1895**
Figure 5A

Type locality. "Malaysia: Sabah: Ranau–Mt. Kinabalu" (E.A. Smith, 1895)
Examined materials. *Pulau Mengalum*: BOR/MOL 12297.
Distribution in Sabah. *Island*: [West] Pulau Mengalum; [North] Pulau Balambangan. *Mainland*: No record.
Remarks. There is no recent record of this species from the mainland. The only record on the mainland is in the original description of the species by Smith (1895).

Arinia borneensis **E.A. Smith, 1894**
Figure 5B

Type locality. "Malaysia: Sabah: Sandakan–Gomantong" (E.A. Smith, 1894b)
Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3721, BOR/MOL 7172, BOR/MOL 7177, BOR/MOL 7183. *Pulau Mantanani Kecil*: BOR/MOL 3729, BOR/MOL 7196. *Pulau Lungisan*: BOR/MOL 3742. *Pulau Tiga*: BOR/MOL 6598, BOR/MOL 11100. *Pulau Usukan*: BOR/MOL 12026, BOR/MOL 12028, BOR/MOL 12037, BOR/MOL 12048, BOR/MOL 12051, BOR/MOL 12053. *Pulau Kuraman*: BOR/MOL 12102, BOR/MOL 12107.
Distribution in Sabah. *Island*: [West] Mantanani group, Pulau Tiga, Pulau Usukan, Pulau Kuraman. *Mainland*: Kudat Division, Sandakan Division and Tawau Division.
Remarks. Endemic and widespread in Sabah.

Arinia **sp.**
Figure 5C

Type locality. Not applicable.
Examined materials. *Pulau Rusukan Besar*: BOR/MOL 12252.

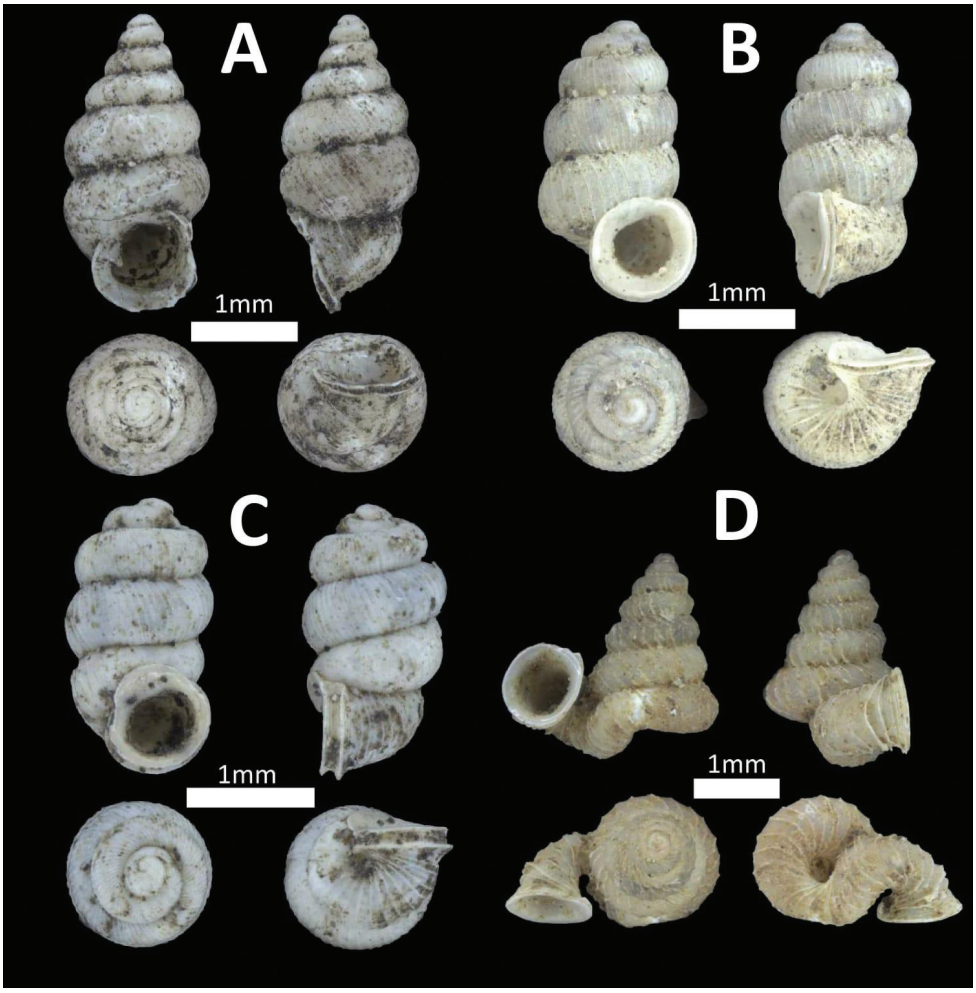

Figure 5. Family Diplommatinidae. **A** *Diplommatina recta* (BOR/MOL 12297) **B** *Arinia borneensis* (BOR/MOL 12053) **C** *Arinia* sp. (BOR/MOL 12252) **D** *Plectostoma jucundum* (BOR/MOL 7179).

Distribution in Sabah. *Island*: [West] Pulau Rusukan Besar. *Mainland*: No record.

Remarks. Unknown status. Does not match with any other *Arinia* species in Borneo treated in the revision by Vermeulen (1996).

***Plectostoma jucundum* (E.A. Smith, 1893)**

Figure 5D

Type locality. "Malaysia: Sabah: Kota Belud–Mantanani Island" (E.A. Smith, 1892)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3720, BOR/MOL 5601, BOR/MOL 7179.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar. *Mainland*: No record.

Remarks. Endemic to Pulau Mantanani Besar. Critically endangered as this species is only found in one locality and is threatened by habitat loss (Schilthuizen and Vermeulen 2004a).

Diplommatina sp.

Type locality. Not applicable.

Examined materials. Pulau Sapangar: BOR/MOL 11993.

Distribution in Sabah. *Island*: [West] Pulau Sapangar. *Mainland*: No record.

Remarks. Unable to identify because the only shell found was juvenile.

FAMILY TRUNCATELLIDAE

Truncatella guerinii (Villa & Villa, 1841)

Figure 6A

Type locality. "France: Reunion" (Villa & Villa, 1841)

Examined materials. *Pulau Mantanani Kecil*: BOR/MOL 3731. *Pulau Peduk*: BOR/MOL 10348. *Pulau Burong*: BOR/MOL 12333.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Kecil, Pulau Peduk, Pulau Burong; [North] Pulau Banggi, Pulau Balambangan. *Mainland*: West Coast Division.

Remarks. Unknown status. Relatively scarce information about the distribution in Sabah as its habitat at coastal areas has rarely been surveyed. Presumably widespread along coastal areas since this species was known from across the Indo-pacific region (Clench and Turner 1948).

Truncatella marginata Küster, 1855

Figure 6B

Type locality. "Malaysia: Sabah: Labuan" (Küster, 1855)

Examined materials. *Pulau Burong*: BOR/MOL 12445.

Distribution in Sabah. *Island*: [West] Pulau Burong. *Mainland*: No record.

Remarks. Unknown status. Scarce information about the distribution in Sabah as its habitat at coastal area has rarely been surveyed.

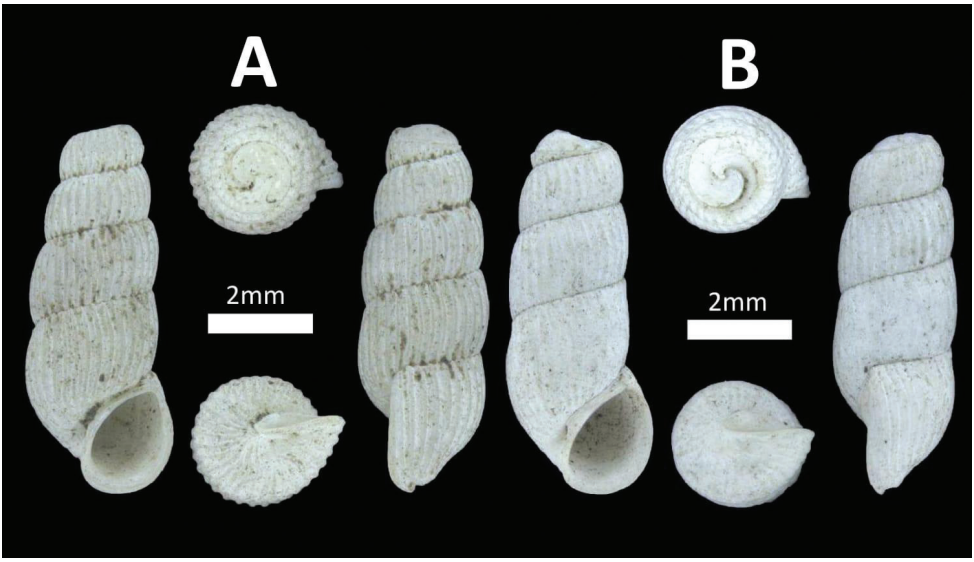

Figure 6. Family Truncatellidae. **A** *Truncatella guerinii* (BOR/MOL 12333) **B** *Truncatella marginata* (BOR/MOL 12445).

Unranked clade: NERITIMORPHA
FAMILY HELICINIDAE

***Aphanoconia usukanensis* (Godwin-Austen, 1889)**
Figure 7

Type locality. "Malaysia: Sabah: Kota Belud–Usukan island" (Godwin-Austen 1889)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3719, BOR/MOL 6703, BOR/MOL 7164, BOR/MOL 7200. *Pulau Mantanani Kecil*: BOR/MOL 3730, BOR/MOL 3755. *Pulau Lungisan*: BOR/MOL 3743. *Pulau Mengalum*: BOR/MOL 6067, BOR/MOL 6163, BOR/MOL 6170, BOR/MOL 6179, BOR/MOL 8730, BOR/MOL 8734, BOR/MOL 8735, BOR/MOL 8736, BOR/MOL 8858, BOR/MOL 8859, BOR/MOL 8860, BOR/MOL 8863, BOR/MOL 9993, BOR/MOL 9996, BOR/MOL 9997, BOR/MOL 12345, BOR/MOL 12279, BOR/MOL 12288, BOR/MOL 12296, BOR/MOL 12302, BOR/MOL 12312, BOR/MOL 12315, BOR/MOL 12320. *Pulau Mamutik*: BOR/MOL 6692, BOR/MOL 6696, BOR/MOL 6697, BOR/MOL 6698, BOR/MOL 6765, BOR/MOL 6768, BOR/MOL 10008, BOR/MOL 10014, BOR/MOL 10023, BOR/MOL 10025. *Pulau Manukan*: BOR/MOL 6750, BOR/MOL 6751, BOR/MOL 6753, BOR/MOL 6754, BOR/MOL 6756, BOR/MOL 6761, BOR/MOL 6762, BOR/MOL 6772, BOR/MOL 10301, BOR/MOL 10309. *Pulau Usukan*: BOR/MOL 7884, BOR/MOL

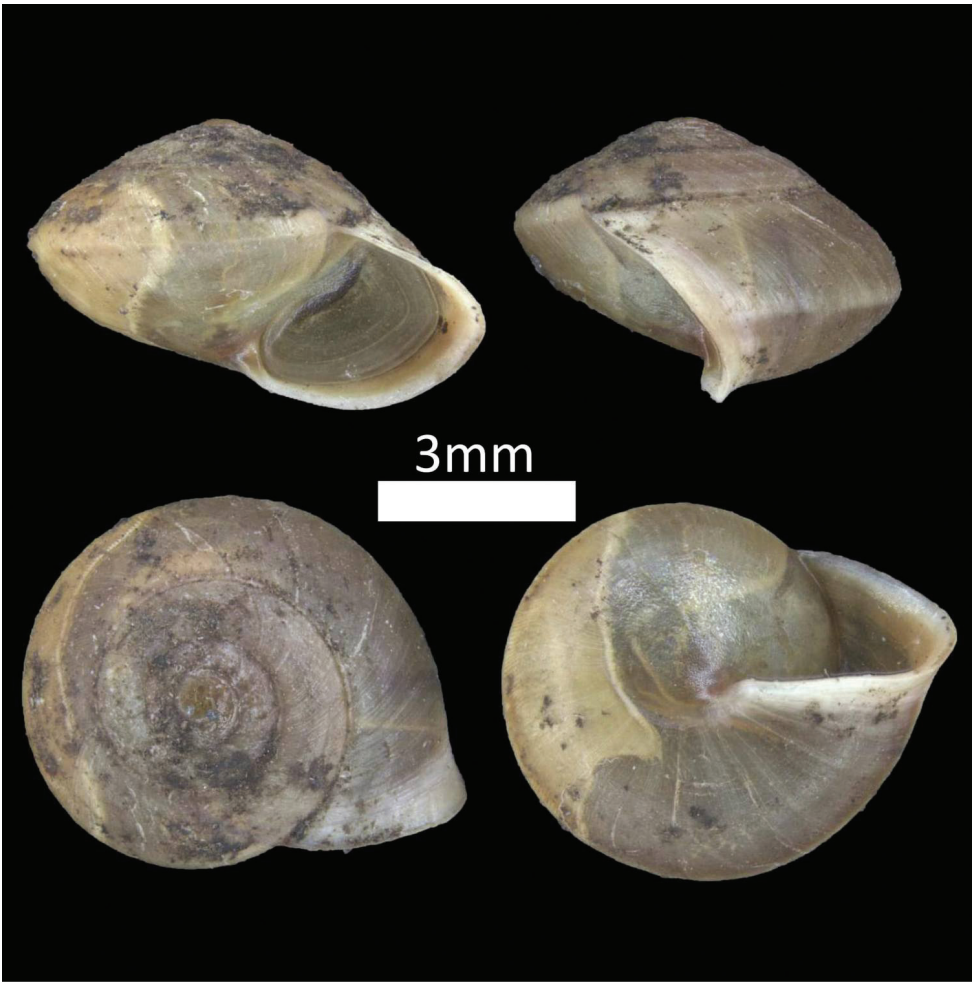

Figure 7. Family Helicinidae. *Aphanoconia usukanensis* (BOR/MOL 7200).

7885, BOR/MOL 7893, BOR/MOL 7895, BOR/MOL 7898, BOR/MOL 7883, BOR/MOL 12477. *Pulau Dinawan*: BOR/MOL 7685, BOR/MOL 7692, BOR/MOL 8902, BOR/MOL 8911.

Distribution in Sabah. *Island*: [West] Mantanani group, Pulau Mengalum, Pulau Mamutik, Pulau Manukan, Pulau Usukan, Pulau Dinawan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bohey Dulang, Pulau Sebangkat, Pulau Selakan, Pulau Tetagan, Pulau Mantabuan, Pulau Sibuan, Pulau Maiga. *Mainland*: Sandakan Division, and Tawau Division.

Remarks. Endemic and widespread in Sabah.

FAMILY HYDROCENIDAE

***Georissa saulae* (van Benthem Jutting, 1966)**
Figure 8A

Type locality. "Malaysia: Sabah: Keningau–Lian Cave" (van Benthem Jutting 1966)

Examined materials. *Pulau Tiga*: BOR/MOL 27.

Distribution in Sabah. *Island*: [West] Pulau Tiga. *Mainland*: West Coast Division and Interior Division.

Remarks. Endemic to Sabah. The examined sample was collected in 2000 and not found in the current survey.

***Georissa scalinella* (van Benthem Jutting, 1966)**
Figure 8B

Type locality. "Malaysia: Sabah: Lahad Datu–Lahad Batu Caves on Teck Guan Estate" (van Benthem Jutting 1966).

Examined materials. *Pulau Tiga*: BOR/MOL 41.

Distribution in Sabah. *Island*: [West] Pulau Tiga. *Mainland*: Interior Division, Sandakan Division, and Tawau Division.

Remarks. Endemic to Sabah. The examined sample was collected in 2000 and not found in the current survey.

***Georissa williamsi* Godwin-Austen, 1889**
Figure 8C

Type locality. "Borneo" (Godwin-Austen 1889)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3718, BOR/MOL 7161, BOR/MOL 7174. *Pulau Lungisan*: BOR/MOL 3744.

Distribution in Sabah. *Island*: [West] Mantanani Island group. *Mainland*: West Coast Division and Sandakan Division.

Remarks. Widespread in Sabah mainland.

Clade: PULMONATA Cuvier
FAMILY ACHATINELLIDAE

***Elasmias globulosum* Quoi & Gaimard ex Zilch, 1962**

Type locality. "Philippines: Mindanao" (Quoi & Gaimard ex Zilch 1962)

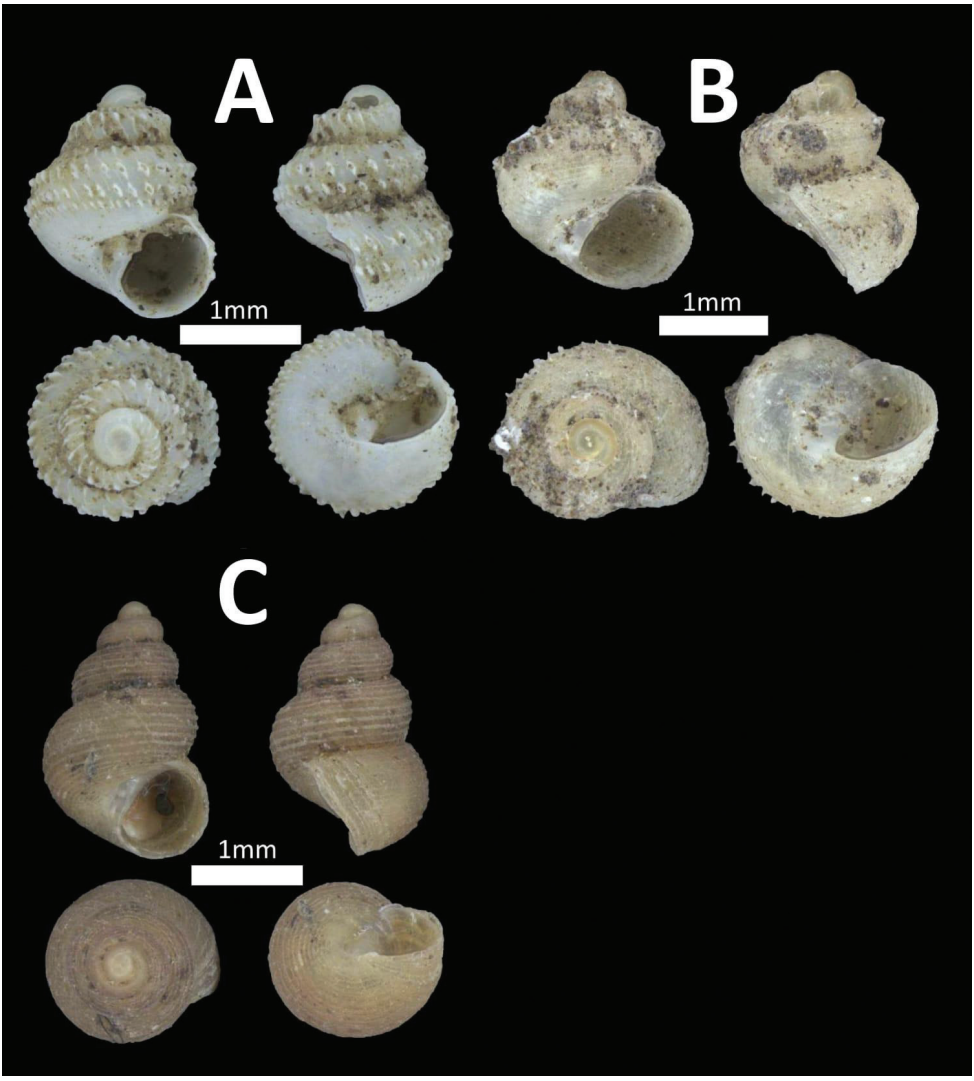

Figure 8. FAMILY HYDROCENIDAE. **A** *Georissa saulae* (BOR/MOL 27) **B** *Georissa scalinella* (BOR/MOL 41) **C** *Georissa williamsi* (BOR/MOL 7174).

Examined materials. Pulau Mantanani Besar: BOR/MOL 3717 (Not seen).

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar; [North] Pulau Balambangan. *Mainland*: No record.

Remarks. Only found in Pulau Mantanani Besar and Pulau Balambangan, which are close to the Palawan archipelago in the Philippines. This species is reported in Schilthuizen et al. (2013) but the specimen could not be found in the BORNEENSIS collection.

***Elasmias manilense* (Dohrn, 1863)**
Figure 9A

Type locality. "Philippines: Luzon– near Manila" (Dohrn 1863)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 7163. *Pulau Gaya*: BOR/MOL 8470. *Pulau Rusukan Kecil*: BOR/MOL 8554, BOR/MOL 8607, BOR/MOL 8549, BOR/MOL 8551, BOR/MOL 12356. *Pulau Rusukan Besar*: BOR/MOL 8562, BOR/MOL 8567, BOR/MOL 8568, BOR/MOL 8582, BOR/MOL 12228, BOR/MOL 12241, BOR/MOL 12249, BOR/MOL 12254. *Pulau Kuraman*: BOR/MOL 8649, BOR/MOL 8651, BOR/MOL 12109.

Disribution in Sabah. *Island*: [West] Pulau Mantanani Besar, Pulau Gaya, Labuan Marine Park; [East] Pulau Bohey Dulang, Pulau Mantabuan, Pulau Sibuan. *Mainland:* No record.

Remarks. Widespread in Sabah on islands.

***Tornatellinops moluccana* (Boettger, 1891)**
Figure 9B

Type locality. "Indonesia: Maluku–Ambon" (Boettger 1891)

Examined materials. *Pulau Dinawan*: BOR/MOL 8912. *Pulau Udar Besar*: BOR/MOL 11075, BOR/MOL 11076. *Pulau Sapangar*: BOR/MOL 11974. *Pulau Gaya*: BOR/MOL 8470. *Pulau Rusukan Besar*: BOR/MOL 12228, BOR/MOL 12241, BOR/MOL 12542.

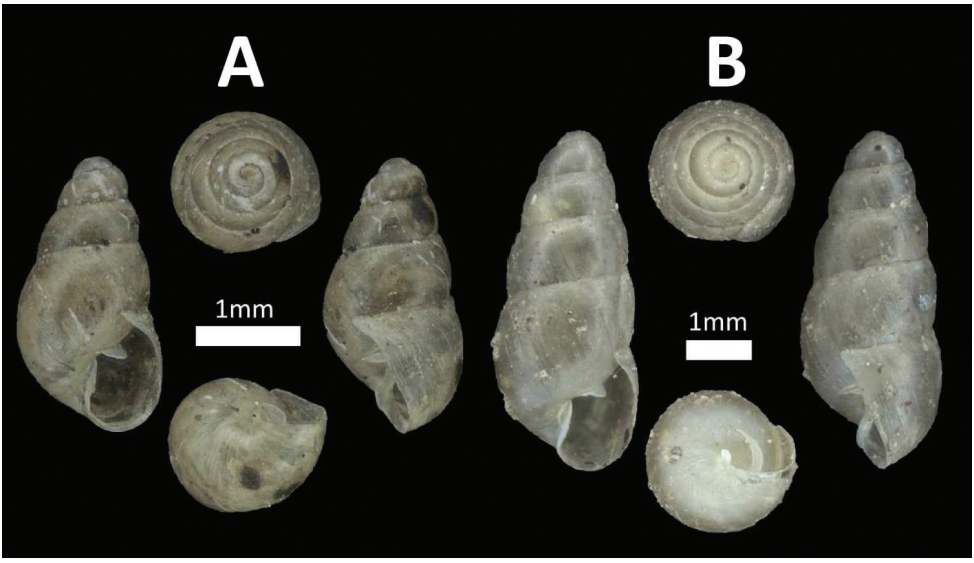

Figure 9. Family Achatinellidae. **A** *Elasmias manilense* (BOR/MOL 12356) **B** *Tornatellinops moluccana* (BOR/MOL 11974).

Distribution in Sabah. *Island*: [West] Pulau Dinawan, Pulau Udar Besar, Pulau Sapangar, Pulau Gaya, Pulau Rusukan Besar. *Mainland*: Tawau Division.

Remarks. Rather widespread in Sabah.

FAMILY ACHATINIDAE

***Achatina fulica* (Bowdich, 1822)**
Figure 10

Type locality. Not stated.

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 1824, BOR/MOL 3716, BOR/MOL 3756, BOR/MOL 7191. *Pulau Lungisan*: BOR/MOL 3745. *Pulau Labuan*: BOR/MOL 6592, BOR/MOL 7901, BOR/MOL 7903, BOR/MOL 7926, BOR/MOL 7927, BOR/MOL 8814, BOR/MOL 12183, BOR/MOL 12200, BOR/MOL 12214, BOR/MOL 12224, BOR/MOL 12338, BOR/MOL 12341, BOR/MOL 12344, BOR/MOL 12446, BOR/MOL 12482. *Pulau Dinawan*: BOR/MOL 8923. *Pulau Usukan*: BOR/MOL 12022, BOR/MOL 12023, BOR/MOL 12079, BOR/MOL 12080, BOR/MOL 12081, BOR/MOL 12339, BOR/MOL 12340, BOR/MOL 12480. *Pulau Papan*: BOR/MOL 12066.

Distribution in Sabah. *Island*:[West] Pulau Mantanani Besar, Pulau Lungisan, Pulau Labuan, Pulau Dinawan, Pulau Usukan, Pulau Papan; [North] Pulau Banggi, Pulau Balambangan. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Introduced and widespread in Sabah.

FAMILY ARIOPHANTIDAE

***Hemiplecta humphreysiana* (Lea, 1841)**
Figure 11A

Type locality. "India: Puducherry: Pondicherry" (Lea 1841)

Examined materials. *Pulau Tiga*: BOR/MOL 998, BOR/MOL 1008, BOR/MOL 1009, BOR/MOL 1389, BOR/MOL 4262, BOR/MOL 2811, BOR/MOL 2816, BOR/MOL 3049, BOR/MOL 6567, BOR/MOL 6570, BOR/MOL 6571, BOR/MOL 6574, BOR/MOL 6594, BOR/MOL 6612, BOR/MOL 6581, BOR/MOL 6583, BOR/MOL 6585, BOR/MOL 7860, BOR/MOL 7870,.BOR/MOL 7872, BOR/MOL 7879, BOR/MOL 8436, BOR/MOL 8442, BOR/MOL 8430, BOR/MOL 8515, BOR/MOL 8517, BOR/MOL 8596, BOR/MOL 8602, BOR/MOL 8604, BOR/MOL 11089, BOR/MOL 11102, BOR/MOL 11103, BOR/MOL 11113, BOR/MOL 11114, BOR/MOL 11115. *Pulau Gaya*: BOR/MOL 6302, BOR/MOL 6304, BOR/MOL 6616, BOR/MOL 6625, BOR/MOL 6626, BOR/MOL

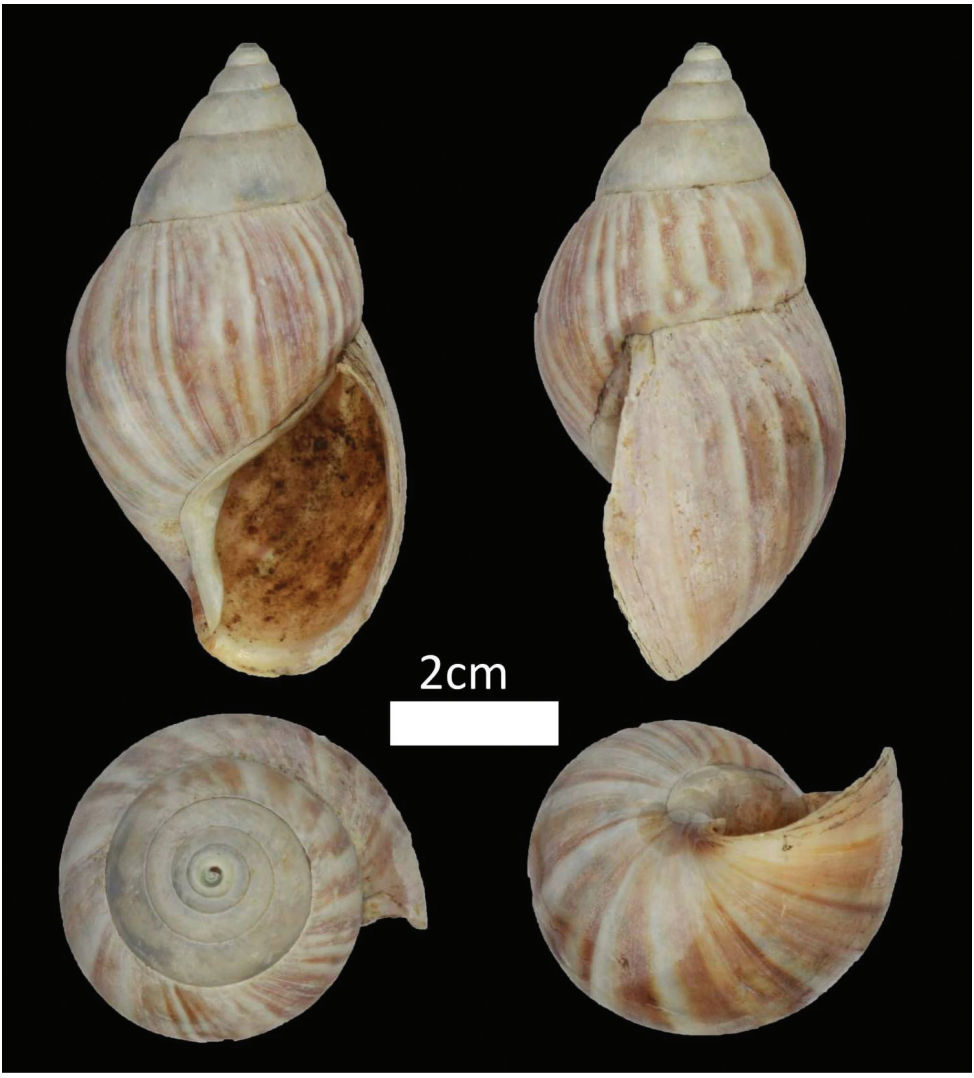

Figure 10. Family Achatinidae. *Achatina fulica* (BOR/MOL 12339).

6639, BOR/MOL 6640, BOR/MOL 6647, BOR/MOL 6649, BOR/MOL 6672, BOR/MOL 6676, BOR/MOL 6680, BOR/MOL 6682, BOR/MOL 8483, BOR/MOL 8485, BOR/MOL 8490, BOR/MOL 8506, BOR/MOL 8513, BOR/MOL 8522, BOR/MOL 8849, BOR/MOL 8853, BOR/MOL 8854, BOR/MOL 8855, BOR/MOL 8856, BOR/MOL 9721, BOR/MOL 10364, BOR/MOL 9729. *Pulau Rusukan Besar*: BOR/MOL 12268.

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Tiga, Pulau Rusukan Besar; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya. *Mainland:* Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

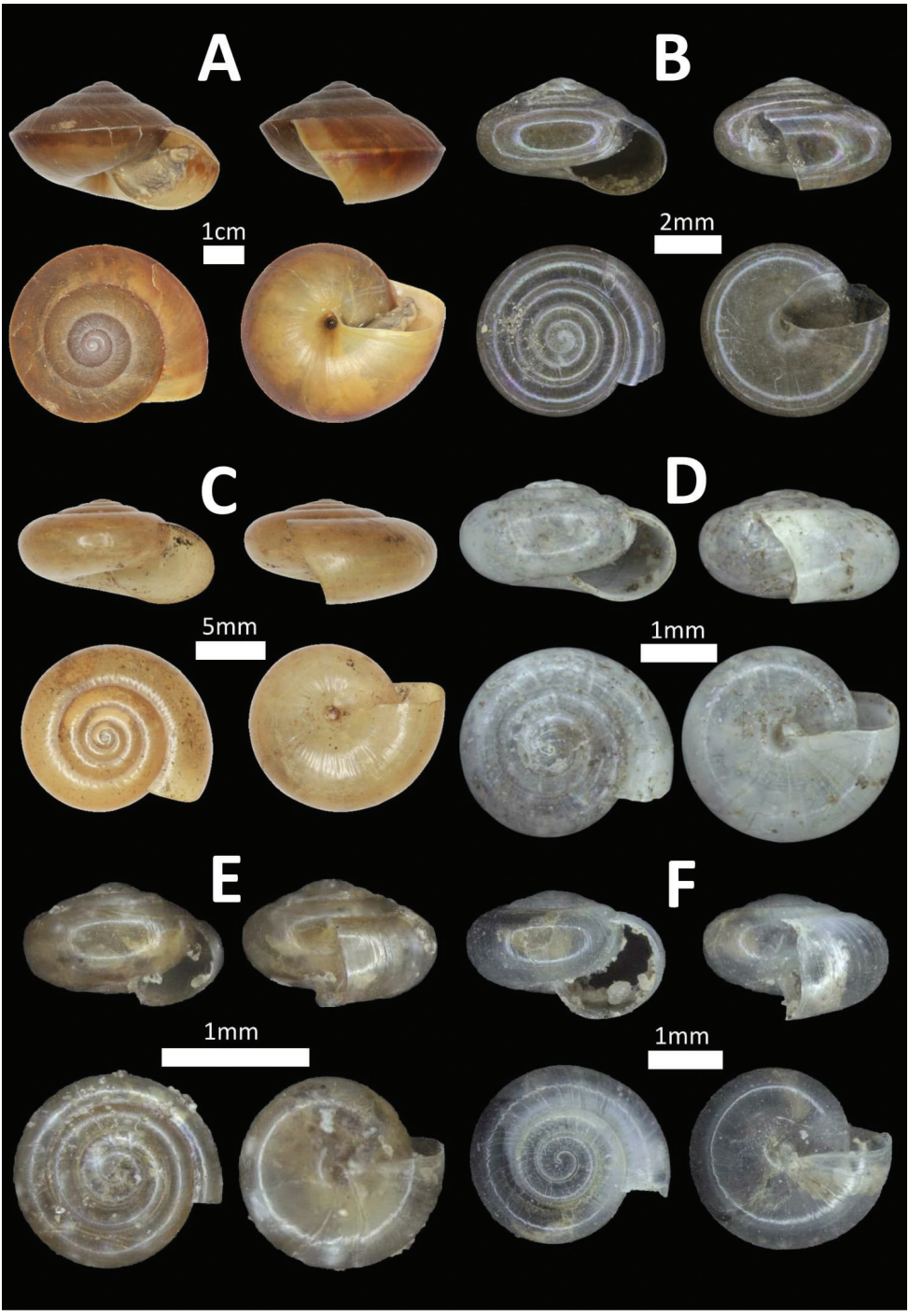

Figure 11. FAMILY ARIOPHANTIDAE. **A** *Hemiplecta humphreysiana* (BOR/MOL 7870) **B** *Macrochlamys tersa* (BOR/MOL 10299) **C** *Macrochlamys indica* (BOR/MOL 12490) **D** *Microcystina striatula* (BOR/MOL 10310) **E** *Microcystina sinica* (BOR/MOL 12047) **F** *Microcystina microrhynchus* (BOR/MOL 11982).

Remarks. Widespread in Sabah. Specimens from Pulau Rusukan Besar (BOR/MOL 12268) are probably fossilised.

***Macrochlamys tersa* (Issel, 1874)**
Figure 11B

Type locality. "Borneo" (Issel 1874)

Examined materials. *Pulau Tiga*: BOR/MOL 2828, BOR/MOL 6577, BOR/MOL 6580, BOR/MOL 1062. *Pulau Mantanani Besar*: BOR/MOL 7171. *Pulau Labuan*: BOR/MOL 7928, BOR/MOL 12171, BOR/MOL 12193, BOR/MOL 12210. *Pulau Papan*: BOR/MOL 7825, BOR/MOL 7826, BOR/MOL 12060, BOR/MOL 12068, BOR/MOL 12069, BOR/MOL 12070. *Pulau Gaya*: BOR/MOL 9723. *Pulau Manukan*: BOR/MOL 10299. *Pulau Sapangar*: BOR/MOL 11998, BOR/MOL 11975, BOR/MOL 11985, BOR/MOL 11996.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Mantanani Besar, Pulau Labuan, Pulau Papan, Pulau Gaya, Pulau Manukan, Pulau Sapangar; [North] Pulau Banggi; [East] Pulau Bohey Dulang, Pulau Bod Gaya, Pulau Mantabuan, Pulau Sebangkat, Pulau Sibuan, Pulau Maiga. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Macrochlamys indica* (Godwin-Austen, 1883)**
Figure 11C

Type locality. "India: West Bengal: Calcutta" (Godwin-Austen 1883)

Examined materials. *Pulau Papan*: BOR/MOL 7821. *Pulau Labuan*: BOR/MOL 8591, BOR/MOL 12167, BOR/MOL 12169, BOR/MOL 12181, BOR/MOL 12186, BOR/MOL 12191, BOR/MOL 12209, BOR/MOL 12219, BOR/MOL 12220, BOR/MOL 12221, BOR/MOL 12226, BOR/MOL 12273, BOR/MOL 12488, BOR/MOL 12489, BOR/MOL 12490.

Distribution in Sabah. *Island*: [West] Pulau Papan, Pulau Labuan. *Mainland:* West Coast Division, Interior Division.

Remarks. Introduced to Sabah.

***Microcystina striatula* Vermeulen, Liew & Schilthuizen, 2015**
Figure 11D

Type locality. "Malaysia: Sabah: Lahad Datu–Tabin Valley" (Vermeulen et al. 2015)

Examined materials. *Pulau Tiga*: BOR/MOL 1100. *Pulau Manukan*: BOR/MOL 10310. *Pulau Udar Kecil*: BOR/MOL 10370, BOR/MOL 10375. *Pulau Usu-*

kan: BOR/MOL 12029, BOR/MOL 12033, BOR/MOL 12043, BOR/MOL 12054, BOR/MOL 12055, BOR/MOL 12470. *Pulau Papan*: BOR/MOL 12063, BOR/MOL 12065. *Pulau Rusukan Kecil*: BOR/MOL 12155. *Pulau Labuan*: BOR/MOL 12460.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Manukan, Pulau Udar Kecil, Pulau Usukan, Pulau Papan, Pulau Papan, Pulau Rusukan Kecil; [North] Pulau Banggi; [East] Pulau Bod Gaya, Pulau Sebangkat. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Endemic to Borneo and widespread in Sabah.

Microcystina sinica Von Moellendorff, 1885

Figure 11E

Type locality. "China: GuangDong Province–Shiu Heng Hap" (Von Moellendorff 1885)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3713, BOR/MOL 7168, BOR/MOL 7180, BOR/MOL 7184. *Pulau Mantanani Kecil*: BOR/MOL 3734. *Pulau Mengalum*: BOR/MOL 6175, BOR/MOL 12287, BOR/MOL 12313. *Pulau Tiga*: BOR/MOL 6602, BOR/MOL 8435, BOR/MOL 8424. *Pulau Gaya*: BOR/MOL 6620, BOR/MOL 6623, BOR/MOL 8452, BOR/MOL 8459, BOR/MOL 8473, BOR/MOL 8445, BOR/MOL 8505, BOR/MOL 8493, BOR/MOL 10365. *Pulau Dinawan*: BOR/MOL 8919, BOR/MOL 8901. *Pulau Usukan*: BOR/MOL 12031, BOR/MOL 12032, BOR/MOL 12041, BOR/MOL 12044, BOR/MOL 12047, BOR/MOL 12471, BOR/MOL 12478. *Pulau Labuan*: BOR/MOL 12185, BOR/MOL 12206.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar, Pulau Mantanani Kecil, Pulau Mengalum, Pulau Tiga, Pulau Gaya, Pulau Dinawan, Pulau Usukan, Pulau Labuan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Sebangkat, Pulau Selakan, Pulau Tetagan. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

Microcystina microrhynchus Vermeulen, Liew & Schilthuizen, 2015

Figure 11F

Type locality. "Malaysia: Sabah: Interior Province–Gua Pungiton" (Vermeulen et al. 2015)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3714. *Pulau Mantanani Kecil*: BOR/MOL 3733. *Pulau Gaya*: BOR/MOL 8453, BOR/MOL 8456, BOR/MOL 8463, BOR/MOL 8468, BOR/MOL 8474, BOR/MOL 8480, BOR/MOL 8508, BOR/MOL 8487, BOR/MOL 10367. *Pulau Mamutik*: BOR/MOL 10005. *Pulau Sapangar*: BOR/MOL 12001, BOR/MOL 11976, BOR/MOL 11982, BOR/MOL 11983, BOR/MOL 11986, BOR/MOL 11987, BOR/MOL 11988. *Pulau Labuan*: BOR/MOL 12207, BOR/MOL 12211.

Distribution in Sabah. *Island*: [West] Mantanani group, Pulau Gaya, Pulau Mamutik, Pulau Sapangar, Pulau Labuan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Endemic to Borneo and widespread in Sabah.

Microcystina callifera Vermeulen, Liew & Schilthuizen, 2015

Figure 12A

Type locality. "Malaysia: Sabah: Kota Belud–Mantanani Group, Pulau Lungisan" (Vermeulen et al. 2015)

Examined materials. *Pulau Lungisan*: BOR/MOL 3746, *Pulau Mantanani Besar*: BOR/MOL 3715, BOR/MOL 7159, BOR/MOL 7176, BOR/MOL 7186. *Pulau Mantanani Kecil*: BOR/MOL 3732.

Distribution in Sabah. *Island*: [West] Mantanani group; [North] Pulau Banggi. *Mainland:* No record.

Remarks. Endemic to Sabah. Only found in Pulau Mantanani Besar and Pulau Balambangan, which are close to the Palawan archipelago in the Philippines.

Microcystina physotrochus Vermeulen, Liew & Schilthuizen, 2015

Figure 12B, C

Type locality. "Malaysia: Sabah: Sandakan–Kinabatangan Valley, Batu Keruak 2, near Sukau" (Vermeulen et al. 2015)

Examined materials. *Pulau Gaya*: BOR/MOL 8451, BOR/MOL 8457, BOR/MOL 8464, BOR/MOL 8478, BOR/MOL 8482, BOR/MOL 8447, BOR/MOL 8507, BOR/MOL 8498. *Pulau Lungisan*: V 9862 (Not seen).

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Lungisan. *Mainland:* West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Endemic to Borneo and widespread in Sabah. The specimen BOR/MOL 8457 consists of a single white, translucent shell (Figure 12C) which differs from other brown shells.

Microcystina muscorum van Benthem Jutting, 1959

Figure 12D

Type locality. "Indonesia: North Sumatra: Karo Regency–Berastagi" (van Benthem Jutting 1959)

Examined materials. *Pulau Dinawan*: BOR/MOL 8920, BOR/MOL 8903, BOR/MOL 8906, BOR/MOL 8907. *Pulau Manukan*: BOR/MOL 10306, BOR/

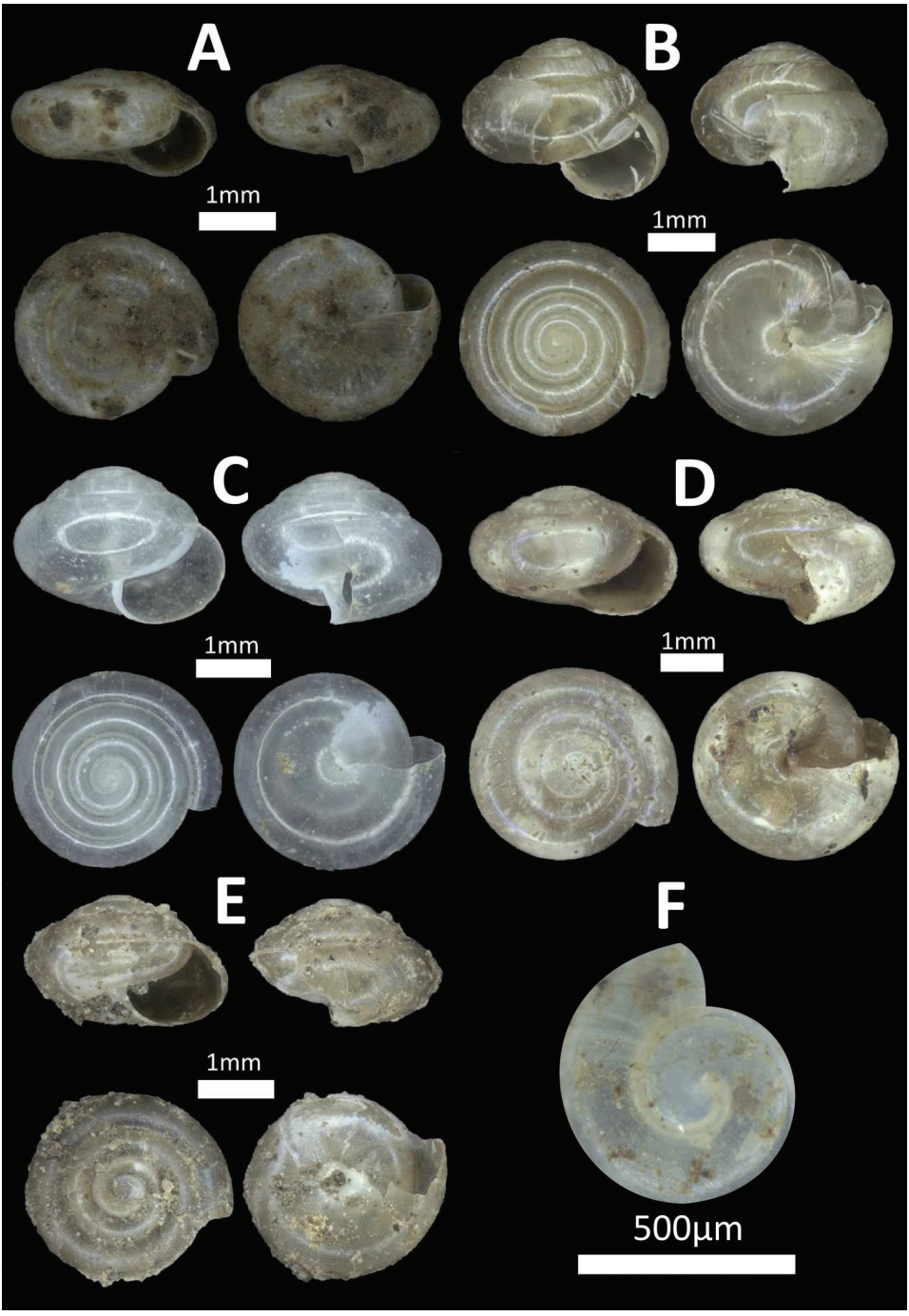

Figure 12. Family Ariophantidae. **A** *Microcystina callifera* (BOR/MOL 7176) **B** *Microcystina physotrochus* (BOR/MOL 8457) **C** *Microcystina physotrochus* (BOR/MOL 857) **D** *Microcystina muscorum* (BOR/MOL 8920) **E** *Microcystina* sp. 1 (BOR/MOL 1286) *Probably juvenile **F** *Microcystina* sp. 2 (BOR/MOL 10352) *Broken shell.

MOL 10315, BOR/MOL 10323, BOR/MOL 10565. *Pulau Gaya*: BOR/MOL 10360. *Pulau Mantukod*: BOR/MOL 11066, BOR/MOL 10994, BOR/MOL 12465. *Pulau Tiga*: BOR/MOL 8439, BOR/MOL 8416, BOR/MOL 11080. *Pulau Sapangar*: BOR/MOL 11970, BOR/MOL 11995. *Pulau Labuan*: BOR/MOL 12179, BOR/MOL 12197. *Pulau Mengalum*: BOR/MOL 12286.

Distribution in Sabah. *Island*: [West] Pulau Dinawan, Pulau Manukan, Pulau Mantukod, Pulau Gaya, Pulau Tiga, Pulau Sapangar, Pulau Labuan, Pulau Mengalum; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Sibuan. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Microcystina* sp. 1**
Figure 12E

Type locality. Not applicable.

Examined materials. *Pulau Labuan*: BOR/MOL 12486.

Distribution in Sabah. *Island*: [West] Pulau Labuan. *Mainland:* No record.

Remarks. Morphology differs from others *Microcystina* species in Sabah which was revised recently by Vermeulen et al. (2015).

***Microcystina* sp. 2**
Figure 12F

Type locality. Not applicable

Examined materials. *Pulau Peduk*: BOR/MOL 10352.

Distribution in Sabah. *Island*: [West] Pulau Peduk. *Mainland*: No record.

Remarks. Morphology differs from others *Microcystina* species in Sabah which was revised recently by Vermeulen et al. (2015).

FAMILY BRADYBAENIDAE

***Bradybaena similaris* (Férussac, 1821)**
Figure 13

Type locality. "Indonesia: East Nusa Tenggara–Timor" (Férussac 1821)

Examined materials. *Pulau Mamutik*: BOR/MOL 6299, BOR/MOL 6763, BOR/MOL 6766, BOR/MOL 10327, BOR/MOL 10564. *Pulau Labuan*: BOR/MOL 8669, BOR/MOL 8803, BOR/MOL 12165. *Pulau Kuraman*: BOR/MOL 8623, BOR/MOL 12125. *Pulau Sapangar*: BOR/MOL 12012.

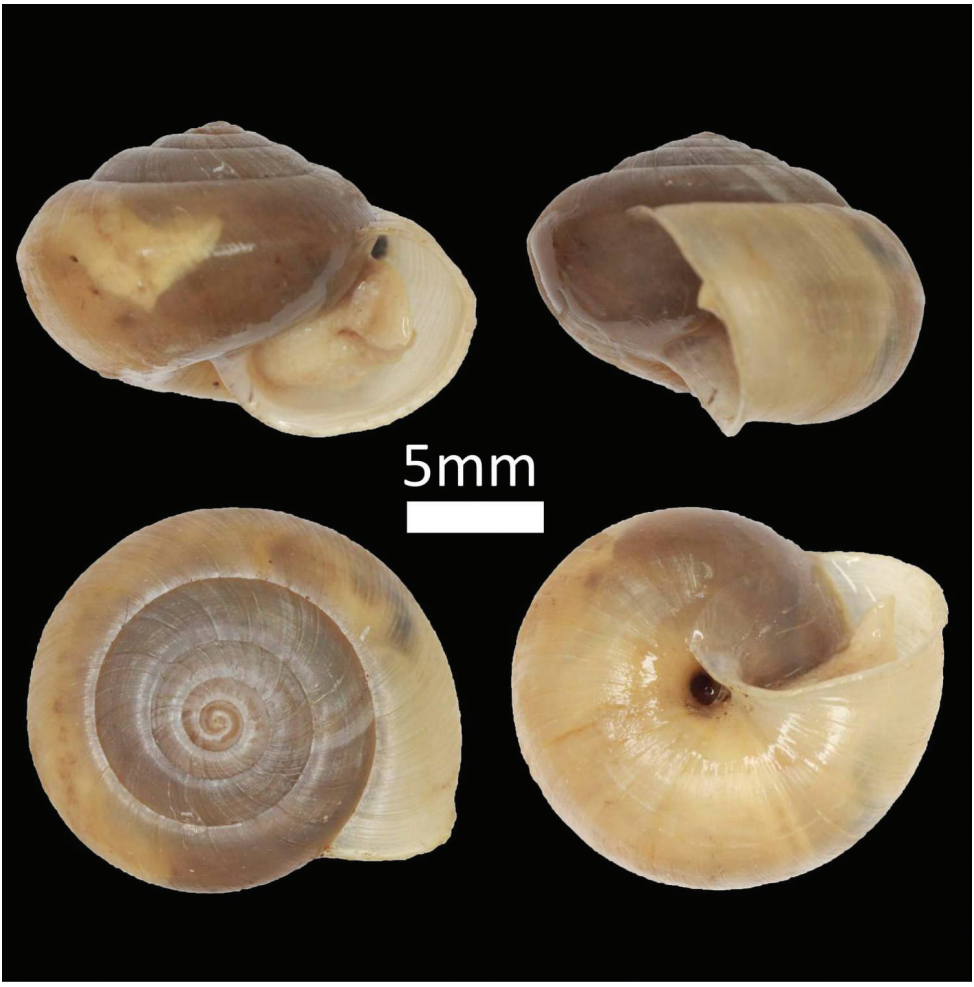

Figure 13. Family Bradybaenidae. *Bradybaena similaris* (BOR/MOL 6766).

Distribution in Sabah. *Island*: [West] Pulau Mamutik, Pulau Labuan, Pulau Kuraman, Pulau Sapangar; [North] Pulau Banggi. *Mainland*: West Coast Division, Sandakan Division, and Tawau Division.

Remarks. Introduced and widespread in Sabah.

FAMILY CAMAENIDAE

***Amphidromus adamsi adamsi* (Reeve, 1848)**
Figure 14A

Type locality. "Malaysia: Sabah: Kudat–Banguey island" (Fulton 1896)

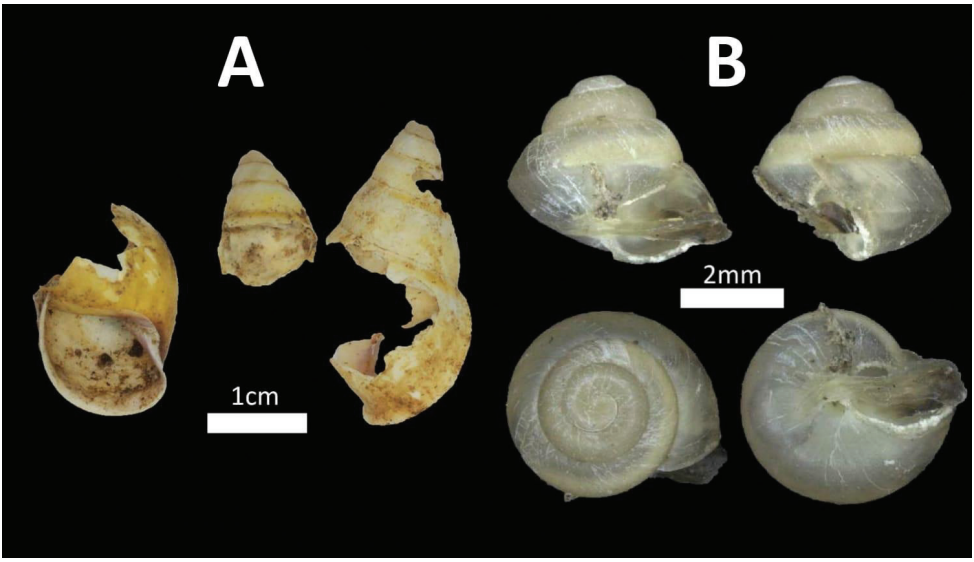

Figure 14. Family Camaenidae. **A** *Amphidromus adamsi adamsi* (BOR/MOL 3712) *Broken shell **B** *Ganesella tigaensis* (BOR/MOL 6573) *Juvenile.

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3712, BOR/MOL 7192, BOR/MOL 7202. *Pulau Mantanani Kecil*: BOR/MOL 3735.

Distribution in Sabah. *Island*: [West] Mantanani group; [North] Pulau Balambangan, Pulau Banggi. *Mainland*: No record.

Remarks. Only found in Pulau Mantanani Besar and Pulau Balambangan, which are close to the Palawan archipelago in the Philippines. All specimens from the Mantanani Island group are broken shells.

***Ganesella tigaensis* (Godwin-Austen, 1891)**
Figure 14B

Type locality. "Malaysia: Sabah: Kuala Penyu–Tiga Island" (Godwin-Austen 1891)

Examined materials. *Pulau Tiga*: BOR/MOL 6573.

Distribution in Sabah. *Island*: [West] Pulau Tiga. *Mainland*: No record.

Remarks. Endemic to Pulau Tiga.

FAMILY CHAROPIDAE

***Discocharopa aperta* (Von Moellendorff, 1888)**
Figure 15A

Type locality. "Philippines: Rizal: Montalban" (Von Moellendorff 1888)

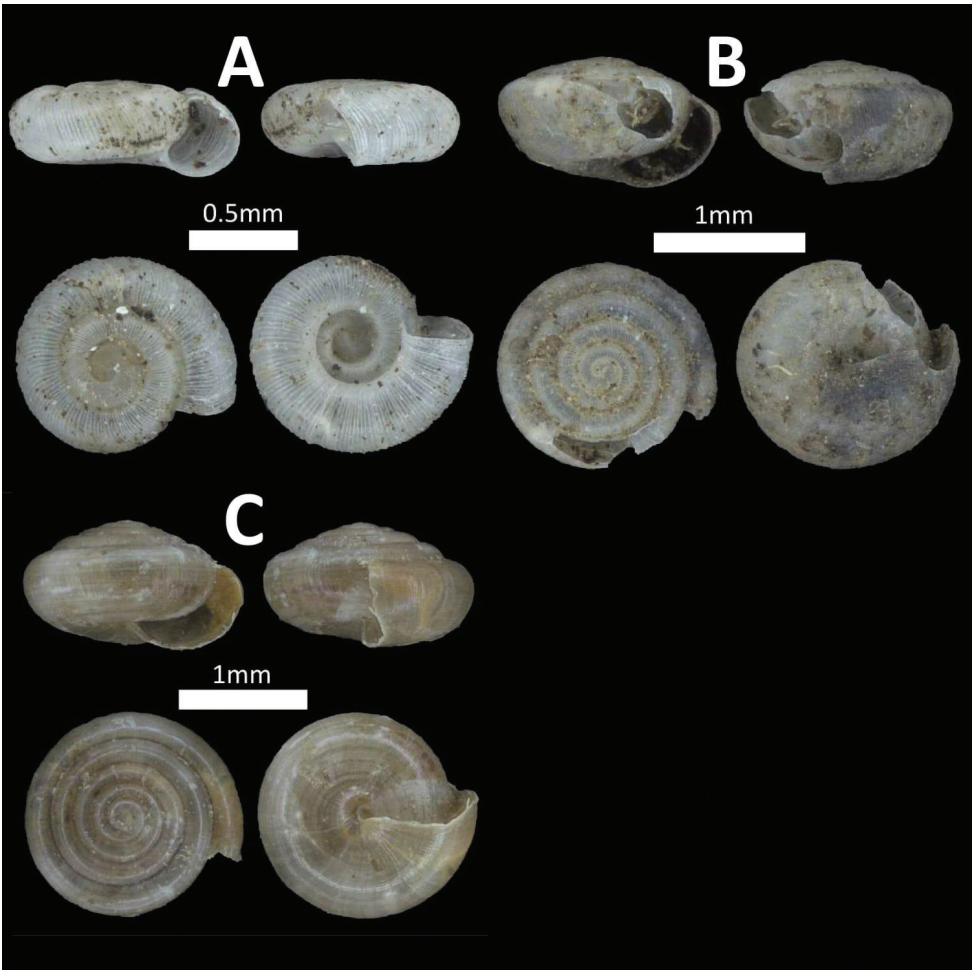

Figure 15. Family Charopidae. **A** *Discocharopa aperta* (BOR/MOL 11092) **B** *Charopa* sp "jugalis" (BOR/MOL 11989) **C** *Charopa* sp "lissobasis" (BOR/MOL 12180).

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3711, BOR/MOL 7165, BOR/MOL 7175, BOR/MOL 7188. *Pulau Mantanani Kecil*: BOR/MOL 7199, BOR/MOL 3736. *Pulau Lungisan*: BOR/MOL 3747. *Pulau Tiga*: BOR/MOL 11092. *Pulau Kuraman*: BOR/MOL 12106. *Pulau Rusukan Besar*: BOR/MOL 12259.

Distribution in Sabah. *Island*: [West] Mantanani Group, Pulau Tiga, Pulau Kuraman, Pulau Rusukan Besar; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Selakan, Pulau Tetagan. *Mainland*: West Coast Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Charopa* sp. "jugalis"**
Figure 15B

Type locality. Not applicable.

Examined materials. *Pulau Sapangar*: BOR/MOL 11989.

Distribution in Sabah. *Island*: [West] Pulau Sapangar. *Mainland*: Sandakan Division, Tawau Division and Interior Division.

Remarks. Provisional working species name based on a manuscript in preparation. Endemic to Borneo. Widespread in Sabah. Only single shell found in Pulau Sapangar.

***Charopa* sp. "lissobasis"**
Figure 15C

Type locality. Not applicable.

Examined materials. Pulau Labuan: BOR/MOL 12180.

Distribution in Sabah. *Island*: [West] Pulau Labuan. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Provisional working species name based on a manuscript in preparation. Endemic and widespread in Sabah. Only single shell found in Pulau Labuan.

FAMILY DYAKIIDAE

***Everettia jucunda* (Pfeiffer, 1863)**
Figure 16A

Type locality. "Malaysia: Sabah: Labuan" (Pfeiffer 1863)

Examined materials. *Pulau Tiga*: BOR/MOL 932, BOR/MOL 4237, BOR/MOL 4261, BOR/MOL 6566, BOR/MOL 6569, BOR/MOL 6601, BOR/MOL 6609, BOR/MOL 6611, BOR/MOL 6597, BOR/MOL 6576, BOR/MOL 6579, BOR/MOL 8413, BOR/MOL 8441, BOR/MOL 8443, BOR/MOL 8419, BOR/MOL 8514, BOR/MOL 8516, BOR/MOL 8520, BOR/MOL 8597, BOR/MOL 11088, BOR/MOL 11090, BOR/MOL 11095, BOR/MOL 11105, BOR/MOL 11111, BOR/MOL 11116. *Pulau Labuan*: BOR/MOL 6671, BOR/MOL 7912, BOR/MOL 7916, BOR/MOL 7918, BOR/MOL 7919, BOR/MOL 7920, BOR/MOL 8796, BOR/MOL 12225, BOR/MOL 12448, BOR/MOL 12450, BOR/MOL 12451, BOR/MOL 12453, BOR/MOL 12454, BOR/MOL 12457.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Labuan. *Mainland:* Interior Division.

Remarks. Endemic to Borneo.

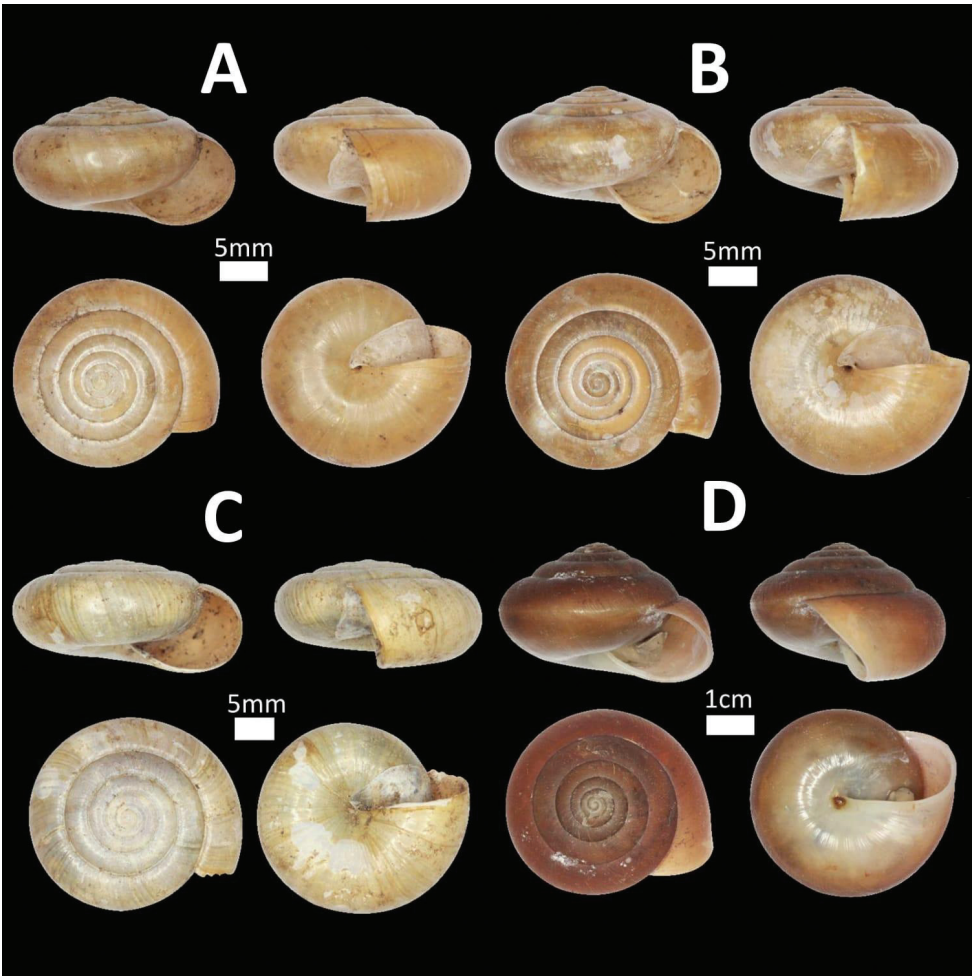

Figure 16. Family Dyakiidae. **A** *Everettia jucunda* (BOR/MOL 8419) **B** *Everettia subconsul* (BOR/MOL 12121) **C** *Everettia* sp. (BOR/MOL 12491) **D** *Quantula striata* (BOR/MOL 7923).

***Everettia subconsul* (Smith, 1887)**
Figure 16B

Type locality. "North Borneo" (Smith 1887)

Examined materials. *Pulau Gaya*: BOR/MOL 6617, BOR/MOL 6642, BOR/MOL 6644, BOR/MOL 6645, BOR/MOL 6666, BOR/MOL 6667, BOR/MOL 6677, BOR/MOL 6679, BOR/MOL 8479, BOR/MOL 8491, BOR/MOL 8499, BOR/MOL 8510, BOR/MOL 8511, BOR/MOL 8521, BOR/MOL 8852, BOR/MOL 9719, BOR/MOL 10366, BOR/MOL 11117. *Pulau Mengalum*: BOR/MOL 6158, BOR/MOL 6167, BOR/MOL 12327, BOR/MOL 12329, BOR/MOL 12346, BOR/MOL 12348, BOR/MOL 12304, BOR/MOL 12347. *Pulau Sapangar*: BOR/

MOL 6783, BOR/MOL 6785, BOR/MOL 6787, BOR/MOL 6790, BOR/MOL 6793, BOR/MOL 6795, BOR/MOL 6797, BOR/MOL 6779, BOR/MOL 6781, BOR/MOL 12007, BOR/MOL 12008, BOR/MOL 12009, BOR/MOL 11972, BOR/MOL 11973, BOR/MOL 11992, BOR/MOL 12010, BOR/MOL 12017, BOR/MOL 12018, BOR/MOL 12019, BOR/MOL 12020, BOR/MOL 12021. *Pulau Kuraman*: BOR/MOL 8613, BOR/MOL 8627, BOR/MOL 8628, BOR/MOL 8633, BOR/MOL 8637, BOR/MOL 8645, BOR/MOL 8648, BOR/MOL 8654, BOR/MOL 12104, BOR/MOL 12113, BOR/MOL 12119, BOR/MOL 12121, BOR/MOL 12122, BOR/MOL 12132, BOR/MOL 12133, BOR/MOL 12135, BOR/MOL 12141, BOR/MOL 12142, BOR/MOL 12146. *Pulau Rusukan Besar*: BOR/MOL 12264, BOR/MOL 12269.

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Mengalum, Pulau Sapangar, Pulau Kuraman, Pulau Rusukan Besar; [North] Pulau Banggi, Pulau Balambangan. *Mainland:* West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Endemic and widespread in Sabah.

***Everettia* sp.**
Figure 16C

Type locality. Not applicable.

Examined materials. *Pulau Labuan*: BOR/MOL 7905.

Distribution in Sabah. *Island*: [West] Pulau Labuan. *Mainland*: No record.

Remarks. Morphology found to differ from other known *Everettia* species in Sabah based on comparisons with materials from Liew et al. (2009).

***Quantula striata* (Gray, 1834)**
Figure 16D

Type locality. Not stated.

Examined materials. *Pulau Labuan*: BOR/MOL 7923, BOR/MOL 7924, BOR/MOL 8812, BOR/MOL 8815, BOR/MOL 12163, BOR/MOL 12170, BOR/MOL 12182, BOR/MOL 12189, BOR/MOL 12190, BOR/MOL 12216, BOR/MOL 12447, BOR/MOL 12449, BOR/MOL 12452, BOR/MOL 12487. *Pulau Papan*: BOR/MOL 7819, BOR/MOL 7820, BOR/MOL 7829, BOR/MOL 7832, BOR/MOL 7833, BOR/MOL 12056, BOR/MOL 12057, BOR/MOL 12061, BOR/MOL 12067, BOR/MOL 12071, BOR/MOL 12074, BOR/MOL 12076, BOR/MOL 12077, BOR/MOL 12078.

Distribution in Sabah. *Island*: [West] Pulau Labuan, Pulau Papan. *Mainland*: No record.

Remarks. Introduced to Sabah. This is the first record of this species in Sabah.

FAMILY ELLOBIIDAE

Pythia chrysostoma Tapparone Canefri, 1883

Figure 17

Type locality. "Indonesia: North Maluku: Ternate–near house of Sultan" (Tapparone Canefri 1883)

Examined materials. *Pulau Tiga*: BOR/MOL 6605, BOR/MOL 7866, BOR/MOL 8429, BOR/MOL 11106. *Pulau Gaya*: BOR/MOL 6619, BOR/MOL 6673, BOR/MOL 6690, BOR/MOL 8484, BOR/MOL 8512. *Pulau Sapangar*: BOR/MOL

Figure 17. Family Ellobiidae. *Pythia chrysostoma* (BOR/MOL 12272).

6798, BOR/MOL 12003, BOR/MOL 12004, BOR/MOL 12016. *Pulau Udar Besar*: BOR/MOL 6801, BOR/MOL 11077, BOR/MOL 11078. *Pulau Mantanani Besar*: BOR/MOL 7167. *Pulau Mantanani Kecil*: BOR/MOL 7197. *Pulau Lungisan*: BOR/MOL 3751. *Pulau Dinawan*: BOR/MOL 7699. *Pulau Labuan*: BOR/MOL 8810, BOR/MOL 12164. *Pulau Mamutik*: BOR/MOL 10002, BOR/MOL 10010, BOR/MOL 10026. *Pulau Sulug*: BOR/MOL 10342, BOR/MOL 10347. *Pulau Manukan*: BOR/MOL 10343, BOR/MOL 10344. *Pulau Peduk*: BOR/MOL 10357. *Pulau Papan*: BOR/MOL 12062. *Pulau Mengalum*: BOR/MOL 12325, BOR/MOL 12277, BOR/MOL 12280, BOR/MOL 12281, BOR/MOL 12285. *Pulau Rusukan Kecil*: BOR/MOL 12158, BOR/MOL 12159. *Pulau Kuraman*: BOR/MOL 12137. *Pulau Rusukan Besar*: BOR/MOL 12272. *Pulau Usukan*: BOR/MOL 12275. *Pulau Burong*: BOR/MOL 12334.

Distribution in Sabah. *Island*: [West] Mantanani group, Tunku Abdul Rahman Park, Labuan Marine Park, Pulau Tiga, Pulau Mengalum, Pulau Labuan, Pulau Papan, Pulau Usukan, Pulau Burong, Pulau Sapangar, Pulau Udar Besar; [North] Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Sebangkat, Pulau Mantabuan, Pulau Sibuan, Pulau Maiga, Pulau Bohey Dulang. *Mainland:* Kudat Division, Tawau Division

Remarks. Widespread in Sabah.

FAMILY EUCONULIDAE

***Kaliella doliolum* (Pfeiffer, 1846)**
Figure 18A

Type locality. "Philippines: Cebu: Sibonga" (Pfeiffer 1846)

Examined materials. *Pulau Tiga*: BOR/MOL 853, BOR/MOL 2701, BOR/MOL 8609, BOR/MOL 8610, BOR/MOL 6593, BOR/MOL 6600, BOR/MOL 6614, BOR/MOL 7862, BOR/MOL 7864, BOR/MOL 7865, BOR/MOL 8412, BOR/MOL 8433, BOR/MOL 8420, BOR/MOL 8599, BOR/MOL 8600, BOR/MOL 11082, BOR/MOL 11097. *Pulau Papan*: BOR/MOL 7823, BOR/MOL 7824. *Pulau Rusukan Besar*: BOR/MOL 8561, BOR/MOL 8565, BOR/MOL 8566, BOR/MOL 12230, BOR/MOL 12248, BOR/MOL 12261. *Pulau Kuraman*: BOR/MOL 8617, BOR/MOL 8618, BOR/MOL 8640, BOR/MOL 8652, BOR/MOL 8657, BOR/MOL 12100, BOR/MOL 12115, BOR/MOL 12129, BOR/MOL 12143. *Pulau Labuan*: BOR/MOL 8668, BOR/MOL 12455. *Pulau Dinawan*: BOR/MOL 8913, BOR/MOL 10991. *Pulau Sulug*: BOR/MOL 10329, BOR/MOL 10335. *Pulau Sapangar*: BOR/MOL 11999, BOR/MOL 11994. *Pulau Mengalum*: BOR/MOL 12298, BOR/MOL 12306, BOR/MOL 12318. *Pulau Pandan Pandan*: BOR/MOL 12468.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Papan, Pulau Rusukan Besar, Pulau Kuraman, Pulau Labuan, Pulau Dinawan, Pulau Sulug, Pulau Sapangar, Pulau Mengalum, Pulau Pandan Pandan; [North] Pulau Banggi, Pulau Balambangan;

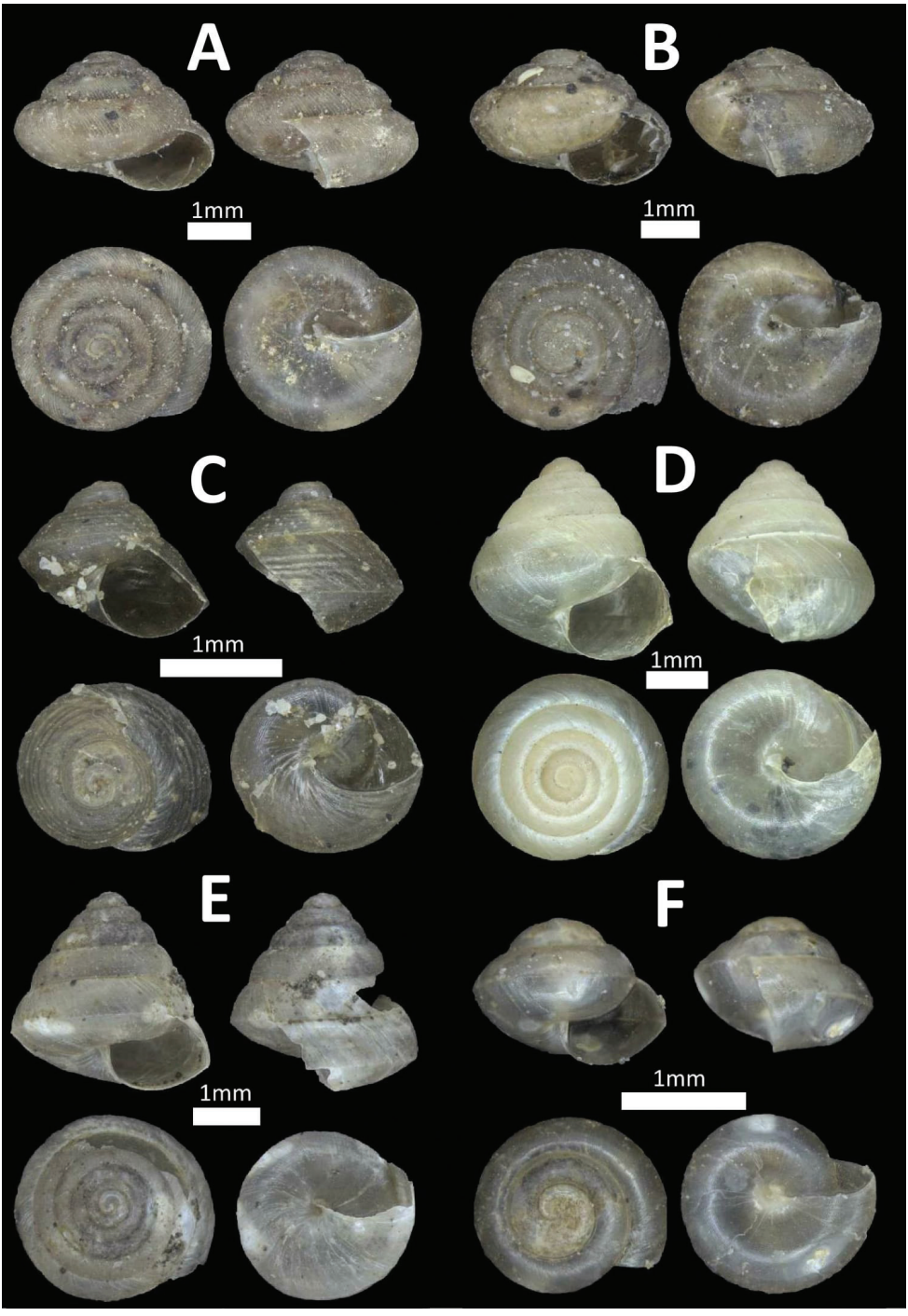

Figure 18. Family Euconulidae. **A** *Kaliella doliolum* (BOR/MOL 11994) **B** *Kaliella scandens* (BOR/MOL 6688) **C** *Kaliella dendrophila* (BOR/MOL 11971) *Juvenile **D** *Kaliella calculosa* (BOR/MOL 10989) **E** *Kaliella microconus* (BOR/MOL 12202) **F** *Kaliella barrakporensis* (BOR/MOL 12461) *Juvenile.

[East] Pulau Bohey Dulang, Pulau Tetagan, Pulau Mantabuan, Pulau Sibuan, Pulau Maiga. *Mainland:* Interior Division and Sandakan Division.

Remarks. Widespread in Sabah.

Kaliella scandens (Cox, 1871)

Figure 18B

Type locality. "Australia: New South Wales–Port Macquarie" (Cox 1871)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3710, BOR/MOL 7160, BOR/MOL 7190. *Pulau Mantanani Kecil*: BOR/MOL 3737, BOR/MOL 7198. *Pulau Mengalum*: BOR/MOL 6171, BOR/MOL 12309. *Pulau Gaya*: BOR/MOL 6621, BOR/MOL 6686, BOR/MOL 8465, BOR/MOL 8472, BOR/MOL 8448, BOR/MOL 8504, BOR/MOL 8509, BOR/MOL 8486, BOR/MOL 8497, BOR/MOL 9724. *Pulau Sapi*: BOR/MOL 6688, BOR/MOL 10290. *Pulau Sapangar*: BOR/MOL 6778, BOR/MOL 11980, BOR/MOL 12517. *Pulau Labuan*: BOR/MOL 7915, BOR/MOL 7921, BOR/MOL 7925, BOR/MOL 12198, BOR/MOL 12203, BOR/MOL 12351, BOR/MOL 12352. *Pulau Dinawan*: BOR/MOL 7686, BOR/MOL 7689, BOR/MOL 7690, BOR/MOL 9718. *Pulau Tiga*: BOR/MOL 8421. *Pulau Rusukan Kecil*: BOR/MOL 8553, BOR/MOL 8608, BOR/MOL 8547, BOR/MOL 8548, BOR/MOL 12152. *Pulau Rusukan Besar*: BOR/MOL 8563, BOR/MOL 8569, BOR/MOL 8570, BOR/MOL 8581, BOR/MOL 12232, BOR/MOL 12250. *Pulau Mamutik*: BOR/MOL 10004, BOR/MOL 10016, BOR/MOL 10020. *Pulau Manukan*: BOR/MOL 10313. *Pulau Sulug*: BOR/MOL 10337. *Pulau Peduk*: BOR/MOL 10349, BOR/MOL 10355. *Pulau Udar Kecil*: BOR/MOL 10372, BOR/MOL 10377. *Pulau Udar Besar*: BOR/MOL 11068, BOR/MOL 11073. *Pulau Mantukod*: BOR/MOL 10993, BOR/MOL 10997. *Pulau Usukan*: BOR/MOL 12034, BOR/MOL 12038, BOR/MOL 12046, BOR/MOL 12050, BOR/MOL 12476. *Pulau Papan*: BOR/MOL 12059.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar, Pulau Mantanani Kecil, Tunku Abdul Rahman Park, Pulau Mengalum, Pulau Sapangar, Pulau Labuan, Pulau Dinawan, Pulau Tiga, Pulau Rusukan Kecil, Pulau Rusukan Besar, Pulau Peduk, Pulau Udar Kecil, Pulau Udar Besar, Pulau Mantukod, Pulau Usukan, Pulau Papan; [North] Pulau Balambangan; [East] Pulau Bohey Dulang, Pulau Bod Gaya, Pulau Selakan. *Mainland:* Kudat Division, West Coast Division, Sandakan Division, Tawau Division and Interior Division.

Remarks. Widespread in Sabah.

Kaliella dendrophila (van Benthem Jutting, 1950)

Figure 18C

Type locality. "Indonesia: Java" (van Benthem Jutting 1950)

Examined materials. *Pulau Sapangar*: BOR/MOL 6789, BOR/MOL 11971, BOR/MOL 11981, BOR/MOL 11990. *Pulau Mantukod*: BOR/MOL 7859, BOR/MOL 11070, BOR/MOL 12464. *Pulau Gaya*: BOR/MOL 8462, BOR/MOL 8476. *Pulau Dinawan*: BOR/MOL 9717, BOR/MOL 8904. *Pulau Sapi*: BOR/MOL 10296. *Pulau Manukan*: BOR/MOL 10321. *Pulau Mengalum*: BOR/MOL 12291.

Distribution in Sabah. *Island*: [West] Pulau Sapangar, Pulau Mantukod, Pulau Gaya, Pulau Dinawan, Pulau Sapi, Pulau Manukan, Pulau Mengalum. *Mainland*: Interior Division and Sandakan Division.

Remarks. Widespread in Sabah.

***Kaliella calculosa* (Gould, 1852)**
Figure 18D

Type locality. "France Polynesia: Society Islands–Tahiti" (Gould 1852)

Examined materials. *Pulau Gaya*: BOR/MOL 6674, BOR/MOL 6675, BOR/MOL 10989. *Pulau Labuan*: BOR/MOL 7911, BOR/MOL 7902, BOR/MOL 7908, BOR/MOL 7909. *Pulau Kuraman*: BOR/MOL 8666.

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Labuan, Pulau Kuraman. *Mainland:* Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Kaliella microconus* (Mousson, 1865)**
Figure 18E

Type locality. "Fiji" (Mousson 1865)

Examined materials. *Pulau Gaya*: BOR/MOL 9725, BOR/MOL 10361. *Pulau Labuan*: BOR/MOL 12202, BOR/MOL 12223.

Distribution in Sabah. *Island*: [West] Pulau Gaya, Pulau Labuan; [North] Pulau Balambangan. *Mainland*: West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Kaliella barrakporensis* (Pfeiffer, 1852)**
Figure 18F

Type locality. "India: West Bengal: Kolkata–Barrakpore" (Pfeiffer 1852)

Examined materials. *Pulau Labuan*: BOR/MOL 12199, BOR/MOL 12461.

Distribution in Sabah. *Island*: [West] Pulau Labuan. *Mainland*: West Coast Division, Interior Division Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

FAMILY STREPTAXIDAE

***Huttonella bicolor* (Hutton, 1834)**
Figure 19

Type locality. "India: Uttar Pradesh: Mirzapur" (Hutton 1834)

Examined materials. *Pulau Labuan*: BOR/MOL 12174, BOR/MOL 12213, BOR/MOL 12458. *Pulau Mamutik*: BOR/MOL 10007, BOR/MOL 10022. *Pulau Udar Kecil*: BOR/MOL 10374. *Pulau Usukan*: BOR/MOL 12030, BOR/MOL 12473. *Pulau Rusukan Besar*: BOR/MOL 12233.

Distribution in Sabah. *Island*: [West] Pulau Labuan, Pulau Mamutik, Pulau Udar Kecil, Pulau Usukan, Pulau Rusukan Besar. *Mainland*: Sandakan Division.

Remarks. Introduced to Sabah.

FAMILY SUBULINIDAE

***Paropeas achatinaceum* (Pfeiffer, 1846)**
Figure 20A

Type locality. "Indonesia: Java" (Pfeiffer 1846)

Examined materials. *Pulau Tiga*: BOR/MOL 11081, BOR/MOL 11099, BOR/MOL 11083. *Pulau Mantukod*: BOR/MOL 12463. *Pulau Sapangar*: BOR/MOL 11978. *Pulau Labuan*: BOR/MOL 12178, BOR/MOL 12187, BOR/MOL 12205, BOR/MOL 12208, BOR/MOL 12218, BOR/MOL 12222, BOR/MOL 8811. *Pulau Rusukan Besar*: BOR/MOL 12229, BOR/MOL 12238, BOR/MOL 12240, BOR/MOL 12244, BOR/MOL 12262. *Pulau Burong*: BOR/MOL 12337. *Pulau Rusukan Kecil*: BOR/MOL 12355. *Pulau Papan*: BOR/MOL 12518. *Pulau Dinawan*: BOR/MOL 8908, BORMOL, 8916, BOR/MOL 8921. *Pulau Gaya*: BOR/MOL 12540. *Pulau Kuraman*: BOR/MOL 12101, BOR/MOL 12118, BOR/MOL 12123, BOR/MOL 12140, BOR/MOL 12150. *Pulau Mantanani Besar*: BOR/MOL 7166. *Pulau Mengalum:* BOR/MOL 12292, BOR/MOL 12299, BOR/MOL 12308, BOR/MOL 12317, BOR/MOL 12319, BOR/MOL 12323. *Pulau Pandan Pandan*: BOR/MOL 10382, BOR/MOL 10383, BOR/MOL 12467, BOR/MOL 12469. *Pulau Peduk*: BOR/MOL 10354. *Pulau Sulug*: BOR/MOL 10334. *Pulau Udar kecil*: BOR/MOL 10371. *Pulau Usukan*: BOR/MOL 12035, BOR/MOL 12049, BOR/MOL 12474.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Mantukod, Pulau Sapangar, Pulau Labuan, Pulau Rusukan Besar, Pulau Burong, Pulau Rusukan Kecil, Pulau Papan, Pulau Dinawan, Pulau Gaya, Pulau Kuraman, Pulau Mantanani Besar, Pulau Mengalum, Pulau Pandan Pandan, Pulau Peduk, Pulau Sulug, Pulau Udar Kecil and Pulau Usukan. *Mainland:* West Coast Division, Interior Division and Tawau Division.

Remarks. Widespread in Sabah.

Figure 19. Family Streptaxidae. *Huttonella bicolor* (BOR/MOL 10374).

***Allopeas gracile* (Hutton, 1834)**
Figure 20B

Type locality. "India: Uttar Pradesh: Mirzapur" (Hutton 1834)

Examined materials. *Pulau Gaya*: BOR/MOL 10362, BOR/MOL 8454, BOR/MOL 8458, BOR/MOL 8467, BOR/MOL 8496, BOR/MOL 8503. *Pulau Kuraman*: BOR/MOL 12117, BOR/MOL 12130. *Pulau Labuan*: BOR/MOL 12188, BOR/MOL 12195, BOR/MOL 7914. *Pulau Mamutik*: BOR/MOL 10013, BOR/MOL 10021, BOR/MOL 9999. *Pulau Mantanani Besar*: BOR/MOL 3671, BOR/MOL 3709, BOR/MOL 7178, BOR/MOL 7189. *Pulau Mantanani Kecil*: BOR/MOL 3738, BOR/MOL 3758, BOR/MOL 7195. *Pulau Mantukod*: BOR/MOL 10995, BOR/MOL 10996. *Pulau Manukan*: BOR/MOL 10304, BOR/MOL 10312

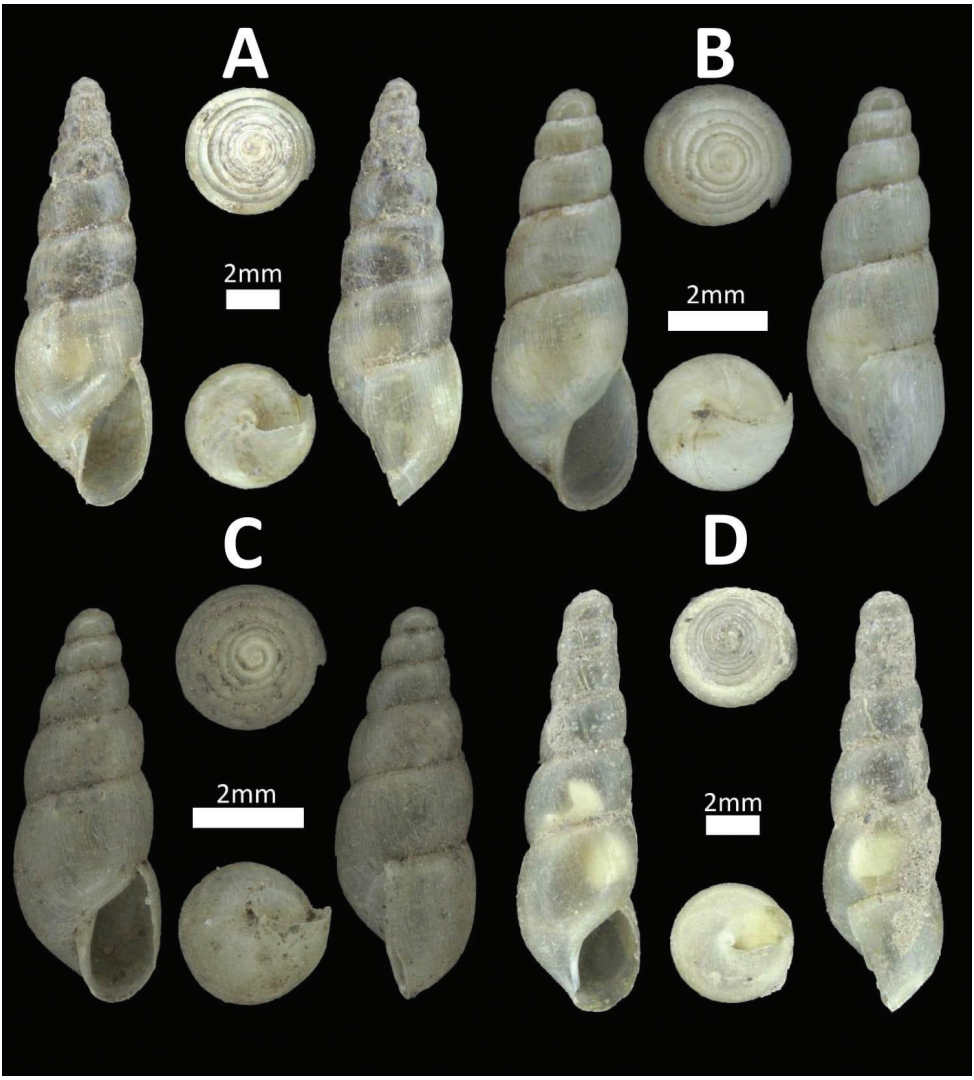

Figure 20. Family Subulinidae. **A** *Paropeas achatinaceum* (BOR/MOL 12518) **B** *Allopeas gracile* (BOR/MOL 12058) *Juvenile **C** *Allopeas clavulinum* (BOR/MOL 12539) **D** *Subulina octona* (BOR/MOL 12160).

BOR/MOL 10314, BOR/MOL 10317, BOR/MOL 10319, BOR/MOL 10322. *Pulau Mengalum*: BOR/MOL 12294, BOR/MOL 6160, BOR/MOL 6174. *Pulau Papan*: BOR/MOL 12058, BOR/MOL 12072, BOR/MOL 12073, BOR/MOL 12075, BOR/MOL 7822, BOR/MOL 7830, BOR/MOL 7831. *Pulau Rusukan Besar*: BOR/MOL 12231, BOR/MOL 12245, BOR/MOL 12258. *Pulau Rusukan Kecil*: BOR/MOL 12357. *Pulau Sapi*: BOR/MOL 10291, BOR/MOL 10297. *Pulau Sapangar*: BOR/MOL 11984, BOR/MOL 12002. *Pulau Sulug*: BOR/MOL 10328, BOR/MOL 10341. *Pulau Tiga*: BOR/MOL 6604, BOR/MOL 8415, BOR/MOL 8422, BOR/MOL 8437, BOR/MOL 8440, BOR/MOL 8598. Pulau Usukan: BOR/MOL 12042, BOR/MOL 12045, BOR/MOL 12479.

Distribution in Sabah. *Island:* [West] Pulau Gaya, Pulau Kuraman, Pulau Labuan, Pulau Mamutik, Pulau Mantanani Besar, Pulau Mantanani Kecil, Pulau Mantukod, Pulau Manukan, Pulau Mengalum, Pulau Papan, Pulau Rusukan Besar, Pulau Rusukan Kecil, Pulau Sapi, Pulau Sapangar, Pulau Sulug, Pulau Tiga, Pulau Usukan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bohey Dulang, Pulau Bod Gaya, Pulau Sebangkat, Pulau Tetagan, Pulau Mantabuan, Pulau Sibuan, Pulau Maiga. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

***Allopeas clavulinum* (Potiez & Michaud, 1838)**
Figure 20C

Type locality. "France: Reunion" (Potiez and Michaud 1838)

Examined materials. *Pulau Tiga*: BOR/MOL 2292. *Pulau Burong*: BOR/MOL 12539. *Pulau Labuan*: BOR/MOL 12541.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Burong, Pulau Labuan. *Mainland:* Kudat Division, West Coast Division, Interior Division, Sandakan Division and Tawau Division.

Remarks. Widespread in Sabah.

***Subulina octona* (Bruguière, 1789)**
Figure 20D

Type locality. "France: Antilles, Guadelupe, Dominican Republic" (Bruguière 1789)

Examined materials. *Pulau Udar Kecil*: BOR/MOL 7157, BOR/MOL 7158, BOR/MOL 10378, BOR/MOL 10384. *Pulau Manukan*: BOR/MOL 6748, BOR/MOL 6757, BOR/MOL 6758, BOR/MOL 10300, BOR/MOL 10305, BOR/MOL 10308, BOR/MOL 10320, BOR/MOL 6759, BOR/MOL 10325. *Pulau Dinawan:* BOR/MOL 7682, BOR/MOL 8918, BOR/MOL 8900, BOR/MOL 8910. *Pulau Rusukan Kecil*: BOR/MOL 8606, BOR/MOL 12153, BOR/MOL 12156, BOR/MOL 12160, BOR/MOL 12151. *Pulau Kuraman*: BOR/MOL 8616, BOR/MOL 8624, BOR/MOL 8625, BOR/MOL 8629, BOR/MOL 8634, BOR/MOL 8643, BOR/MOL 12112, BOR/MOL 12116, BOR/MOL 12124, BOR/MOL 12128, BOR/MOL 12131, BOR/MOL 12138, BOR/MOL 12148, BOR/MOL 12149. *Pulau Labuan*: BOR/MOL 8667, BOR/MOL 12204, BOR/MOL 12215. *Pulau Mamutik*: BOR/MOL 10001, BOR/MOL 10012, BOR/MOL 10017, BOR/MOL 10019, BOR/MOL 10024, BOR/MOL 10326. *Pulau Sapi*: BOR/MOL 10289, BOR/MOL 10292, BOR/MOL 10294. *Pulau Mantukod*: BOR/MOL 10998, BOR/MOL 10999. *Pulau Papan*: BOR/MOL 12064.

Distribution in Sabah. *Island*: [West] Pulau Udar Kecil, Pulau Manukan, Pulau Dinawan, Pulau Rusukan Kecil, Pulau Kuraman, Pulau Labuan, Pulau Mamutik, Pulau Sapi, Pulau Mantukod, Pulau Papan; [North] Pulau Banggi; [East] Pulau Se-

bangkat, Pulau Selakan, Pulau Mantabuan. *Mainland*: West Coast Division, Sandakan Division, Tawau Division.

Remarks. Introduced and widespread in Sabah.

FAMILY TROCHOMORPHIDAE

***Geotrochus conicoides* (Metcalfe, 1851)**
Figure 21A

Type locality. "Borneo" (Metcalfe 1851)

Examined materials. *Pulau Tiga*: BOR/MOL 899. *Pulau Gaya*: BOR/MOL 11119.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Gaya. *Mainland*: No record.

Remarks. The sample from Pulau Tiga was collected in 2000 and not found in the current survey.

***Videna metcalfei* (Pfeiffer, 1845)**
Figure 21B

Type locality. "Philippine: Cebu" (Pfeiffer 1845)

Examined materials. *Pulau Mengalum*: BOR/MOL 6161, BOR/MOL 6169, BOR/MOL 9992, BOR/MOL 9998, BOR/MOL 12283, BOR/MOL 12332, BOR/MOL 12350, BOR/MOL 12278, BOR/MOL 12293, BOR/MOL 12303, BOR/MOL 12311.

Distribution in Sabah. *Island*: [West] Pulau Mengalum; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Sebangkat, Pulau Selakan, Pulau Mantabuan, Pulau Selingaan. *Mainland*: Kudat Division, West Coast Division, Interior Division, Sandakan Division, and Tawau Division.

Remarks. Widespread in Sabah.

FAMILY VERTIGINIDAE

***Gastrocopta avanica* (Benson, 1863)**
Figure 22A

Type locality. "Myanmar: Mandalay region: Kyaukse: Ava" (Benson 1863)

Examined materials. *Pulau Tiga*: BOR/MOL 565. *Pulau Mengalum*: BOR/MOL 6164, BOR/MOL 6173, BOR/MOL 8729, BOR/MOL 8861, BOR/MOL 8864, BOR/MOL 12321, BOR/MOL 12328, BOR/MOL 12349, BOR/MOL 12289, BOR/MOL 12310. *Pulau Udar Kecil*: BOR/MOL 10373, BOR/MOL 10376. *Pulau Rusukan Besar*: BOR/MOL 12257, BOR/MOL 12263. *Pulau Burong*: BOR/MOL 12335. *Pulau Pandan Pandan*: BOR/MOL 12466. *Pulau Labuan*: BOR/MOL 12217.

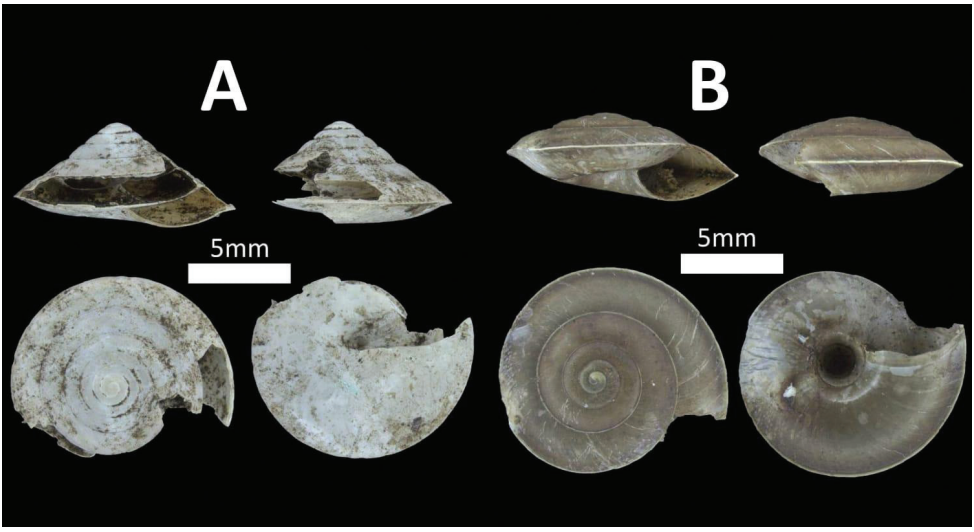

Figure 21. Family Trochomorphidae. **A** *Geotrochus conicoides* (BOR/MOL 899) *Broken shell **B** *Videna metcalfei* (BOR/MOL 12278).

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Mengalum, Pulau Udar Kecil, Pulau Rusukan Besar, Pulau Burong, Pulau Pandan Pandan, Pulau Labuan; [East] Pulau Selingaan. *Mainland*: Tawau Division.

Remarks. Widespread in Sabah on islands.

***Gastrocopta recondita* (Tapparone Canefri, 1883)**
Figure 22B

Type locality. "Indonesia: Maluku–Aru Islands, Wokam" (Tapparone Canefri 1883)

Examined materials. *Pulau Mantanani Kecil*: BOR/MOL 3739, BOR/MOL 7193, BOR/MOL 7194. *Pulau Mantanani Besar*: BOR/MOL 3708. *Pulau Lungisan*: BOR/MOL 3749. *Pulau Pandan Pandan*: BOR/MOL 7899. *Pulau Dinawan*: BOR/MOL 8914.

Distribution in Sabah. *Island*: [West] Mantanani group, Pulau Dinawan, Pulau Pandan Pandan; [East] Pulau Mantabuan, Pulau Sibuan, Pulau Maiga. *Mainland:* No record.

Remarks. Widespread in Sabah on islands.

***Nesopupa moreleti* (Brown, 1870)**
Figure 22C

Type locality. "Indonesia: Riau Islands–Natuna Island"

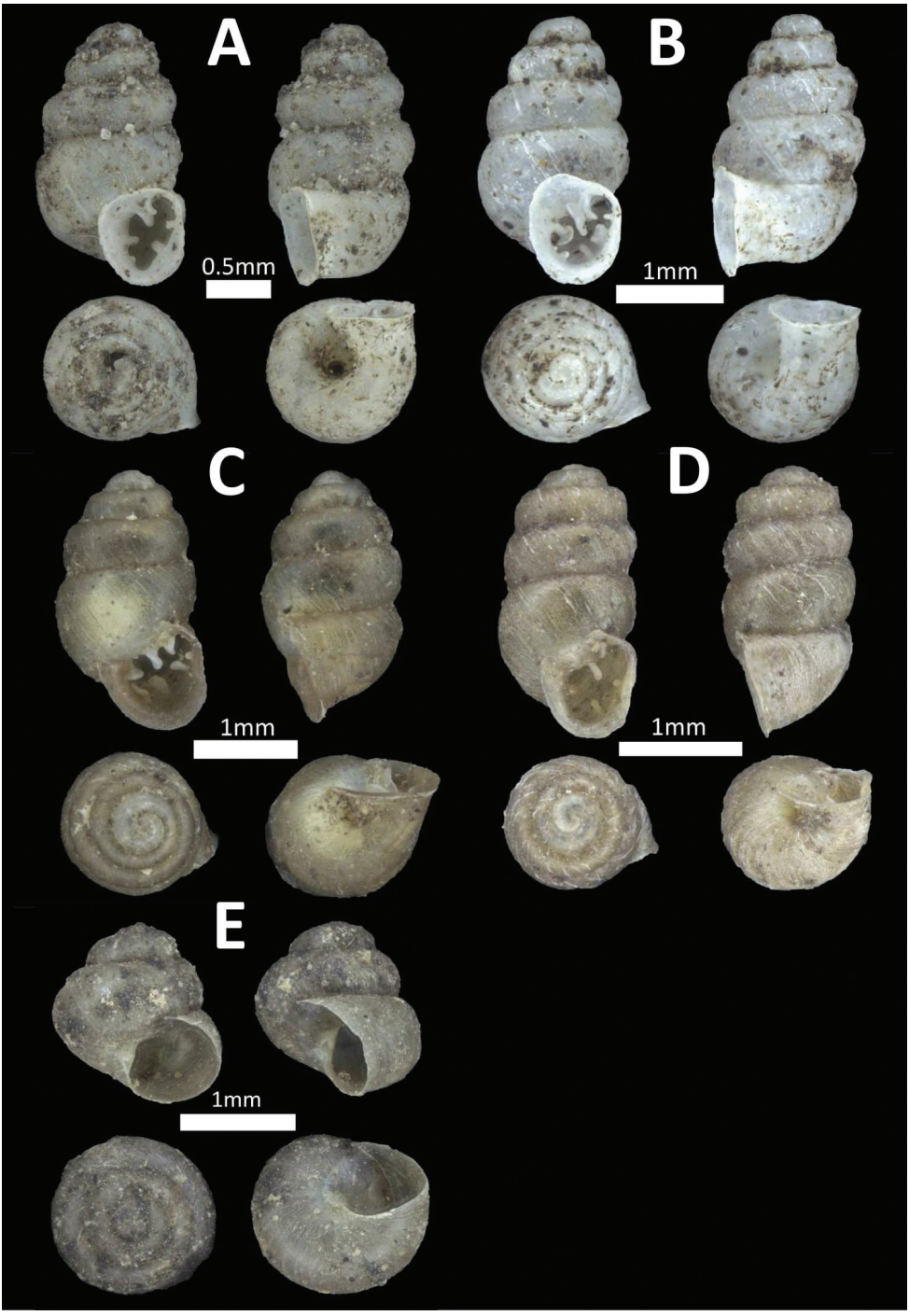

Figure 22. Family Vertiginidae. **A** *Gastrocopta avanica* (BOR/MOL 10376) **B** *Gastrocopta recondita* (BOR/MOL 8914) **C** *Nesopupa moreleti* (BOR/MOL 7182) **D** *Nesopupa malayana* (BOR/MOL 12324) **E** *Ptychopatula orcula* (BOR/MOL 11069).

Examined materials. *Pulau Tiga*: BOR/MOL 588, BOR/MOL 6603, BOR/MOL 11101. *Pulau Mantanani Besar*: BOR/MOL 7170, BOR/MOL 7182. *Pulau Dinawan*: BOR/MOL 7684, BOR/MOL 7691, BOR/MOL 12507. *Pulau Rusukan Besar*: BOR/MOL 8571, BOR/MOL 8580, BOR/MOL 12235, BOR/MOL 12251. *Pulau Kuraman*: BOR/MOL 8650, BOR/MOL 12110. *Pulau Mamutik*: BOR/MOL 10006, BOR/MOL 10015. *Pulau Sapi*: BOR/MOL 10295. *Pulau Sulug*: BOR/MOL 10340. *Pulau Peduk*: BOR/MOL 10351, BOR/MOL 10356. *Pulau Udar Kecil*: BOR/MOL 10381. *Pulau Udar Besar*: BOR/MOL 11072. *Pulau Usukan*: BOR/MOL 12036, BOR/MOL 12052, BOR/MOL 12472. *Pulau Sapangar*: BOR/MOL 11977.

Distribution in Sabah. *Island*: [West] Pulau Tiga, Pulau Mantanani Besar, Pulau Dinawan, Pulau Rusukan Besar, Pulau Kuraman, Pulau Mamutik, Pulau Sapi, Pulau Sulug, Pulau Peduk, Pulau Udar Kecil, Pulau Udar Besar, Pulau Usukan, Pulau Sapangar; [North] Pulau Banggi; [East] Pulau Bohey Dulang. *Mainland*: No record.

Remarks. Widespread in Sabah on islands.

***Nesopupa malayana* (Issel, 1874)**
Figure 22D

Type locality. "Borneo" (Issel 1874)

Examined materials. *Pulau Mantanani Kecil*: BOR/MOL 3740. *Pulau Mengalum*: BOR/MOL 12324. *Pulau Rusukan Besar*: BOR/MOL 12256. *Pulau Labuan*: BOR/MOL 12459.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Kecil, Pulau Mengalum, Pulau Rusukan Besar, Pulau Labuan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bod Gaya, Pulau Bohey Dulang, Pulau Sebangkat. *Mainland*: No record.

Remarks. Widespread in Sabah on islands.

***Ptychopatula orcula* (Benson, 1850)**
Figure 22E

Type locality. "India: Uttar Pradesh–between Jounpur and Benares" (Benson 1850)

Examined materials. *Pulau Mantanani Besar*: BOR/MOL 3707, BOR/MOL 7162, BOR/MOL 7181. *Pulau Lungisan*: BOR/MOL 3750. *Pulau Mengalum*: BOR/MOL 6165, BOR/MOL 6172, BOR/MOL 8862, BOR/MOL 9994, BOR/MOL 12322, BOR/MOL 12290, BOR/MOL 12301, BOR/MOL 12307, BOR/MOL 12314. *Pulau Tiga*: BOR/MOL 6607, BOR/MOL 6613, BOR/MOL 8432, BOR/MOL 8426, BOR/MOL 8428, BOR/MOL 11098, BOR/MOL 10992. *Pulau Udar Besar*: BOR/MOL 6800, BOR/MOL 6805, BOR/MOL 6806, BOR/MOL 6807, BOR/MOL 11069, BOR/MOL 11071, BOR/MOL 11074. *Pulau Sulug*: BOR/MOL 6774, BOR/MOL 6775, BOR/MOL 6776, BOR/MOL 10331, BOR/MOL 10336. *Pulau Dinawan*: BOR/MOL 7687, BOR/MOL 7688, BOR/MOL 9716.

Pulau Papan: BOR/MOL 7827, BOR/MOL 7828, BOR/MOL 7834, BOR/MOL 7836. *Pulau Gaya*: BOR/MOL 8469, BOR/MOL 8488. *Pulau Rusukan Besar*: BOR/MOL 8564, BOR/MOL 8572, BOR/MOL 8573, BOR/MOL 8587, BOR/MOL 12236, BOR/MOL 12239, BOR/MOL 12253. *Pulau Kuraman*: BOR/MOL 8619, BOR/MOL 8620, BOR/MOL 8641, BOR/MOL 8653, BOR/MOL 8665, BOR/MOL 12111, BOR/MOL 12147. *Pulau Mamutik*: BOR/MOL 10003, BOR/MOL 10011, BOR/MOL 10018. *Pulau Manukan*: BOR/MOL 10311, BOR/MOL 10990. *Pulau Peduk*: BOR/MOL 10350, BOR/MOL 10353. *Pulau Udar Kecil*: BOR/MOL 10380. *Pulau Rusukan Kecil*: BOR/MOL 12154, BOR/MOL 12353, BOR/MOL 12354. *Pulau Sapangar*: BOR/MOL 11979. *Pulau Labuan*: BOR/MOL 12196, BOR/MOL 12201.

Distribution in Sabah. *Island*: [West] Pulau Mantanani Besar, Pulau Lungisan, Pulau Mengalum, Pulau Tiga, Pulau Udar Besar, Pulau Sulug, Pulau Dinawan, Pulau Gaya, Pulau Papan, Labuan Marine Park, Pulau Mamutik, Pulau Manukan, Pulau Peduk, Pulau Udar Kecil, Pulau Sapangar, Pulau Labuan; [North] Pulau Banggi, Pulau Balambangan; [East] Pulau Bohey Dulang, Pulau Mantabuan, Pulau Maiga, Pulau Bod Gaya. *Mainland:* Interior Division and Sandakan Division.

Remarks. Widespread in Sabah.

Author contributions

Conceived and designed the sampling method: TSL, CCP. Conducted the field samplings: CCP. Materials and logistics: LTS, PCC, FTYY. Compiled and analysed data: CCP, LTS. Wrote the paper: CCP, TSL.

Acknowledgements

We thank various agencies for their permission to conduct this study on the islands: Sabah Parks for Tunku Abdul Rahman Park and Pulau Tiga Marine Park (permit TS/PTD/5/4 Jld.54(112)); Department of Marine Park Malaysia for Labuan Marine Park (permit JTLM630- 7 Jld.7(19)); Labuan Corporation for Pulau Labuan and Pulau Papan (permit PL/PEN/100- 4/10); Labuan Survey and Mapping Department for Timbalai Hill in Labuan (permit JUWPL(PEN)1/82JLD.4(2)); Sapangar Navy Base (TLDM) for Pulau Udar Kecil (permit MWL2.100- 2/2/3- (9)). We are also grateful to the staff of various agencies for providing logistic support for fieldwork: Justinus Guntabid, Muhammad Aliff bin Suhaimin, Victor Siam, Sukur B. Sukardi, Simon Limbawang and others (Sabah Parks); Anuar Deraman (Labuan Marine Park Department); Dr. Zulherry Isnain, Assoc. Prof. Dr. Rossita Hj. Shapawi (Universiti Malaysia Sabah); staff of Marudu Travel Express (Pulau Dinawan); Mazlan Bin Juhari, Hafiz Abdullah, Relly Martin (Emma Glorious Tours and Travel). We thank Simon Kuyun, Yeong Kam Cheng, Phung Kin Wah, Foo She Fui, and Chang Zi Yuan for their as-

sistance during fieldwork and laboratory work. Thanks to Foon Junn Kitt, Mathavan Vickneswaran and Assoc. Prof. Jason Lim for manuscript checking. Lastly, we thank the editor, Martin Haase and the reviewer, Menno Schilthuizen who have contributed significantly with their constructive comments to the improvement of the present paper.This research is supported by Research Acculturation Grant Scheme (RAGS), the Ministry of Higher Education Malaysia (RAG0063-STWN-2015).

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Supplementary material 1

Species list and occurrences

Authors: Chee-Chean Phung, Fred Tuh Yit Yu, Thor-Seng Liew

Data type: occurrence

Explanation note: An excel spreadsheet which provided following information: list of species, references for the species identification, occurrence of each species on every island and species richness of each island.

ZooKeys 673: 105–123 (2017)
doi: 10.3897/zookeys.673.12544
http://zookeys.pensoft.net

RESEARCH ARTICLE

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A preliminary checklist of the freshwater snails of Sabah (Malaysian Borneo) deposited in the BORNEENSIS collection, Universiti Malaysia Sabah

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Academic editor: *F. Köhler* | Received 6 March 2017 | Accepted 25 April 2017 | Published 15 May 2017

http://zoobank.org/EACC134E-B3FD-4545-B5DC-DD79E81EE9BD

Citation: Ng TH, Dulipat J, Foon JK, Lopes-Lima M, Zieritz A, Liew T-S (2017) A preliminary checklist of the freshwater snails of Sabah (Malaysian Borneo) deposited in the BORNEENSIS collection, Universiti Malaysia Sabah. ZooKeys 673: 105–123. https://doi.org/10.3897/zookeys.673.12544

Abstract

Sabah, a Malaysian state at the north-eastern tip of Borneo, is situated in one of the Earth's biodiversity hotspots yet its freshwater gastropod diversity remains poorly known. An annotated checklist of the freshwater gastropods is presented, based on specimens deposited in the *BORNEENSIS* collection of the Institute for Tropical Biology and Conservation at Universiti Malaysia Sabah, Malaysia. A KMZ file is also provided, which acts as a repository of digital images and complete collection data of all examined material, so that it can be shared and adapted to facilitate future research.

Keywords

Diversity, Kalimantan, Mollusca, non-marine gastropods, North Borneo, Sarawak

Introduction

Mollusca is the second most diverse animal phylum after Arthropoda, and nearly 4000 species of gastropods have been described from freshwater habitats alone (Strong et al. 2008). Freshwater gastropods achieve the highest diversity and endemism in tropical South-east Asia which includes the ancient lakes of Sulawesi (Indonesia) and Inle (Myanmar), as well as large river systems like the Mekong river basin (Strong et al. 2008). However, the total number of known species might represent only half of the species diversity, and many species remain to be discovered and described (Lydeard et al. 2004). In addition, although the IUCN conservation status has been assessed for only approximately 10% of these known species, freshwater gastropods account for 20% of recorded mollusc extinctions (Lydeard et al. 2004, Strong et al. 2008).

Although the number of extinct molluscs recorded in Asia is far less than other regions (Régnier et al. 2009), it may not reflect the reality that Asian malacofauna face a vast variety of threats (Köhler et al. 2012). Rather, this paradox is more likely due to the expertise and knowledge of freshwater gastropod being biased towards other regions (Bouchet 1997, Cuttelod et al. 2011, Johnson et al. 2013). Despite the high diversity of freshwater molluscs in South-east Asia, research involving freshwater snails has been mainly concentrated on the field of medical malacology, with most of the focus being on the zoonotic parasites hosted by these snails (e.g., Lim et al. 1976, TROPMED Medical Group 1986). As a result, little else is known about the molluscan hosts themselves. Seminal work done by van Benthem Jutting (e.g., 1956, 1959) and Brandt (1974) provided the most comprehensive insights into the diversity and distribution of freshwater molluscs in Indonesia, parts of Peninsular Malaysia, and Thailand. Decades later little progress has been made to update the information, where large knowledge gaps remain in the biodiversity, ecology and physiology of South-east Asian freshwater molluscs (Köhler et al. 2012).

Borneo, the third largest island in the world, is regarded as one of the Earth's biodiversity hotspots because of its high species richness and endemism and its highly threatened habitats (Myers et al. 2000). The overall diversity of freshwater gastropods in Borneo, however, remains poorly known compared to the rest of South-east Asia. Previous faunistic studies recorded not more than 30 freshwater gastropod species from Borneo (Issel 1874, Bock 1881, Aldrich 1889, von Martens and Thiele 1908, Solem 1964, Hill et al. 1997, Köhler and Glaubrecht 2002, Shabdin 2010, Ng et al. 2015a). In contrast, more than 300 freshwater gastropod species have been recorded in Indochina (Thailand, Myanmar, Laos, Cambodia) (Brandt 1974, Köhler et al. 2012) and from areas much smaller than Borneo. For example, in Java, more than 60 species are known (Marwoto et al. 2011) and in Singapore, around 20 species have been recorded (Clements et al. 2006, Tan et al. 2012, Ng et al. 2014, 2015b, 2016a, 2016b, 2016c).

In Borneo and particularly in the northern Malaysian state of Sabah (Figure 1), a complete species list that is based on primary data (i.e., based on accessible museum collections) does not exist. Previous studies of selected freshwater snails that focused

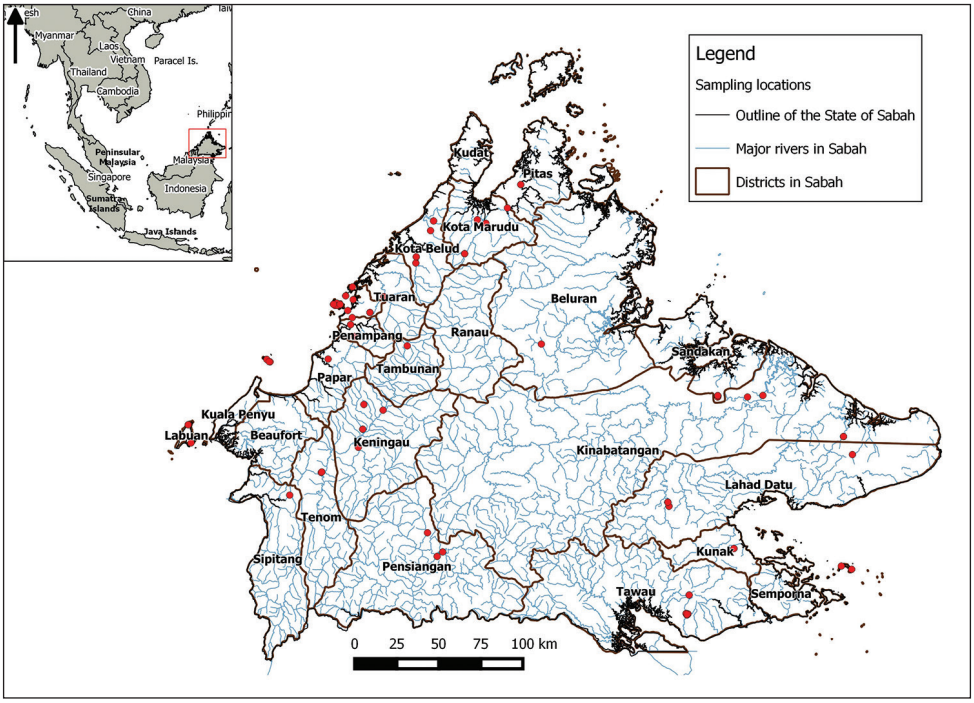

Figure 1. Map of Sabah with districts, major rivers and locations of the examined specimens (red dots). Inset shows the location of Sabah in South-east Asia.

on Sabah were limited to a few ecological (Supian and Ikhwanuddin 2002), parasitic (Lim et al. 1976), and pest control studies (Teo 2001, 2003, 2004). Presently, the task of identifying freshwater gastropods is complicated by the difficulty in obtaining comparative material from these past studies. Hence, an annotated checklist is provided for the freshwater gastropods in Sabah as a baseline framework and an identification tool for future studies. Instead of compiling species listed in previous studies or from unverifiable museum material, this checklist is based solely on the specimens collected from Sabah which are deposited in the *BORNEENSIS* collection of the Institute for Tropical Biology and Conservation at Universiti Malaysia Sabah, Malaysia.

All the specimens were catalogued using the *BORNEENSIS* Mollusca Collection in-house database, under the prefix of BOR/MOL #### to serve as stable specimen identifiers for future interrogation (e.g. Page 2016). In addition to the species list and representative images for each species, we also created a KMZ file as a repository of digital images and complete collection data of all the examined materials. All the specimen data are published under Creative Common license CC BY 4.0 so that it can be shared and adapted to facilitate future research (Meier and Dikow 2004, Miller et al. 2015). As the collection is based on a small number of surveys, this checklist is not a

complete checklist for Sabah freshwater gastropods but it serves as a starting point to explore the diversity and taxonomy of freshwater gastropods not only in Sabah, but also for the rest of Borneo.

Materials and methods

The freshwater gastropods deposited in the *BORNEENSIS* collection, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Malaysia (BOR/MOL), presently consists of 49 dry collection lots and 76 wet collection lots. A total of 849 specimens (between 1 and 59 specimens per lot) were examined. Approximately half of the collection lots were collected in 2016 by J. Dulipat, A. Zieritz, M. Lopes-Lima and T.S. Liew, whereas the rest were collected between 1997 and 2014. Most of the collections were made on the west coast of Sabah (Figure 1). The majority of the specimens were collected opportunistically and picked by hand and it is likely that smaller species were missed.

Identification was done to species level based on the shell morphology by referring to H. Adams (1874), A. Adams (1885), Smith (1894, 1895), von Martens and Thiele (1908), van Benthem Jutting (1956), Brandt (1974), and Tan et al. (2012). Synonymy follows Brandt (1974), Köhler and Glaubrecht (2001), Glaubrecht et al. (2009), Cowie (2015), and Eichhorst (2016). Distribution of each species in the checklist was summarised from the collection information, some of which contain words in the Malay language – *pulau*: island, *gua*: cave, *sungai*: river. The exact GPS coordinates for each collection lot was specified. If no exact GPS coordinates were available for a collection lot, approximate GPS coordinates were determined based on available locality information. Representative specimens of each of the collection lots were photograph using a single-lens reflex camera. Lastly, a KMZ file was created which consists of a main KML file and a supporting folder with all the photographs taken from each collection lot.

Results and discussion

In total, 18 species were identified, from 14 genera and nine families of freshwater gastropods, including four non-native species. Their details are provided in the checklist below. The number of species recorded in this list is similar to that of Singapore (20 species), which has a much smaller landmass compared to Sabah (Clements et al. 2008, Ng et al. 2014, 2015, 2016b, 2016c). As such, it is clear that this list represents only a small fraction of the total freshwater gastropod diversity in Sabah which, together with bivalves, have been estimated to be 100 species (Solem 1964). Nevertheless, this checklist presents complete specimen information (Suppl. materials 1 and 2) for nearly two-thirds of previously known taxa in Borneo (Issel 1874, von Martens and Thiele 1908, Solem 1964, Hill et al. 1997, Shabdin 2010, Ng et al. 2015a).

Systematics

Family AMPULLARIIDAE Gray
Genus *Pila* Röding, 1798

***Pila ampullacea* (Linnaeus, 1758)**
Figure 2A

Synonyms. *Helix ampullacea* Linnaeus, 1758; *Ampullaria sumatrensis* Philippi, 1851; *Ampullaria magnifica* Philippi, 1852; *Ampullaria turbinis* Lea, 1856; *Ampullaria ampullacea* var. *javensis* Nevill, 1885; *Ampullaria turbinis* var. *subglobosa* Nevill, 1885; *Ampullaria turbinis* var *subampullacea* Nevill, 1885; *Ampullaria dalyi* Blanford, 1903; *Pachylabra turbinis* race *lacustris* Annandale, 1920.

Material examined. BOR/MOL3378, BOR/MOL3773, BOR/MOL3775, BOR/MOL8671, BOR/MOL8673, BOR/MOL8675, BOR/MOL8708.

Distribution and habitat. Labuan, along the north-west coast of Sabah from Kota Belud, Kota Kinabalu, Penampang, to Papar, and in the interior town of Nabawan. Habitats include freshwater and mangrove swamps, ponds, and rivers.

Remarks. This species was purchased on two separate occasions (BOR/MOL3773, BOR/MOL8708), ten years apart, from the same native market in Penampang.

***Pila scutata* (Mousson, 1848)**
Figure 2B

Synonyms. *Ampullaria conica* W. Wood, 1828; *Ampullaria orientalis* Philippi, 1849; *Ampullaria borneensis* Philippi, 1852; *Ampullaria lubrica* Reeve, 1856; *Ampullaria vittata* Reeve, 1856; *Ampullaria complicata* Reeve, 1856; *Ampullaria stoliczkana* Nevill, 1877; *Ampullaria wellesleyensis* de Morgan, 1885; *Pachylabra javanica* var. *fruhstorferi* Kobelt, 1912; *Pachylabra* (*lubrica* var.?) *quadrasi* Kobelt, 1912.

Material examined. BOR/MOL1758.

Distribution and habitat. The single specimen was collected from a limestone hill in the Lower Kinabatangan valley.

Remarks. The species has previously been recorded from Tuaran and appeared to have been eaten by local communities (Lim et al. 1976).

Genus *Pomacea* Perry, 1810

***Pomacea* sp.**
Figure 2C

Material examined. BOR/MOL537, BOR/MOL1759, BOR/MOL8672, BOR/MOL8711.

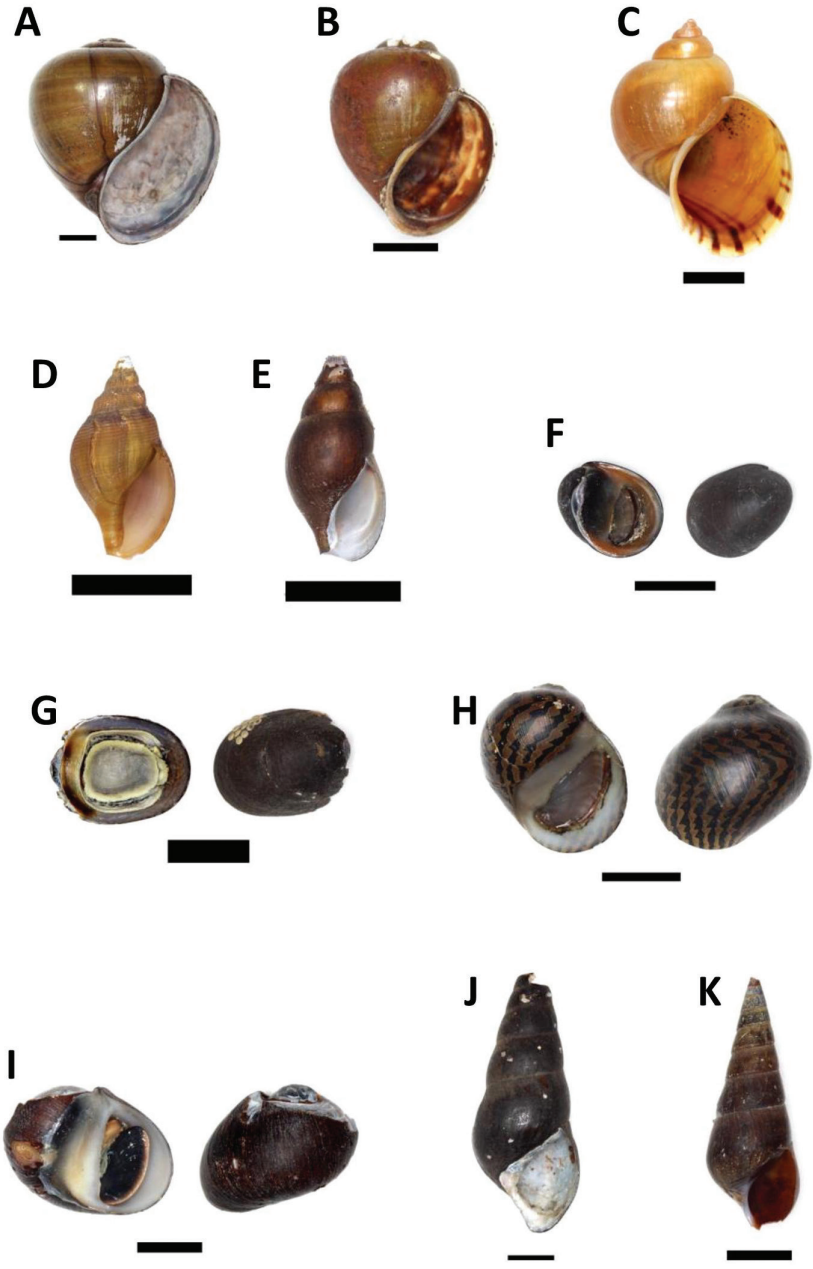

Figure 2. A–C Family Ampullariidae. **A** *Pila ampullacea* (Linnaeus, 1758) – BOR/MOL 8673 **B** *Pila scutata* (Mousson, 1848) – BOR/MOL 1758. **C** *Pomacea* sp. – BOR/MOL 1759 **D–E** Family Nassariidae **D** *Clea bangueyensis* EA Smith, 1895 – BOR/MOL 3397 **E** *Clea* sp. – BOR/MOL 8304 **F–I** Family Neritidae **F** *Neritina pulligera* (Linnaeus, 1767) – BOR/MOL 6705 **G** *Septaria porcellana* (Linnaeus, 1858) – BOR/MOL 8292 **H** *Vittina coromandeliana* (Sowerby, 1836) – BOR/MOL 8303. **I** *Vittina variegata* (Lesson, 1831) – BOR/MOL 6723 **J–K** Family Pachychilidae: *Sulcospira pageli* (Thiele, 1908) **J** BOR/MOL 1753 **K** BOR/MOL 3394. Scale bars 10 mm.

Distribution and habitat. Along the north-western coast from Kota Marudu to Kota Kinabalu and Tenom, and in the interior at Keningau. Habitats include freshwater swamps, rivers, and drains.

Remarks. Ampullariids of the genus *Pomacea* originate from South America and are globally-invasive, causing widespread damage to paddy fields in South-east Asia (Joshi and Sebastian 2006). The harm brought about by *Pomacea* prompted various studies to control their spread, including in Sabah (Teo 2001, 2003, 2004). *Pomacea canaliculata* was first recorded from the state in 1992 (Yahaya et al. 2006), and has previously been found in paddy fields in Tuaran, Tambunan and Keningau (Teo 2004). Another species, the morphologically similar *Pomacea maculata*, has been widely introduced to South-east Asia (Hayes et al. 2008, 2012) and may also be established in Sabah. However, fresh materials were unavailable to confirm the identity of *Pomacea* from Sabah using molecular methods, which are the best for distinguishing between the species (Matsukura et al. 2013).

Family NASSARIIDAE Iredale
Genus *Clea* H Adams & A Adams, 1855

***Clea bangueyensis* EA Smith, 1895**
Figure 2D

Material examined. BOR/MOL552, BOR/MOL553, BOR/MOL554, BOR/MOL1762, BOR/MOL3105, BOR/MOL3385, BOR/MOL3396, BOR/MOL3397, BOR/MOL3595, BOR/MOL6719, BOR/MOL8676.

Distribution and habitat. From northern to eastern Sabah: Kinabalu Park, Danum Valley, Tabin Wildlife Reserve, Kunak, and Tawau, and in the interior in Nabawan and Keningau. Collected from rivers and streams, some in the vicinity of limestone hills.

Remarks. This species was first described from Pulau Banggi, off the north-east coast of Sabah.

***Clea* sp.**
Figure 2E

Material examined. BOR/MOL8293, BOR/MOL8304, BOR/MOL8312, BOR/MOL8700.

Distribution and habitat. Found from two localities close to Kota Kinabalu, rivers on the offshore island of Pulau Gaya, and Kiansom forest, approximately 20km from the city.

Remarks. This species lacks the spiral striae of *Clea bangueyensis* and lacks the transverse striae of *Clea nigricans* A Adams, 1885, which was described from the neighbouring state of Sarawak (Adams 1885).

Family NERITIDAE Rafinesque
Genus *Neritina* Lamarck, 1816

***Neritina pulligera* (Linnaeus, 1767)**
Figure 2F

Synonyms. *Neritina rubella* Müller, 1774; *Neritina oculus* Röding, 1798; *Nerita rossmassleriana* Récluz, 1846; *Neritina larga* Hombron & Jacquinot, 1848; *Neritina brandti* Philippi, 1849; *Neritina pulligera subcanalis* Mousson, 1865; *Neritina subcanalis* Mousson, 1870; *Neritina sulcata* Tennison-Woods, 1878; *Neritina sumatrana* Dautzenberg, 1899.

Material examined. BOR/MOL6705, BOR/MOL6713, BOR/MOL7929, BOR/MOL8294, BOR/MOL8298, BOR/MOL8301, BOR/MOL8308, BOR/MOL8311.

Distribution and habitat. Labuan. The south-east in Tawau, and the north-west on Pulau Gaya and from Kota Kinabalu.

Remarks. This species is generally found in clear, coastal freshwater streams and rivers from Okinawa, and south through South-east Asia and Australasia (van Benthem Jutting 1956, Brandt 1974, Eichhorst 2016).

Genus *Septaria* Férrusac, 1807

***Septaria porcellana* (Linnaeus, 1858)**
Figure 2G

Synonyms. *Navicella aponogetonis* Vahl, 1795; *Sandalium pictum* Schumacher, 1817; *Navicella suborbicularis* Sowerby, 1825; *Navicella depressa* Lesson, 1831; *Navicella zebra* Lesson, 1931; *Navicella gaimardi* Récluz, 1841; *Navicella quoyi* Récluz, 1841; *Navicella affinis* Mousson, 1865; *Navicella fissa* Mousson, 1869; *Navicella haustrum* Reeve, 1856; *Navicella orbicularis* Reeve, 1856; *Navicella squamata* Dohrn, 1858; *Navicella pulcherrima* Tapparone-Canefri, 1883.

Material examined. BOR/MOL8292, BOR/MOL8302, BOR/MOL8307.

Distribution and habitat. All lots were collected from rivers of Pulau Gaya, off the coast of Kota Kinabalu.

Remarks. This species is widespread in coastal freshwater streams, rivers and lakes from Sri Lanka to Australasia (van Benthem Jutting 1956, Eichhorst 2016).

Genus *Vittina* HB Baker, 1924

***Vittina coromandeliana* (Sowerby, 1836)**
Figure 2H

Synonyms. *Nertina cochinsinae* Récluz, 1850; *Nerita ramosa* Meuschen, 1787; *Neritina paralella* Röding, 1798; *Neritina lugubris* Lamarck, 1822; *Neritina coromandeliana* Sowerby,

1836; *Neritina triangularis* Mörch, 1852; *Neritina pulcherrima* Mousson, 1857; *Neritina interstitialis* von Martens, 1877; *Neritina hieroglyphica* Wattlebled, 1886.

Material examined. BOR/MOL8303.

Distribution and habitat. Single lot collected from Kuari River on Pulau Gaya.

Remarks. This species can be found in brackish estuarine areas (streams and mangrove swamps) from Japan through South-east Asia to Australasia, and India (Brandt 1974, Eichhorst 2016).

***Vittina variegata* (Lesson, 1831)**
Figure 2I

Synonyms. *Neritina pulchra* Sowerby, 1836; *Neritina cuvieriana* Récluz, 1841; *Neritina turrita* Schmeltz, 1866; *Neritina granulosa* Schmeltz, 1869; *Nertina zelandicus* Mousson, 1869; *Neritella granulum* Schmeltz, 1974.

Material examined. BOR/MOL6723.

Distribution and habitat. Single lot collected from a river on Pulau Bohey Dulang, off the eastern town of Semporna.

Remarks. This species can be found in coastal freshwater bodies in South-east Asia and Australasia, and the Pacific islands (van Benthem Jutting 1956, Brandt 1974, Eichhorst 2016).

Family PACHYCHILIDAE P Fischer & Crosse
Genus *Sulcospira* Troschel, 1858

***Sulcospira pageli* (Thiele, 1908)**
Figure 2J,K

Synonym. *Melania schmidti* Martens, 1908.

Material examined. BOR/MOL542, BOR/MOL543, BOR/MOL544, BOR/MOL547, BOR/MOL548, BOR/MOL550, BOR/MOL1752, BOR/MOL1753, BOR/MOL3100, BOR/MOL3394, BOR/MOL3450, BOR/MOL3457, BOR/MOL3761, BOR/MOL3825, BOR/MOL5947, BOR/MOL5950, BOR/MOL6707, BOR/MOL6709, BOR/MOL6711, BOR/MOL6715, BOR/MOL6717, BOR/MOL6718, BOR/MOL6722, BOR/MOL8693, BOR/MOL8694, BOR/MOL8695, BOR/MOL8696, BOR/MOL8697, BOR/MOL8698, BOR/MOL8701.

Distribution and habitat. West from Kota Marudu to Kota Kinabalu, in the interior in Tenom and Keningau, and eastern Sabah in Beluran, Kinabatangan, Lahad Datu, Kunak, Tawau. Found in forest streams and in the vicinity of limestone caves, rivers, and in streams along paddy fields.

Remarks. This species has previously been synonymised with *Sulcospira schmidti* (Martens, 1908), which was also originally described from Borneo (Köhler and Glaubrecht 2001). Shells appear to be highly plastic, with material examined having shells

with rounded or pointed basal lips, with or without raised ribs, and with or without spiral striae at the bottom of final body whorl. Other species of *Sulcospira* have previously been described from Borneo (see e.g., Köhler and Glaubrecht 2001, 2002, Köhler and Dames 2009), but pending further analysis and availability of fresh material for molecular sequencing, we tentatively consider all material conspecific.

Family VIVIPARIDAE Gray
Genus *Sinotaia* Haas, 1839

***Sinotaia guangdungensis* (Kobelt, 1906)**
Figure 3A

Material examined. BOR/MOL8674, BOR/MOL8709.

Distribution and habitat. Collected from a paddy field stream in Kota Marudu, and from a pond in Nabawan.

Remarks. *Sinotaia guangdungensis* is native to Southern China and has to date, been introduced to Peninsular Malaysia, Singapore, and Australia (Ng et al. 2014). This is a first record for Sabah.

Family PALUDOMIDAE Stoliczka
Genus *Paludomus* Swainson, 1840

***Paludomus everetti* EA Smith, 1894**
Figure 3B

Material examined. BOR/MOL545, BOR/MOL1226, BOR/MOL1227, BOR/MOL1754, BOR/MOL1755, BOR/MOL1756, BOR/MOL3127, BOR/MOL3398, BOR/MOL3596, BOR/MOL5853, BOR/MOL5870.

Distribution and habitat. Eastern Sabah in Kunak, Danum Valley, Tawau, and Kinabatangan. Found in forest streams and in the vicinity of limestone caves.

Remarks. Originally described from Batang Lupar in neighbouring Sarawak, and Gua Gomantong in the Kinabatangan area. The material in *BORNEENSIS* include shells collected from the vicinity of Gua Gomantong.

***Paludomus luteus* Adams, 1874**
Figure 3C

Material examined. BOR/MOL1225.

Distribution and habitat. Single lot found in the vicinity of Gua Gomantong in the Kinabatangan area.

Remarks. Distinguished from *Paludomus everetti* by the lack of spiral striae at the suture.

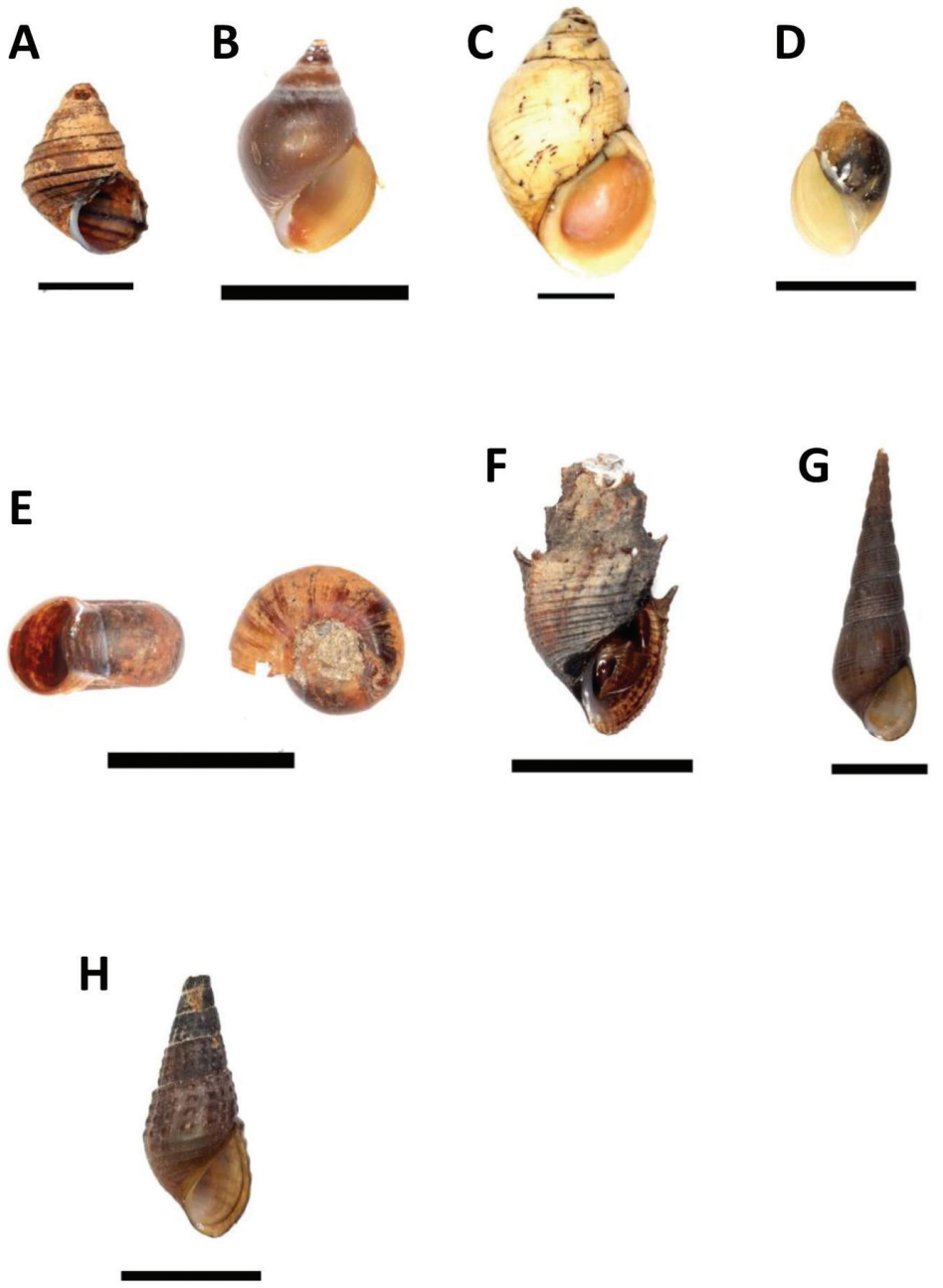

Figure 3. A Family Viviparidae: *Sinotaia guangdungensis* (Kobelt, 1906) – BOR/MOL 8709 **B–C** Family Paludomidae. **B** *Paludomus everetti* EA Smith, 1894 – BOR/MOL 3398 **C** *Paludomus luteus* Adams, 1874 – BOR/MOL 1225 **D** Family Physidae: *Physa acuta* Draparnaud, 1805 – BOR/MOL 3451 **E** Planorbidae *Indoplanorbis exustus* (Deshayes, 1834) – BOR/MOL 8681 **F–H** Family Thiaridae **F** *Mieniplotia scabra* (OF Müller, 1774) – BOR/MOL 8310 **G** *Melanoides tuberculata* (OF Müller, 1774) – BOR/MOL 6799 **H** *Tarebia granifera* (Lamarck, 1822) – BOR/MOL 8688. Scale bars 10 mm.

Family PHYSIDAE Fitzinger
Genus *Physa* Draparnaud, 1801

***Physella acuta* (Draparnaud, 1805)**
Figure 3D

Material examined. BOR/MOL3451.

Distribution and habitat. Single lot collected from Kiansom forest, 20km inland from Kota Kinabalu.

Remarks. This species is native to North America and has been widely introduced to neighbouring Sarawak and Brunei, on Borneo (Ali 1993, Ng et al. 2015b). This appears to be the first record of the species in Sabah.

Family PLANORBIDAE Rafinesque
Genus *Indoplanorbis* Anandale & Prashad, 1920

***Indoplanorbis exustus* (Deshayes, 1834)**
Figure 3E

Material examined. BOR/MOL6716, BOR/MOL8681.

Distribution and habitat. Collected from rivers in Tawau and Tuaran.

Remarks. *Indoplanorbis exustus* has a wide distribution across Asia and is an intermediate host of zoonotic parasites (Liu et al., 2010). In Peninsular Malaysia, the species has been shown to host *Schistosoma spindale*, that causes cercarial dermatitis in infected humans (Chiew et al. 2009). The snail was not recorded from Tuaran in the 1970's (Lim et al. 1976), and both lots in *BORNEENSIS* were only collected in 2016.

Family THIARIDAE Gill
Genus *Mieniplotia* Low & Tan, 2014

***Mieniplotia scabra* (OF Müller, 1774)**
Figure 3F

Synonyms. *Helix aspera* Gmelin, 1791; *Melania spinulosa* Lamarck, 1822; *Melania doreyana* Lesson, 1831; *Melania spinescens* Lesson, 1831; *Melanium granum* von dem Busch, 1842; *Melania scabrella* Mousson, 1848; *Melania acanthica* Lea, 1850; *Melania denticulata* Lea, 1850; *Melania pagoda* Lea, 1850; *Melania datura* Dohrn, 1858; *Melania elegans* Reeve, 1859; *Melania pugilis* Reeve, 1859; *Melania rugosa* Brot, 1860; *Melania snellemanni* Schepman, 1880; *Melania bockii* Brot, 1881; *Melania savinieri* Morlet, 1884; *Melania subcancellata* Boettger, 1890; *Melania pinguicola* Martens in Weber, 1897; *Melania varia* Bullen, 1904; *Melania intrepida* Fulton, 1914; *Melania sykesi* Degner, 1928.

Material examined. BOR/MOL8300, BOR/MOL8306, BOR/MOL8310, BOR/MOL8690.

Distribution and habitat. Off Kota Kinabalu on Pulau Gaya, and northern Sabah in Pitas. Collected from rivers.

Remarks. This cryptogenic species is widespread across tropical Asia and is invasive around the world (Cianfanelli et al. 2016).

Genus *Melanoides* Olivier, 1804

Melanoides tuberculata (OF Müller, 1774)

Figure 3G

Synonym. *Melanoides fasciolata* Olivier, 1804.

Material examined. BOR/MOL551, BOR/MOL1760, BOR/MOL1761, BOR/MOL6708, BOR/MOL6720, BOR/MOL6724, BOR/MOL6725, BOR/MOL6799, BOR/MOL7930, BOR/MOL7931, BOR/MOL8295, BOR/MOL8296, BOR/MOL8297, BOR/MOL8299, BOR/MOL8305, BOR/MOL8309, BOR/MOL8427, BOR/MOL8444, BOR/MOL8682, BOR/MOL8692, BOR/MOL8699.

Distribution and habitat. Labuan. Widely-distributed throughout the state and on offshore islands, including Tenom, Kota Kinabalu, Pulau Gaya, Pulau Tiga, Tuaran, Kota Belud, Tawau, and Pulau Bohey Dulang and Pulau Bodgaya, off Semporna. Recorded from rivers, paddy fields, and concrete drains.

Remarks. This species originates from West Asia and East Africa but has become widespread and invasive across the world (Pointier 1999).

Genus *Tarebia* H Ada& A Adams, 1884

Tarebia granifera (Lamarck, 1822)

Figure 3H

Synonyms. *Helix lineata* Gray in Wood, 1828; *Melania celebensis* Quoy & Gaimard, 1834; *Melania lirata* Benson, 1836*; Melania semigranosa* von dem Busch in Philippi, 1842; *Melania batana* Gould, 1843; *Melania coffea* Philippi, 1843; *Melania flavida* Dunker, 1844; *Melania verrucosa* Hinds, 1844; *Melania crenifera* Lea, 1850; *Melania lateritia* Lea, 1850; *Melania microstoma* Lea, 1850; *Melania rudis* Lea, 1850; *Melania granospira* Mousson, 1857; *Melania broti* Reeve, 1859; *Melania lyrata* Reeve, 1859; *Melania chocolatum* Brot, 1860; *Melania granospiralis* Zollinger, 1860; *Melania asperula* Brot, 1868; *Melania obliquigranosa* Smith, 1878; *Melania junghuhni* Martin, 1879; *Melania tjariangensis* Martin, 1905; *Melania kritjianensis* Martin, 1905; *Melania tjibodasensis* Leschke, 1914; *Melania margaritana* Leschke, 1914; *Melania martini* Oostingh, 1935.

Material examined. BOR/MOL546, BOR/MOL3109, BOR/MOL3382, BOR/MOL6721, BOR/MOL8683, BOR/MOL8684, BOR/MOL8685, BOR/MOL8686, BOR/MOL8687, BOR/MOL8688, BOR/MOL8689, BOR/MOL8691.

Distribution and habitat. Widely-distributed throughout the state, found from Nabawan, Keningau, Sepitang, Tuaran, Kota Belud, Pitas, Kota Marudu, Tawau. Most were collected from rivers.

Remarks. This species is widespread in most water bodies from India to Australasia (van Benthem Jutting 1956).

Acknowledgements

We would like to thank Siong Kiat Tan for help in identifying some of the species and for providing useful references and comments. In addition, we thank many of our colleagues and students who collected the specimens and deposited at *BORNEENSIS*, Universiti Malaysia Sabah. The sampling on the islands of the west coast of Sabah by TSL and JD was supported by Research Acculturation Grant Scheme (RAGS), Ministry of Higher Education Malaysia (RAG0063-STWN-2015), and AZ's fieldwork in Sabah was supported by the Mohamed bin Zayed Species Conservation Fund (Project 152510591). We appreciate valuable comments from Frank Köhler, Thomas von Rintelen, and an anonymous reviewer which improved this manuscript.

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Supplementary material 1

Collection data, image links and distribution data for freshwater snails of Sabah deposited in the BORNEENSIS collection, Universiti Malaysia Sabah

Authors: Ting Hui Ng, Jasrul Dulipat, Junn Kitt Foon, Manuel Lopes-Lima, Alexandra Zieritz, Thor-Seng Liew

Data type: KMZ file

Explanation note: A KMZ file consisting of collection data, image links and distribution data. https://figshare.com/s/1d2e39c49f1e5eaa0840, https://doi.org/10.6084/m9.figshare.4725562.v1

Supplementary material 2

A spreadsheet of collection and distribution data for freshwater snails of Sabah deposited in the BORNEENSIS collection, Universiti Malaysia Sabah

Authors: Ting Hui Ng, Jasrul Dulipat, Junn Kitt Foon, Manuel Lopes-Lima, Alexandra Zieritz, Thor-Seng Liew

Data type: Microsoft Excel spreadsheet

Explanation note: A Microsoft Excel spreadsheet file consists of detailed collection and distribution data. https://figshare.com/s/1d2e39c49f1e5eaa0840, https://doi.org/10.6084/m9.figshare.4725562.v1

ZooKeys 673: 125–133 (2017)
doi: 10.3897/zookeys.673.10265
http://zookeys.pensoft.net

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Ptychadena in Mauritania and the first record of *Ptychadena schillukorum*

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Academic editor: *A. Ohler* | Received 23 August 2016 | Accepted 12 April 2017 | Published 15 May 2017

http://zoobank.org/69BEED14-F9AE-4B3E-95CF-B906669487E5

Citation: Sánchez-Vialas A, Calvo-Revuelta M, Márquez R (2017) *Ptychadena* in Mauritania and the first record of *Ptychadena schillukorum*. ZooKeys 673: 125–133. https://doi.org/10.3897/zookeys.673.10265

Abstract

The study of specimens of the genus *Ptychadena* of the herpetological collection of the Museo Nacional de Ciencias Naturales de Madrid reveals the first record of *Ptychadena schillukorum* from Mauritania, extending the known distribution range of the species in West Africa more than 450 km northwards. A key is provided for the four Mauritanian species of *Ptychadena* to solve problems in identification encountered in previous studies.

Keywords

Herpetological collection, identification key, *Ptychadena schillukorum*, Sahel, taxonomic problems, West Africa

Introduction

Ptychadena Boulenger, 1917 is a genus of medium-sized Afrotropical frogs that comprises 50 known living species (Frost 2017) which occur mainly in savannahs and wetlands. Several species of *Ptychadena* share a similar appearance and show interspecific overlap in morphological variation hampering the identification of diagnostic

characters (Poynton 1970, Rödel 2000). Padial et al. (2013) show a map of Mauritania with the known localities of all amphibian species represented except for *Ptychadena,* where the locations are pooled by genus, due to the ambiguity of its specific identification in literature. However, Guibé and Lamotte (1957) revised the *Ptychadena* of West Africa providing a morphological key and Bwong et al. (2009) and Dehling and Sinsch (2013) suggested that morphologically similar species of *Ptychadena* may be identified using quantitative and qualitative morphological data (Zimkus et al. 2017).

The western portions of the Sahel ecoregion includes a diversified group of species of *Ptychadena*, namely *P. pumilio* (Boulenger, 1920), *P. bibroni* (Hallowell, 1845), *P. tellini* (Peracca, 1904) (as *P. schubotzi* (Sternfeld, 1917)), *P. longirostris* (Peters, 1870), *P. oxyrhynchus* (Smith, 1849), *P. trinodis* (Boettger, 1881), *P. mascareniensis* (Dúmeril & Bibron, 1841), *P. tournieri* (Guibé & Lamotte, 1955), *P. stenocephala* (Boulenger, 1901), *P. submascareniensis* (Guibé & Lamotte, 1953), *P. retropunctata* (Angel, 1949), and *P. schillukorum* (Werner, 1908) (as *P. floweri*, (Boulenger 1917)) (Rödel 2000). At the northwestern limit of this area, along southern Mauritania, *Ptychadena* is represented by three species: *P. trinodis*, *P. mascareniensis* and *P. bibroni* (Padial 2003, Padial et al. 2013, Padial and De la Riva 2004). *Ptychadena mascareniensis* comprise a group of closely related species widely distributed across Africa but the taxonomy and phylogenetic affinities of the western populations from Senegal to Mauritania are still unresolved (Padial and De la Riva 2004, Vences et al. 2004, Zimkus 2017).

Ptychadena trinodis differs from the other two species of *Ptychadena* recorded in Mauritania by the presence of a tarsal tubercle and by very large inner and outer metatarsal tubercles; in Mauritania it has been reported in two localities: Guelta Oumm Lebare and Guelta Metraucha. *Ptychadena* cf. *mascareniensis* is cited only at one locality in Mauritania: Zoueina; it differs from *P. bibroni* by a very subtle outer metatarsal tubercle, lack of supernumerary tubercles on toe IV, dorsal median ridges that reach the posterior edge of the eyes, different webbing formula ($2^{2/3}$–3 in *P.* cf. *mascareniensis* and 2–$2^{1/3}$ in *P. bibroni*), and by a continuous lateral ridge which is broken in *P. bibroni. Ptychadena bibroni* is known by two records in Mauritania: Kaedi and Mahmoûdé Lake (Lamotte and Ohler 1997, Rödel 2000, Padial 2003, Padial and De la Riva 2004) (Fig. 1).

Abrupt climate changes and hydrological fluctuations that took place in southern Mauritania during Pleistocene–Holocene, created a dynamic transitional zone promoting dispersal and contraction of distributional areas of Afrotropical species (Gasse 2000; Foley et al. 2003; Brito et al. 2014; Sow et al. 2015). Most amphibians in Mauritania are restricted to the southern part of the country where they inhabit the Sahel savanna ecoregion (including all known *Ptychadena*). Only *Hoplobatrachus occipitalis*, *Sclerophrys xeros*, and *Tomopterna cryptotis*, are present across the north in the Saharan realm (Padial et al. 2013).

In this note, a new species record of *Ptychadena* is reported from southern Mauritania based on material of the herpetological collection of the Museo Nacional de Ciencias Naturales of Madrid (MNCN) and on field data obtained by RM.

Material and methods

The specimens of *Ptychadena* held at the National Museum of Natural Sciences of Madrid (**MNCN-CSIC**) were examined. Thirty-one specimens were collected in Mauritania: one specimen of *Ptychadena trinodis* (cited in Padial 2003), one of *P.* cf. *mascareniensis* (cited in Padial and De la Riva 2004) and 29 individuals identified by us as *Ptychadena schillukorum*. Four specimens studied of *P. bibroni* were collected in Senegal (Table 1). Most individuals of *P. schillukorum* (19) were collected in October 1998 by RM, a few days after a (rare) event of rainfall in Southern Mauritania in the proximities of Aleg ("2 kilometers east of Aleg", coordinates: 17°04'41"N, 13°53'41"W, and "west limit of Lake Aleg", coordinates: 17°08'2"N, 14°04'0"W). Additionally, 10 individuals (MNCN 43846–43855) were collected in October 2006 by J. M. Padial and I. De la Riva in Aleg surroundings (17°30'10.0"N, 13°54'50.1"W) (Fig. 1).

Morphological characters used in this study for comparison between the species of *Ptychadena* from Mauritania are: tarsal tubercle, inner metatarsal tubercle, outer metatarsal tubercle, lateral ridge, dorsal ridge, thigh pattern, supernumerary tubercles on toes and webbing extension in the fourth toe (Table 1).

The measure of the range extension of *P. schillukorum* was taken by airline distance using Google Earth tool, from the northern most locality in West Africa at Niokolo-Koba in Senegal to Aleg in Mauritania.

Results and discussion

The poor conditions in which we found the specimen of *P.* cf. *mascareniensis* collected in Mauritania by Padial and De la Riva (Padial and De la Riva 2004) makes its identification difficult due to the lack of morphological characters such as the dorsal and lateral ridges. The existence of three phalanges of the fourth toe free of web and the mottled pattern of thigh makes us question its identity (see Table 1). Unfortunately, the only existing picture provided by J. M. Padial (Fig. 5C) of the same specimen does not allow us to conclude its specific identification as *Ptychadena* of the *mascareniensis* group. Genetic samples of it will be analysed to solve this question (in prep.). In this work the criteria of Padial and De la Riva considering the presence of *P.* cf. *mascareniensis* in Mauritania are followed.

The morphology of the studied individuals of *Ptychadena schillukorum* from Mauritania fitted with the description of the species (Channing and Howell 2006, Rödel 2000): dorsal and lateral ridges are not continuous; the legs are relatively short: tibiotarsal articulation reaches the level of the eye; lack of tarsal tubercles; outer metatarsal tubercles are inconspicuous; the pattern of thigh are speckled (fine vermiculation); the webbing is reduced: 2.5-three phalanges of the fourth toe free of web and no supernumerary tubercles are present in the toes. Tympanum small: its diameter reaches less than 0.7 diameter of the eye.

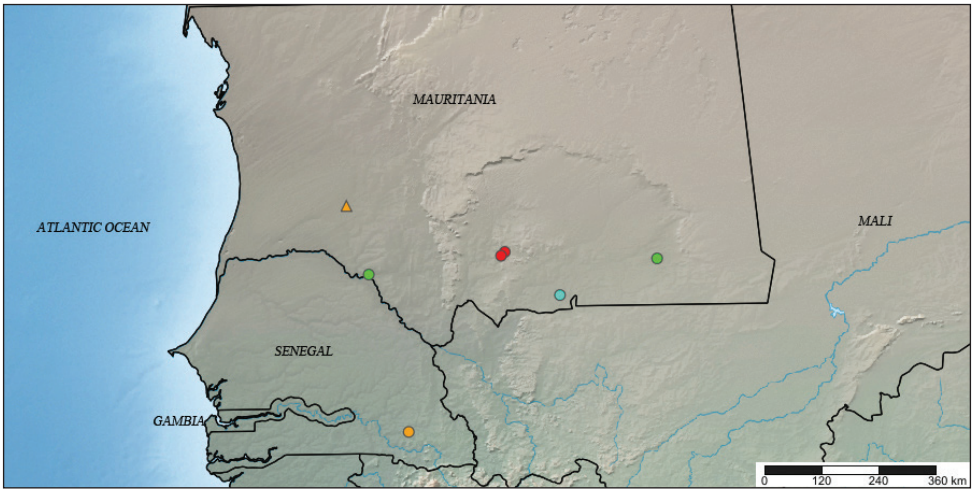

Figure 1. Geographic records published of the species of *Ptychadena* from Mauritania identified at species level. Yellow dot from Senegal represent the previous northernmost record in West Africa of *P. schillukorum*. Green dot represent the localities were *P. bibroni* has been recorded in Mauritania. Localities with presence of *P. trinodis* are represented by red dots. The record of *P.* cf. *mascareniensis* is the blue coloured dot. The new record of *P. schillukorum* from Mauritania is shown as a yellow triangle (map created from http://www.simplemappr.net/).

Table 1. Morphological characters of MNCN voucher specimens used in this study for comparing between the species of *Ptychadena* present in Mauritania.

	P. bibroni	***P. cf. mascareniensis***	***P. trinodis***	***P. schillukorum***
Catalog number (MNCN)	44071–44074	41784	41783	43846–43855; 42221–42231; 42208; 42210–42216
Tarsal tubercle	absent	absent	present	absent
Inner metatarsal tubercle as long as toe I	absent	absent	present	absent
Outer metatarsal tubercle distinctive	present	absent	present	absent
Lateral ridge continuous	absent	?	present	absent
Dorsal ridges continuous	present	?	present	absent
Mottled pattern of thigh	absent	present	absent	present
Number of phalanges of toe 4 free of web	2	3	2	3
Supernumerary tubercles on toe IV	present	absent	absent	absent

The examined individuals MNCN 42223, MNCN 42224, MNCN 42226, MNCN 42229, MNCN 42212, MNCN 42215, MNCN 42216 and MNCN 43849, present a thin yellow vertebral stripe. Therefore, the examined specimens are characterised by the tibia pattern with interrupted transversal bands.

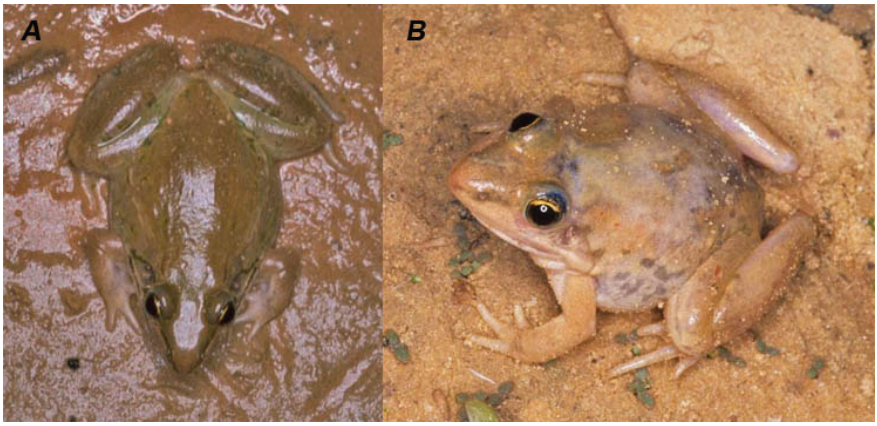

Figure 2. Different individuals of *Ptychadena schillukorum* from Aleg, Mauritania. Museum number of photographed specimens: **A** MNCN 42210 (SVL = 32.7 mm) **B** MNCN 42221 (SVL = 27.3 mm) (photos Rafael Márquez).

Figure 3. Temporal pond where *Ptychadena schillukorum* was found in Aleg, Mauritania (photo Rafael Márquez).

The nearest locality to Mauritania where *Ptychadena schillukorum* has been reported is in southern Senegal at Niokolo-Koba (Lamotte 1969, Joger and Lambert 2002). The record from Aleg in Mauritania extends 450 km northwards the distribution of the species (Fig. 1).

Ptychadena schillukorum (Fig. 2A, B) inhabits the dry savannahs and grasslands from Senegal to the extreme southern Somalia and also in isolation from Egypt (Baha el Din 2006, Nago et al. 2006) and southwards to east Africa from Kenya to Mozambique (Channing and Howell 2006). The reproduction of *P. schillukorum* in West Africa takes place in shallow savannah ponds during the rainy season (Nago et al. 2009).

Figure 4. *Tomopterna cryptotis* and *Ptychadena schillukorum* (museum number: MNCN 42214, SVL = 31.8 mm) found in syntopy, Aleg, Mauritania (photo Rafael Márquez).

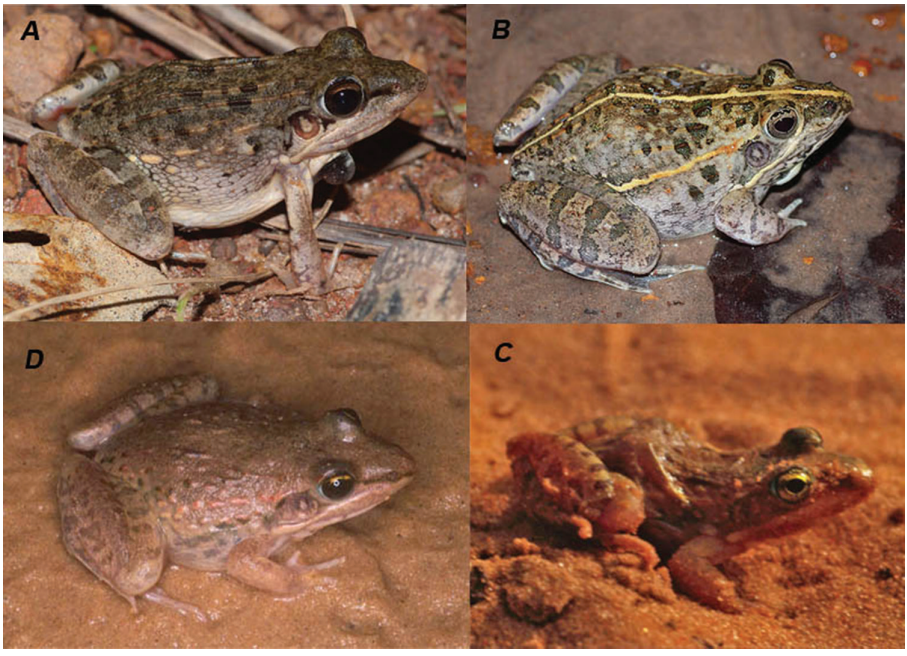

Figure 5. The four species of *Ptychadena* recorded in Mauritania: *Ptychadena bibroni* from Gourel Yoba, Senegal; male specimen, not collected (**A**), *Ptychadena trinodis* from Toubakouta, Senegal; male specimen, not collected (**B**), *Ptychadena* cf. *mascareniensis* from Zoueina, Mauritania (MNCN 41784, SVL=29.6 mm) (**C**), *Ptychadena schillukorum* from Aleg, Mauritania (MNCN 42214, SVL=31.8 mm) (**D**) [photos Alberto Sánchez Vialas (**A, B**), José Manuel Padial (**C**) and Rafael Márquez (**D**)].

Aleg is located in the Sahel region, characterised by a subtropical dry arid climate with rainy season from July to October. Most individuals were collected in October 1998 by RM, a few days after a (sporadic) event of rainfall that caused the formation of shallow pools and the growth of herbaceous vegetation on the normally barren sand (Fig. 3). Other anuran species that were found concomitantly were *Sclerophrys xeros* and *Tomopterna cryptotis* (Fig. 4).

The four Mauritanian species of *Ptychadena* (Figure 5) are easily distinguishable from each other based on morphological characters. *Ptychadena schillukorum* differs from *P. trinodis* by the lack of tarsal tubercle, smaller inner metatarsal tubercle and inconspicuous outer metatarsal tubercle. Also a fine yellow vertebral line is sometimes present (8 of 29 specimens of *P. schillukorum* examined) while in *P. trinodis* a fine white-yellow vertebral line and light colored lateral ridge is generally present. *Ptychadena schillukorum* differs from *P. bibroni* by its more compact body, shorter legs, lack of supernumerary tubercles on toe IV, always interrupted dorsal ridges, by its inconspicuous outer metatarsal tubercle and by thigh pattern, that is speckled in *P. schillukorum* and usually with yellow longitudinal and irregular line in *P. bibroni*. Finally, *P. schillukorum* is distinctive from *P. mascareniensis* by its compact body shape, dorsal and lateral ridges, always interrupted, and shorter legs.

Based on Rödel (2000) and personal data, a key for the *Ptychadena* species that occur in Mauritania is presented.

Key to the species of *Ptychadena* from Mauritania

1 Tarsal tubercle present. Metatarsal tubercles large. Inner metatarsal tubercle almost as long as the toe 1..... ***P. trinodis***

– Lack of tarsal tubercle. Inner metatarsal tubercle smaller than 0.6 of the length of toe 1 ..... **2**

2 Dorsal ridges continuous **3**

– Dorsal ridges discontinuous, broken into warts..... ***P. schillukorum***

3 Dorsal median ridges to mid-dorsum. Lateral ridge discontinuous. Supernumerary tubercles on toe IV present..... ***P. bibroni***

– Dorsal median ridges to posterior edge of the eyes. Lateral ridge continuous. Supernumerary tubercles on toe IV absent..... ***P. mascareniensis***

Studies concerning amphibian fauna in Mauritania are scarce, suggesting that other populations of *Ptychadena schillukorum* may be discovered in the future. Molecular studies of *P. schillukorum* should be carried out to know how complex is the species across their distribution (expected to be high or a group of species as suggested by Nago et al. 2006) and also to determine what is the systematic position and taxonomy of the Mauritanian population.

Acknowledgements

We are grateful to Mario García París and Iñigo Martínez-Solano for advice and comments on the manuscript. Collection in Mauritania was possible thanks to Santiago Martínez de Orense who provided lodging, transportation, and help in the field.

This research was partially funded by project TATANKA (CGL2011-25062) obtained from Ministerio de Ciencia e Innovación, Spain. We are grateful to José Manuel Padial who kindly provided the picture 5C, and to Daniel Hinkley who revised the MS in English. We are also deeply grateful to Annemarie Ohler, Edgar Lehr and to an anonymous reviewer whose comments have helped in improving the manuscript.

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ZooKeys 673: 135–151 (2017)
doi: 10.3897/zookeys.673.12084
http://zookeys.pensoft.net

RESEARCH ARTICLE

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Three new remarkable species of the genus *Endonura* Cassagnau, 1979 from the Middle East and Central Asia (Collembola, Neanuridae, Neanurinae, Neanurini)

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Academic editor: *L. Deharveng* | Received 3 February 2017 | Accepted 20 April 2017 | Published 15 May 2017

http://zoobank.org/1E035DB3-77A8-41B9-8D09-15546BA2282A

Citation: Smolis A, Shayanmehr M, Kuznetsova N, Lafooraki EY (2017) Three new remarkable species of the genus *Endonura* Cassagnau, 1979 from the Middle East and Central Asia (Collembola, Neanuridae, Neanurinae, Neanurini). ZooKeys 673: 135–151. https://doi.org/10.3897/zookeys.673.12084

Abstract

New species belonging to the genus *Endonura* is described and illustrated in detail. *Endonura longirostris* **sp. n.**, from northern Iran, is distinctive due to an exceptionally elongate buccal cone compared to that of most other species of the genus. Other characteristic features of the species are the white body with pigmented eyes, a reduced chaetotaxy of the lateral part of the head, the thorax II–III and abdomen I–III with free chaetae De2 and 3, and abdomen IV with particularly short chaetae Di1. The main characteristics of *Endonura paracentaurea* **sp. n.** include a white body with dark pigmented eyes, a nonogival labrum, the presence of tubercles Di on the first thoracic segment and of microchaetae on the rudimentary furca. *Endonura turkmenica* **sp. n.** can be recognized by its bluish-grey body, labral chaetotaxy, free chaetae E on the head, and notably short chaetae De3 on the thorax and the abdomen. Short remarks on the possible importance of labral modifications are also provided.

Keywords

Feeding habits, Iran, labral modifications, springtails, taxonomy, Turkmenistan

Introduction

Amongst springtails, primitive and wingless insects, the subfamily Neanurinae is one of the most diversified, widespread, and species-rich systematic units and evolutionary lineages. Up to date, Neanurinae encompasses nearly 800 species, classified into six tribes (Cassagnau 1989). The Neanurini is the second largest tribe within the subfamily, after Paleonurini, currently containing over 170 valid species belonging to 22 genera (Cassagnau 1989, Hopkin 1997, Deharveng and Bedos 2000, Deharveng et al. 2007, Smolis 2007, 2011, Mayvan et al. 2015). The genus considered in this paper, *Endonura* Cassagnau, 1979, is among the most thoroughly studied and largest genera within the tribe, with 48 valid species at the moment (Dallai 1983, Deharveng 1979, 1982, Fanciulli and Dallai 2008, Pozo and Simón 1981, Smolis and Kaprus' 2003, 2009, Smolis 2008, 2016, Smolis et al. 2007, 2011, 2016a, b). Regarding the actual distribution of its members, *Endonura* is a Holarctic genus, with the highest concentration of forms in Europe. Recent discoveries, however, slowly change this picture as a notable number of newly described species has been recorded in the Middle East, the Caucasus, and Central Asia (Smolis et al. 2011, 2016a, b).

In 2008, the first author redefined *Endonura* as follows (Smolis 2008): 0–2 ocelli on either side of the head, reduced mouth parts usually with a thin mandible and a styliform maxilla, separate tubercles Di and De on the head, the non-cross-type of chaetotaxy on the head, and three or two tubercles on the penultimate abdominal segment. Amongst Neanurini, the genus is more similar, and presumably seems to be closely related, to two genera: *Cryptonura* Cassagnau, 1979, and *Deutonura* Cassagnau, 1979, which share the following characters with *Endonura*: maximum 2+2 eyes on the head, the non-cross-type of chaetotaxy, and differentiation in size of dorsal chaetae. Nonetheless, *Endonura* can be separated from the former by having two or three tubercles on the dorsal side of the penultimate abdominal segment (in *Cryptonura*, four tubercles), and from the latter by the separation of tubercles Di on the head (in *Deutonura*, fused).

The examination of rich materials of Neanurinae from northern Iran and Turkmenistan has revealed three unknown species of the genus. One of them seems to be particularly remarkable because of an exceptionally elongated and pointed labrum. Descriptions of all the three taxa are provided with comments on their affinities and the significance of labral modifications in the taxonomy and ecology of the genus and the subfamily Neanurinae.

Material and methods

Terminology

Terminology and layout of the tables used in the paper follow Deharveng (1983), Deharveng and Weiner (1984), Smolis and Deharveng (2006) and Smolis (2008).

Abbreviations used

General morphology:

Abd abdomen,
Ant antenna,
AOIII sensory organ of antennal segment III,
Cx coxa,
Fe femur,
Scx2 subcoxa 2,
T tibiotarsus,
Th thorax,
Tr trochanter,
VT ventral tube.

Tubercles:

Af antenno–frontal,
Cl clypeal,
De dorsoexternal,
Di dorsointernal,
Dl dorsolateral,
L lateral,
Oc ocular,
So subocular.

Groups of chaetae:

Ag antegenital,
An chaetae of anal lobes,
ap apical,
ca centroapical,
cm centromedial,
cp centroposterior,
d dorsal,
Fu furcal,
vc ventrocentral,
Ve or **ve** ventroexternal,
Vea ventroexternoanterior,
Vem ventroexternomedial,
Vep ventroexteroposterior,
Vel ventroexternolateral,
Vec ventroexternocentral,
Vei ventroexternointernal,
Vi or **vi** ventrointernal,
Vl ventrolateral.

Types of chaetae:

A, **B**, **C**, **D**, **E**, **O**, **So**, **L**, **Dl** cephalic chaetae,
Ml long macrochaeta,
Mc short macrochaeta,
Mcc very short macrochaeta,
me mesochaeta,
mi microchaeta,
ms s–microchaeta,
S or **s** chaeta s,
bs s–chaeta on Ant IV,
miA microchaetae on Ant IV,
iv ordinary chaetae on ventral Ant IV,
or organite of Ant IV,
brs border s–chaeta on Ant IV,
i ordinary chaeta on Ant IV,
mou cylindrical s–chaetae on Ant IV („soies mousses"),
x labial papilla x,
L' ordinary lateral chaeta on Abd V,
B4, **B5** ordinary chaetae on tibiotarsi.

The specimens were cleared in Nesbitt's fluid, subsequently mounted on slides in Swan's medium and studied using a Nikon Eclipse E600 phase contrast microscope. Figures were drawn with camera lucida and prepared for publication using Adobe Photoshop CS3.

Institutions of depository of materials: **DIBEC** Department of Invertebrate Biology, Evolution and Conservation, Institute of Environmental Biology, University of Wrocław, Poland and **MSPU** Moscow State Pedagogical University, Moscow, Russia.

Taxonomy

***Endonura longirostris* sp. n.**
http://zoobank.org/4255D53B-46C3-4428-BE7A-894D98925C26
Figs 1–10, Table 1

Type material. Holotype: adult female on slide, Iran, Mazandarn province, Behshahr region, Abbas-Abad forest (36°40'N; 53°32'E), leaf litter and soil, 28.III.2013, leg. E. Yoosefi Lafooraki (DIBEC). Paratypes: 2 females on slide, same data as holotype.

Other material. Juvenile on slide, Iran, Mazandarn province, Noor region, Kadirsar village (36°26'N; 51°49'E), leaf litter and soil, 1.III.2013, leg. E. Yoosefi Lafooraki (DIBEC).

Etymology. The name *longirostris* refers to an exceptionally long buccal cone of this species.

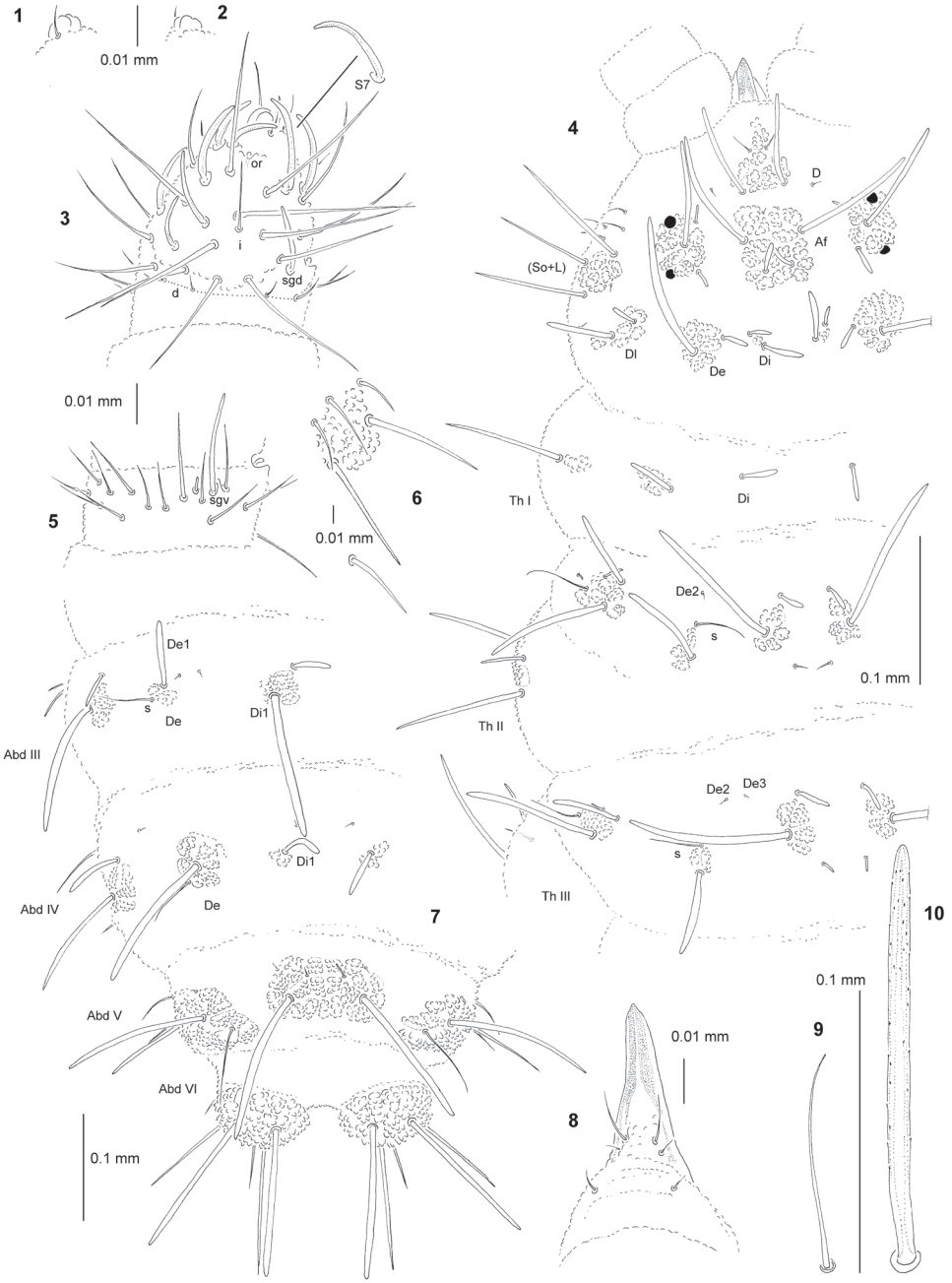
Diagnosis. Habitus typical of the genus *Endonura*. Dorsal tubercles present and well developed. 2+2 pigmented eyes. Buccal cone exceptionally long, labrum ogival. Head with chaetae A, B, C and D. Chaetae O and E absent. Tubercles Cl and Af separate. Tubercles Dl and (L+So) on head with 4 and 8 chaetae respectively. Tubercles Di on Th I absent. Tubercles De on Th II and III with 3 and 4 chaetae respectively. Tubercles L on Abd III and IV with 3 and 5-6 chaetae respectively. Abd IV and V with 8 and 3 tubercles respectively. Claw without inner tooth. Tibiotarsi with chaetae B4 and B5 short.

Description. General. Body length (without antennae): 0.50 (juvenile) to 1.45 mm (holotype: 1.45 mm). Colour of the body white. 2+2 medium black eyes, in a typical arrangement for the genus (one anterior and one posterior eyes, Fig. 4).

Chaetal morphology. Dorsal ordinary chaetae of five types: long macrochaetae, short macrochaetae, very short macrochaetae, mesochaetae and microchaetae. Long macrochaetae thick, slightly arc-like or straight, narrowly sheathed, feebly serrated, apically rounded (Fig. 10). Macrochaetae Mc and Mcc morphologically similar to long macrochaetae, but much shorter. Mesochaetae similar to ventral chaetae, thin, smooth and pointed. Microchaetae similar to mesochaetae, but apparently short. S–chaetae of tergites thin, smooth and short, shorter than nearby macrochaetae (Figs 4, 7, 9).

Antennae. Typical of the genus. Dorsal chaetotaxy of Ant III–IV as in Fig. 3 and Table 1b. S–chaetae of Ant IV of medium length and moderately thickened, S2, S7 and S8 notably longer than others (Fig. 3). Apical vesicle distinct, trilobed (Figs 1, 2). Ventral chaetotaxy of Ant III–IV as in Fig. 5 and Table 1b.

Mouthparts. Buccal cone particularly long with labral sclerifications ogival. Labrum chaetotaxy: 0/2, 4 (Fig. 8). Labium with four basal, three distal and four lateral chaetae, papillae x absent. Maxilla styliform, mandible thin and tridentate.



Figures 1–10. *Endonura longirostris* sp. n.: **1** apical bulb, dorsal view **2** apical bulb, ventral view **3** dorsal chaetotaxy of Ant III–IV **4** chaetotaxy of head and Th (holotype), dorsolateral view **5** ventral chaetotaxy of Ant III **6** tubercle L of Abd IV **7** dorsal chaetotaxy of Abd III–VI **8** chaetotaxy and ventral sclerifications of labrum **9** sensillum of Abd V **10** chaeta Di1 of Abd V.

Table 1a. Chaetotaxy of *Endonura longirostris* sp. n.: cephalic chaetotaxy dorsal side.

Tubercle	Number of chaetae	Types of chaetae	Names of chaetae
Cl	4	Ml me	F G
Af	8	Ml Mc Mcc or mi mi	B A C D
Oc	3	Ml Mc Mcc	Ocm Ocp Oca
Di	2	Ml Mcc	Di1 Di2
De	2	Mc Mcc	De1 De2
Dl	4	Ml Mc or Mcc mi	Dl5 Dl1 Dl2, Dl4
(L+So)	8	Ml mi me	L1, L4, So1 L2 So3–6

Table 1b. Chaetotaxy of *Endonura longirostris* sp. n.: chaetotaxy of antennae.

Segment, Group	Number of chaetae	Segment, Group	Number of chaetae adult
I	7	IV	or, 8 S, i, 12 mou, 6 brs, 2 iv
II	11	ap	
III	5 sensilla AO III		
ve	5		8 bs, 5 miA
vc	4	ca	2 bs, 3 miA
vi	4	cm	3 bs, 1 miA
d	5	cp	8 miA, 1 brs

Table 1c. Chaetotaxy of *Endonura longirostris* sp. n.: postcephalic chaetotaxy.

	Terga				Legs				
	Di	**De**	**Dl**	**L**	**Scx2**	**Cx**	**Tr**	**Fe**	**T**
Th I	1	2	1	-	0	3	6	13	19
Th II	3	2+s	3+s+ms	3	2	7	6	12	19
Th III	3	3+s	3+s	3	2	8	6	11	18
							Sterna		
Abd I	2	3+s	2	3	VT: 4				
Abd II	2	3+s	2	3	Ve: 5; chaeta Ve1 present				
Abd III	2	3+s	2	3	Vel:4; Fu: 4–5 me, 0 mi				
Abd IV	2	2+s	3	5–6	Vel: 4; Vec: 2; Vei: 2; Vl: 4				
Abd V	(3+3)	7+s			Ag: 3; Vl: 1, L‘: 1				
Abd VI		7			Ve: 14; An: 2mi				

Dorsal chaetotaxy and tubercles. Chaetotaxy of head reduced, chaetae E, O, Dl3, Dl6, So2 and L3 absent (Fig. 4). Tubercles Di on Th I not differentiated (Fig. 4). Thorax and abdomen with chaetae De2 and De3 free (Figs 4, 7). On Abd I–III, the line of chaetae De1–chaeta s non-perpendicular to the dorsomedian line. On Abd IV chaetae Di1 notably short (Fig. 7). Cryptopygy absent, Abd VI well visible from above.

Ventral chaetotaxy. On head, groups Vea, Vem and Vep with 3, 3, 3-4 chaetae respectively. Group Vi on head with 6 chaetae. On Abd IV, furca rudimentary without microchaetae. On Abd IV, tuberle L with one chaeta free (Fig. 6). On Abd V, chaetae Vl and L' present.

Legs. Chaetotaxy of legs as in Table 1c. Claw without internal tooth. On tibiotarsi, chaeta M present and chaetae B4 and B5 relatively short and pointed.

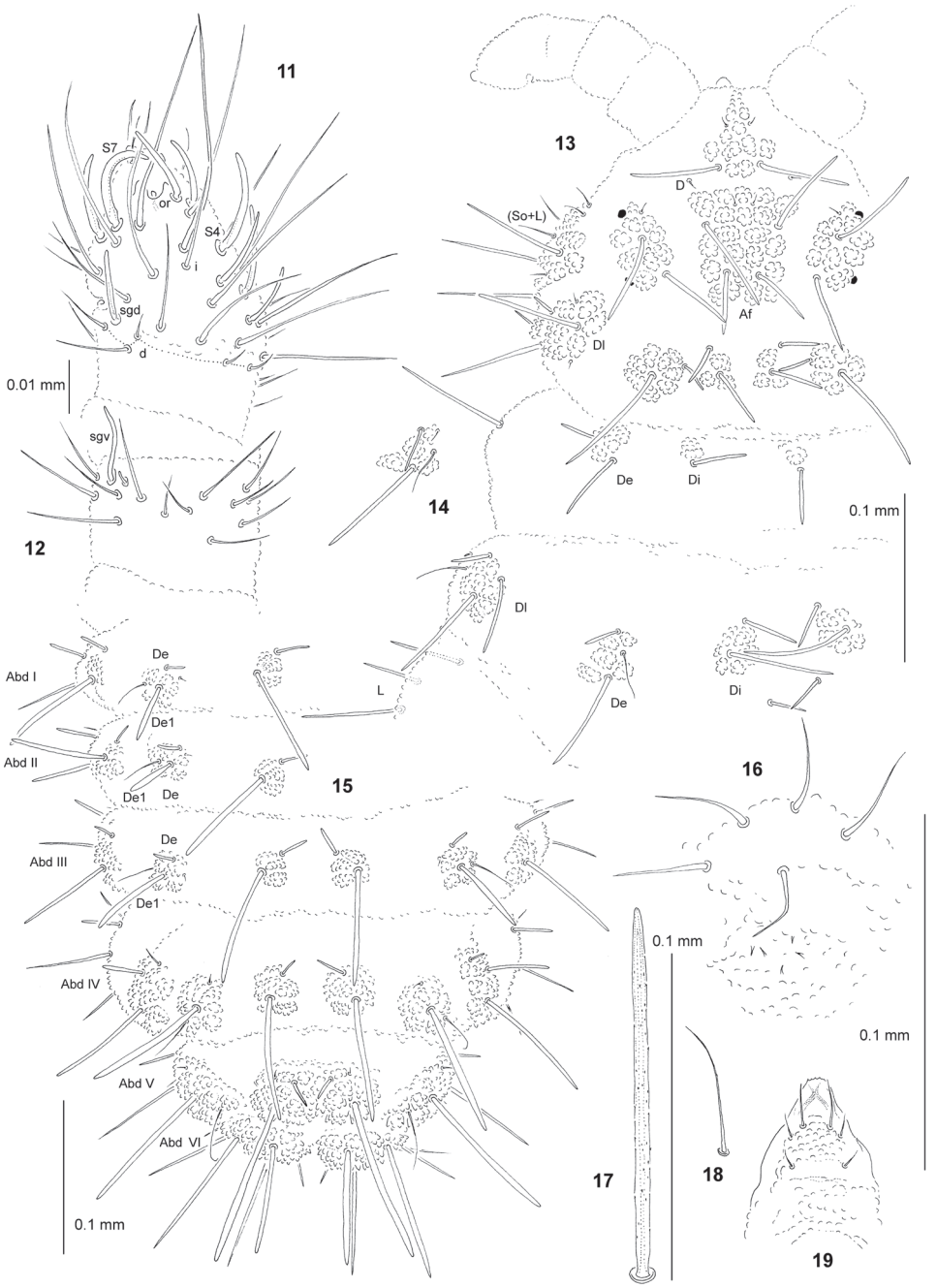
Remarks. Because of the presence of particularly elongated mouthparts and substantial reduction of chaetotaxy on lateral part of head, *E. longirostris* sp. n. strongly resembles *E. cretensis* (Ellis, 1976), known to date from Greece (Crete, Ellis 1976) and Israel (Smolis and Kaprus' 2009). Nevertheless, these species can be easily distinguished from each other by the set of characters: body colour (in *longirostris* white, in *cretensis* bluish), presence/absence of chaeta O on head (in *longirostris* absent, in *cretensis* present), number of labial chaetae (in *longirostris* ten, in *cretensis* eight), presence/absence of tubercles Di on Th I (in *longirostris* absent, in *cretensis* present), number of ordinary chaetae De on Abd I-III (in *longirostris* three, in *cretensis* two) and number of chaetae Di on penultimate abdominal segment (in *longirostris* 3+3, in *cretensis* 1-2+1-2).

Viewing the recently published key to *Endonura* species (Smolis et al. 2016b), *E. longirostris* sp. n. is placed the nearest to *E. saleri* Fanciulli et Dallai, 2008, described from northeastern Italy (Fanciulli and Dallai 2008). However, these species differ in a number of details, including: shape of labrum (in *longirostris* ogival, in *saleri* non-ogival), number of chaetae (L+So) on head (in *longirostris* eight, in *saleri* nine), number of chaetae Dl on head (in *longirostris* four, in *saleri* five), location of chaetae De 2 on Th II-III (in *longirostris* free, in *saleri* connected with tubercle De), location of chaetae De 2 on Abd I-III (in *longirostris* free, in *saleri* connected with tubercle De) and length of chaeta Di1 on Abd IV (in *longirostris* distinctly shorter than chaeta Di1 of Abd V, in *saleri* slightly shorter than chaeta Di1 of Abd V).

***Endonura paracentaurea* sp. n.**
http://zoobank.org/9CC758B3-42F6-44D3-841B-D46B371997DD
Figs 11–19, Table 2

Type material. Holotype: adult female on slide, Iran, Mazandarn province, Behshahr region, Abbas-Abad forest (36°40'N; 53°32'E), rooting wood, 28.III.2013, leg. E. Yoosefi Lafooraki (DIBEC). Paratypes: 3 females on slide, same data as holotype.

Etymology. The name "*paracentaurea*" refers to a strong similarity of the new species to *E. centaurea*.



Figures 11–19. *Endonura paracentaurea* sp. n.: **11** dorsal chaetotaxy of Ant III–IV **12** ventral chaetotaxy of Ant III **13** chaetotaxy of head and Th I–II (holotype), dorsolateral view **14** chaetotaxy of tubercle De of Th III **15** dorsal chaetotaxy of Abd I–VI **16** furca rudimentary **17** chaeta Di1 of Abd V **18** sensillum of Abd V **19** chaetotaxy and ventral sclerifications of labrum.

Diagnosis. Habitus typical of the genus *Endonura*. Dorsal tubercles present and well developed. 2+2 pigmented eyes. Buccal cone short, labrum nonogival. Head with chaetae A, B, C and D. Chaetae O and E absent. Tubercles Cl and Af separate. Tubercles Dl and (L+So) on head with six and eight chaetae respectively. Tubercles Di on Th I present. Tubercles De on Th II and III with three and four chaetae respectively. Tubercles L on Abd III and IV with three and six chaetae respectively. Abd IV and V with eight and three tubercles respectively. Claw without inner tooth. Tibiotarsi with chaetae B4 and B5 short.

Description. General. Body length (without antennae): 0.90 to 1.65 mm (holotype: 1.65 mm). Colour of the body white. 2+2 small black eyes, in a typical arrangement for the genus (Fig. 13).

Chaetal morphology. Dorsal ordinary chaetae of five types: long macrochaetae, short macrochaetae, very short macrochaetae , mesochaetae and microchaetae. Long macrochaetae thick, slightly arc-like or straight, narrowly sheathed, feebly serrated, apically rounded or pointed (Figs 13, 15, 17). Macrochaetae Mc and Mcc morphologically similar to long macrochaetae, but shorter. Mesochaetae similar to ventral chaetae, thin, smooth and pointed. Microchaetae similar to mesochaetae, but apparently short. S–chaetae of tergites thin, smooth and short, notably shorter than nearby macrochaetae (Figs 13, 15, 18).

Antennae. Typical of the genus. Dorsal chaetotaxy of Ant III–IV as in Fig. 11 and Table 2b. S–chaetae of Ant IV of medium length and moderately thickened, S4 and S7 notably longer than other S–chaetae, S1 distinctly shorter and thinner than others (Fig. 11). Apical vesicle poorly developed, unilobate. Ventral chaetotaxy of Ant III–IV as in Fig. 12 and Table 2b.

Mouthparts. Buccal short with labral sclerifications nonogival. Labral chaetotaxy: 0/2, 4 (Fig. 19). Labium with four basal, three distal and four lateral chaetae, papillae x absent. Maxilla styliform, mandible thin and tridentate.

Dorsal chaetotaxy and tubercles. Head without chaetae E, O, So2 and L3 (Fig. 13). Tubercles Di on Th I differentiated, not fused with tubercles De (Fig. 13). Thorax and abdomen without free chaetae De2 and De3 (Figs 13–15). On Abd I–III, the line of chaetae De1–chaeta s perpendicular to the dorsomedian line. On Abd I-III chaetae De1 notably short (Fig. 15). Cryptopygy absent, Abd VI visible from above.

Ventral chaetotaxy. On head, groups Vea, Vem and Vep with 3, 4, 4 chaetae respectively. Group Vi on head with 6 chaetae. On Abd IV, furca rudimentary with 4-5 microchaetae without visible chaetopores (Fig. 16). On Abd V, chaetae Vl and L' present.

Legs. Chaetotaxy of legs as in Table 1C. Claw without internal tooth. On tibiotarsi, chaeta M present and chaetae B4 and B5 relatively short and pointed.

Remarks. Morphologically, *E. paracentaurea* sp. n. strongly recalls *E. centaurea* Cassagnau et Péja, 1979, a form shortly described from Greece (Cassagnau and Péja 1979) and recently redescribed (Smolis 2016). Both species are characterised in having white body, same number of chaetae on tubercles Dl and Af on head, same number of dorsal chaetae on Th and Abd and microchaetae on furca rudimentary. Nevertheless, the new species can be recognised by presence of pigment on eyes (in *centaurea* absent),

Table 2a. Chaetotaxy of *Endonura paracentaurea* sp. n.: cephalic chaetotaxy dorsal side.

Tubercle	Number of chaetae	Types of chaetae	Names of chaetae
Cl	4	Ml	F
		me	G
Af	8	Ml	B
		Mc	A
		mi	C, D
Oc	3	Ml	Ocm
		Mc	Ocp
		mi	Oca
Di	2	Ml	Di1
		Mc	Di2
De	2	Mc	De1
		Mcc	De2
Dl	6	Ml	Dl5, Dl1
		Mcc	Dl3, Dl4
		mi	Dl2, Dl6
(L+So)	8	Ml	L1, L4, So1
		mi	L2
		me	So3–6

Table 2b. Chaetotaxy of *Endonura paracentaurea* sp. n.: chaetotaxy of antennae.

Segment, Group	Number of chaetae	Segment, Group	Number of chaetae adult
I	7	IV	
II	11	ap	or, 8 S, i, 12 mou, 6 brs, 2 iv
III	5 sensilla AO III		
ve	5		8 bs, 5 miA
vc	4	ca	2 bs, 3 miA
vi	4	cm	3 bs, 1 miA
d	5	cp	8 miA, 1 brs

Table 2c. Chaetotaxy of *Endonura paracentaurea* sp. n.: postcephalic chaetotaxy.

	Terga				Legs				
	Di	**De**	**Dl**	**L**	**Scx2**	**Cx**	**Tr**	**Fe**	**T**
Th I	1	2	1	-	0	3	6	13	19
Th II	3	2+s	3+s+ms	3	2	7	6	12	19
Th III	3	3+s	3+s	3	2	8	6	11	18
							Sterna		
Abd I	2	3+s	2	3	VT: 4				
Abd II	2	3+s	2	3	Ve: 5–6; chaeta Ve1 present				
Abd III	2	3+s	2	3	Vel:4–5; Fu: 4–5 me, 4–5 mi				
Abd IV	2	2+s	3	6	Vel: 4; Vec: 2; Vei: 2; Vl: 4				
Abd V	(3+3)	5+s			Ag: 3; Vl: 1, L‘: 1				
Abd VI		7			Ve: 13–14; An: 2mi				

presence of eight chaetae (L+So) on head (in *centaurea* nine), absence of non-reticulate area within tubercle Af on head (in *centaurea* present) and presence of tubercle Di on Th I (in *centaurea* absent).

***Endonura turkmenica* sp. n.**
http://zoobank.org/AC92D847-D212-4D5D-9F9C-F81D24AFF82C
Figs 20–34, Table 3

Type material. Holotype: male on slide, Turkmenistan, south-western part of the country (Balkan velayat), Magtymguly (previously Kara-Kala) Area, foothills of the southern slope of the Kopet Dag mountain range, near village Juvankala, right tributary of Sumbar river, leaf litter under elm *Ulmus* spp, 4.II.1977, leg. A. Babenko, A. Uvarov, T. Zheltikova (MSPU). Paratype: juvenile on slide, same data as holotype (DIBEC).

Etymology. The name *turkmenica* is derived from Turkmenistan, the name of the country where the species was found.

Diagnosis. Habitus typical of the genus *Endonura*. Dorsal tubercles present and well developed. 2+2 pigmented eyes. Buccal cone relatively long, labrum ogival. Head with chaetae A, B, C, D and E. Chaeta O absent. Tubercles Cl and Af separate. Tubercles Dl and (L+So) on head with six and eight chaetae respectively. Tubercles Di on Th I absent. Tubercles De on Th II and III with three and four chaetae respectively. Tubercles L on Abd III and IV with three and six chaetae respectively. Abd IV and V with eight and three tubercles respectively. Claw without inner tooth. Tibiotarsi with chaetae B4 and B5medium size.

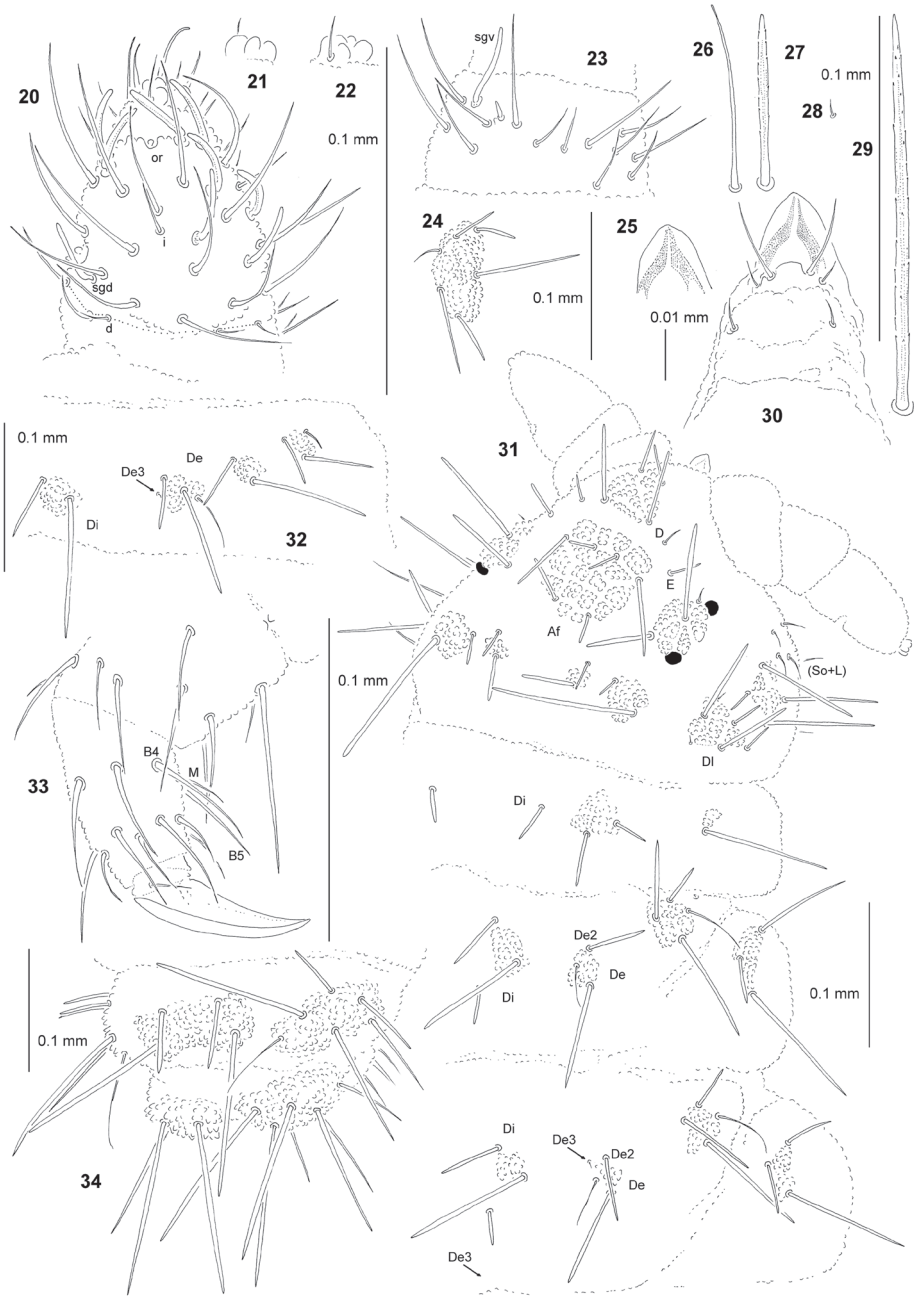
Description. General. Body length (without antennae): 0.50 (juvenile) to 1.45 mm (holotype: 1.45 mm). Colour of the body bluish-grey. 2+2 large black eyes, in a typical arrangement for the genus (Fig. 31).

Chaetal morphology. Dorsal ordinary chaetae of five types: long macrochaetae, short macrochaetae, very short macrochaetae, mesochaetae and microchaetae. Long macrochaetae relatively thin, straight, narrowly sheathed, serrated, apically pointed (Fig. 29). Macrochaetae Mc and Mcc morphologically similar to long macrochaetae, but much shorter (Fig. 27). Mesochaetae similar to ventral chaetae, thin, smooth and pointed. Microchaetae similar to mesochaetae, but apparently short (Fig. 28). S–chaetae of tergites thin, smooth and short, shorter than nearby macrochaetae (Figs 26, 31, 32, 34).

Antennae. Typical of the genus. Dorsal chaetotaxy of Ant III–IV as in Fig. 20 and Table 3b. S–chaetae of Ant IV of medium length and thickened, S5 and S6 slightly longer and thicker than others. Apical vesicle distinct, multilobate (Figs 21, 22). Ventral chaetotaxy of Ant III–IV as in Fig. 23 and Table 3b.

Mouthparts. Buccal cone long with labral sclerifications ogival (Fig. 25). Labrum chaetotaxy: 0/2, 4 (Fig. 30). Labium with four basal, three distal and four lateral chaetae, papillae x absent. Maxilla styliform, mandible thin and tridentate.

Dorsal chaetotaxy and tubercles. Head without chaetae O, So2 and L3 absent (Fig. 31). Tubercles Di on Th I not differentiated (Fig. 31). On Th and Abd, chaetae



Figures 20–34. *Endonura turkmenica* sp. n.: **20** dorsal chaetotaxy of Ant III–IV **21** apical bulb, ventral view **22** apical bulb, dorsal view **23** ventral chaetotaxy of Ant III **24** tubercle L of Abd IV **25** ventral sclerifications of labrum **26** sensillum of Abd V **27** chaeta Di2 of Abd V **28** chaeta Di3 of Abd V **29** chaeta Di1 of Abd V **30** chaetotaxy of labrum **31** chaetotaxy of head and Th (holotype), dorsolateral view **32** chaetotaxy of Abd II **33** leg II, chaetotaxy of T and Fe, lateral view 34 chaetotaxy of Abd V–VI, dorsolateral view.

Table 3a. Chaetotaxy of *Endonura turkmenica* sp. n.: cephalic chaetotaxy dorsal side.

Tubercle	Number of chaetae	Types of chaetae	Names of chaetae
Cl	4	Ml Mc	F G
Af	10	Ml Mc Mcc	B A, E C, D
Oc	3	Ml Mc mi	Ocm Ocp Oca
Di	2	Mc Mcc	Di1 Di2
De	2	Ml Mcc	De1 De2
Dl	6	Ml Mcc mi	Dl5, Dl1 Dl3, Dl4 Dl2, Dl6
(L+So)	8	Ml Mcc me	L1, L4, So1 L2 So3–6

Table 3b. Chaetotaxy of *Endonura turkmenica* sp. n.: chaetotaxy of antennae.

Segment, Group	Number of chaetae	Segment, Group	Number of chaetae adult
I	7	IV	or, 8 S, i, 12 mou, 6 brs, 2 iv
II	12	ap	
III	5 sensilla AO III		
ve	5		8 bs, 5 miA
vc	4	ca	2 bs, 3 miA
vi	4	cm	3 bs, 1 miA
d	5	cp	8 miA, 1 brs

Table 3c. Chaetotaxy of *Endonura turkmenica* sp. n.: postcephalic chaetotaxy.

	Terga				Legs				
	Di	**De**	**Dl**	**L**	**Scx2**	**Cx**	**Tr**	**Fe**	**T**
Th I	1	2	1	-	0	3	6	13	19
Th II	3	2+s	3+s+ms	3	2	7	6	12	19
Th III	3	3+s	3+s	3	2	8	6	11	18
							Sterna		
Abd I	2	3+s	2	3	VT: 4				
Abd II	2	3+s	2	3	Ve: 6; chaeta Ve1 present				
Abd III	2	3+s	2	3	Vel: 5; Fu: 7 me, 0 mi				
Abd IV	2	2+s	3	6	Vel: 4; Vec: 2; Vei: 2; Vl: 4				
Abd V	(3+3)	5+s			Ag: 3; Vl: 1, L‘: 1				
Abd VI		7			Ve: 14; An: 2mi				

De2 and De3 not free (Figs 31, 32), chaetae De3 notably short and hard to detect. On Abd I–III, the line of chaetae De1–chaeta s non perpendicular to the dorsomedian line. Cryptopygy absent, Abd VI visible from above.

Ventral chaetotaxy. On head, groups Vea, Vem and Vep with 3, 4, 4 chaetae respectively. Group Vi on head with six chaetae. On Abd IV, furca rudimentary without microchaetae. On Abd IV, group L without free chaeta (Fig. 24). On Abd V, chaetae Vl and L' present.

Legs. Chaetotaxy of legs as in Table 1C. Claw without internal tooth. On tibiotarsi, chaeta M present and chaetae B4 and B5 relatively long and pointed (Fig. 33).

Remarks. *Endonura turkmenica* sp. n. seems to be the closest *E. ceratolabralis* Smolis et al., 2016 recently described from western part of Iran (Smolis et al. 2016a). They differ in a number of characters: maximum length of body without antennae (in *turkmenica* 1,45 mm, in *ceratolabralis* 2,55), location of chaeta E on head (in *turkmenica* free, in *ceratolabralis* connected with tubercle Af), labral formula of chatotaxy (in *turkmenica*: 0/2,4; in *ceratolabralis*: 0/2, 2), number of chaetae (L+So) on head (in *turkmenica* eight, in *ceratolabralis* nine) and presence/absence of tubercle Di on Th I (in *turkmenica* absent, in *ceratolabralis* present). Additionally, chaetae De3 on Th III and Abd I-III are very minute and can be easily overlooked in *turkmenica* (in *ceratolabralis* well visible and slightly shorter than De2).

Discussion

Unlike most springtails, members of the family Neanuridae completely lack a molar plate on the mandibles and have suctorial mouthparts. Therefore, they are sometimes called sucking forms in contrast to chewing taxa, where mandibles comprise an outlined structure. The highest degree of simplicity of this part of body can be observed within the subfamily Neanurinae, where the majority of genera and species are characterized by a styliform maxilla consisting of no more than one dentate lamella and a thin mandible, usually tridentate with an apical tooth seldom subdivided. For this reason, authors of taxonomic descriptions have usually devoted little attention to the construction of such elements as mandibles or maxillae. Additionally, characteristics of other mouth structures, e.g. the labrum, are frequently omitted from most papers. Interestingly, observations on the genus *Endonura* and other Neanurinae show that the apical part of the labrum can be modified, and its shape is constant and characteristic of the species. In the light of these facts, this mouthpart element is very useful and should be added to the list of diagnostic features in the Neanurinae taxonomy.

Up to date, two main types of shapes of the apical part of the labrum have been observed within *Endonura* and other Neanurinae: nonogival and ogival (Deharveng and Weiner 1984). The latter type, present in two species described herein: *E. longirostris* sp. n. and *E. turkmenica* sp. n., is characterized by a strongly tapered and sharp end. What is interesting and noteworthy for this type seems to be generally less widespread but appears to be more common in representatives of the genus living at lower geographic latitudes. It

is important to question the reasons for such modifications of the labrum and the causes of such a strong elongation of this structure in some species. It is worth noting that such elongation of the labrum is rather not observed in taxa with the first nonogival type.

Recent observations and studies on the diet of some Neanurinae species probably provide an answer to the above question (Smolis 2009, Hoskins et al. 2015). Apparently, an important, and perhaps primary, food resource for this subfamily are slime molds. Like most Neanurinae, this group of organisms can be found mainly in forest habitats, moist and rich in organic matter, in particular in different kinds of decaying wood. It is highly probable that the observed differences in the shape of the labrum allow some Neanurinae species to feed on certain species of slime molds and, in consequence, to reduce interspecies competition. Undoubtedly, to clarify this intricate aspect of the morphology and ecology of Neanurinae, further studies on the *Endonura* species with different modifications of the labrum, are needed.

Acknowledgments

We thank Dr. László Dányi and Prof. Pietro Paolo Fanciulli for reviewing and their helpful comments on the manuscript. The work was financially supported by the Russian Foundations for Basic Research (grant 16-04-01228) and the Institute of Environmental Biology, Faculty of Biological Science, University of Wrocław, Poland (project no. 1076/Ś/IBŚ/2017).

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