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A new land snail, *Arinia* (*Notharinia*) *micro* (Caenogastropoda: Cyclophoroidea: Diplommatinidae), from a limestone karst in Perak, Peninsular Malaysia

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Abstract. A new snail species of the family Diplommatinidae is described from Perak, western Peninsular Malaysia. *Arinia* (*Notharinia*) *micro*, new species, differs from known congeners by its remarkably smaller shell. It is among the smallest land snails in the world with a mean shell height of 0.85 mm and mean shell width of 0.35 mm. The shell has tight radial ribbed whorls (except for the smooth protoconch), pronounced fine spiral ridges, and a semi-detached body whorl. The new species is known only from Gunung Rapat limestone karst complex, parts of which are subjected to rapid, destructive limestone quarrying. The reassignment of *Arinia* (*Notharinia*) from family Pupinidae to Diplommatinidae is based mainly on the oblique apex, which is not known in other members of the Pupinidae, and other shell characters.

Key words. Gastropoda, land snail, Malaysia, Diplommatinidae, Pupinidae, karst conservation, new taxon

INTRODUCTION

The genus *Arinia* (*Notharinia*) Vermeulen, Phung & Truong, 2007, is currently comprised of four nominal species. *Arinia* (*Notharinia*) *attenuata* Vermeulen, Phung & Truong, 2007, *Arinia* (*Notharinia*) *brevior* Vermeulen, Phung & Truong, 2007, and *Arinia* (*Notharinia*) *crassilabris* Vermeulen, Phung & Truong, 2007, inhabit a cluster of limestone karsts in south-western Vietnam while one species, *Arinia* (*Notharinia*) *linnei* Maassen, 2008, is known only from one isolated limestone karst on the east coast of Peninsular Malaysia. *Arinia* (*Notharinia*) species are presumed to be calcicolic endemics as they are thus far known only from limestone karst forests (Vermeulen et al., 2007; Maassen, 2008). All species have shells that are minute (< 2.05 mm), rather cylindrical in shape, white, delicate, and heavily ornamented with radial ribs on all whorls except the smooth, rounded protoconch (Vermeulen et al., 2007). Shells of *Arinia* (*Notharinia*) species are also characterised by their slightly oblique protoconch (Vermeulen et al., 2007).

Here, we describe the second species of *Arinia* (*Notharinia*) in Peninsular Malaysia. Reassignment of *Arinia* (*Notharinia*) to the family Diplommatinidae Benson, 1849, by Egorov (2013) is justified and elaborated. The new species brings the total number of known *Arinia* (*Notharinia*) species to five, and represents a 230 km range extension eastwards for the subgenus. Prior to this study, three diplommatinid genera comprising a total of 70 species occur in Peninsular Malaysia: 19 species of *Diplommatina* Benson, 1849, 24 species of *Opisthostoma* Blandford & Blanford, 1860, 26 species of *Plectostoma* Adams, 1865 and 1 species of *Arinia* (*Notharinia*) (Laidlaw, 1949; Benthem-Jutting, 1952, 1961; Maassen, 2001, 2008; Clements et al., 2008; Vermeulen & Clements, 2008; Egorov, 2013; Liew et al., 2014). The description of *Arinia* (*Notharinia*) *micro* new species, brings the number of diplommatinid species in Peninsular Malaysia to 71.

MATERIAL AND METHODS

Descriptions of *Arinia* (*Notharinia*) *micro*, new species, are based on conchological characteristics. Shell terminology follows Vermeulen et al. (2007), Maassen (2008) and Panha & Burch (2005). The holotype and two paratypes of *Arinia* (*Notharinia*) *micro* new species were photographed and measured with a Leica DFC495 Digital Microscope Camera mounted on a Leica M205C microscope. Shell height was measured from the highest part of the top whorl to the lowest part of the peristome parallel to the dominant coiling axis. Shell width was measured at the widest section perpendicular to the dominant coiling axis. Aperture height was measured at the widest section of the aperture parallel to the dominant coiling axis. The number of whorls including the protoconch was counted (after Kerney & Cameron, 1979). All measurements were measured to the nearest 0.01 mm. The holotype was subsequently sputter coated with gold and viewed under high vacuum with a Scanning Electron Microscope (JEOL JSM-5610LV, JEOL Ltd., Tokyo) to

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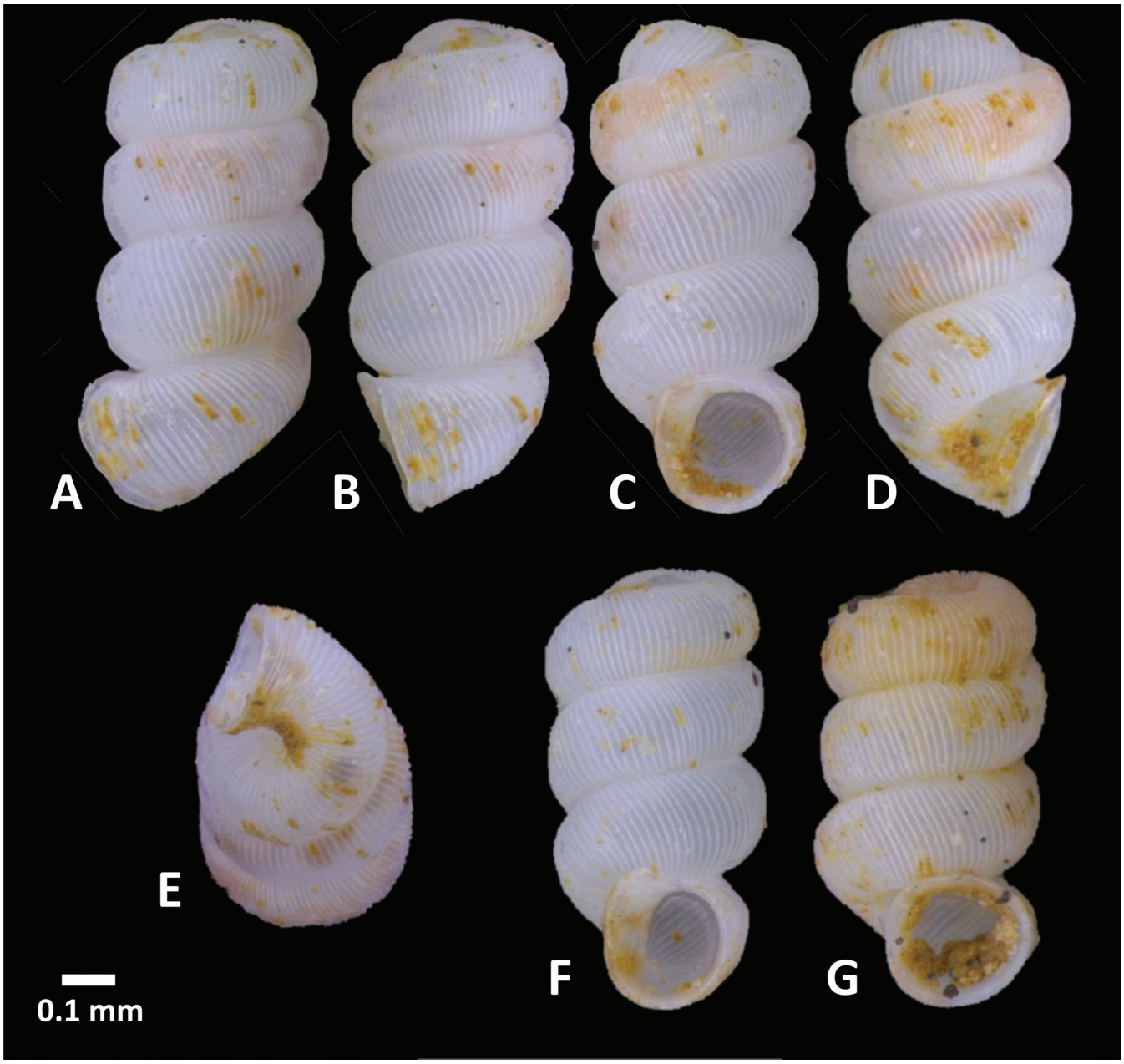

Fig. 1. Shells of *Arinia* (*Notharinia*) *micro* Marzuki & Foon, new species. A–E, Holotype (BOR/MOL 6227): A, right lateral view; B, frontal view; C, apertural view; D, left lateral view; E. bottom view; F. paratype 1 (BOR/MOL 6228/1); G, paratype 2 (BOR/MOL 6228/2).

further discern minute shell sculpture. Specimens were deposited in the BORNEENSIS collection, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia (Abbreviation: BOR/MOL), and the collection of the first author (Abbreviation: ME). The latter will eventually be deposited in the Sarawak Museum, Kuching, Malaysia.

SYSTEMATICS

Family Diplommatinidae Benson, 1849

Genus *Arinia* Adams & Adams, 1856

Subgenus *Notharinia* Vermeulen, Phung & Truong, 2007

Type species. *Arinia* (*Notharinia*) *attenuata* Vermeulen, Phung & Truong, 2007

Arinia (*Notharinia*) *micro* Marzuki & Foon, new species

Figs. 1, 2

Type material. Holotype (BOR/MOL 6227) and paratypes (BOR/MOL 6228/2; ME0000883/>10): Malaysia, Perak, central Gunung [=Mountain] Rapat, limestone outcrops in Kek Lok Tong, approximately 6.9 kilometres south of Ipoh, 4°33’13.45”N, 101°7’50.34”E, coll. M.E. Marzuki, 26 May 2011.

Diagnosis. Shell minute, cylindrical, translucent. Whorls 4.5. All whorls except the protoconch sculptured with dense, prominent, thin radial ribs. Spiral ridges very fine, evenly spaced and distinct. Last part of body whorl detached,

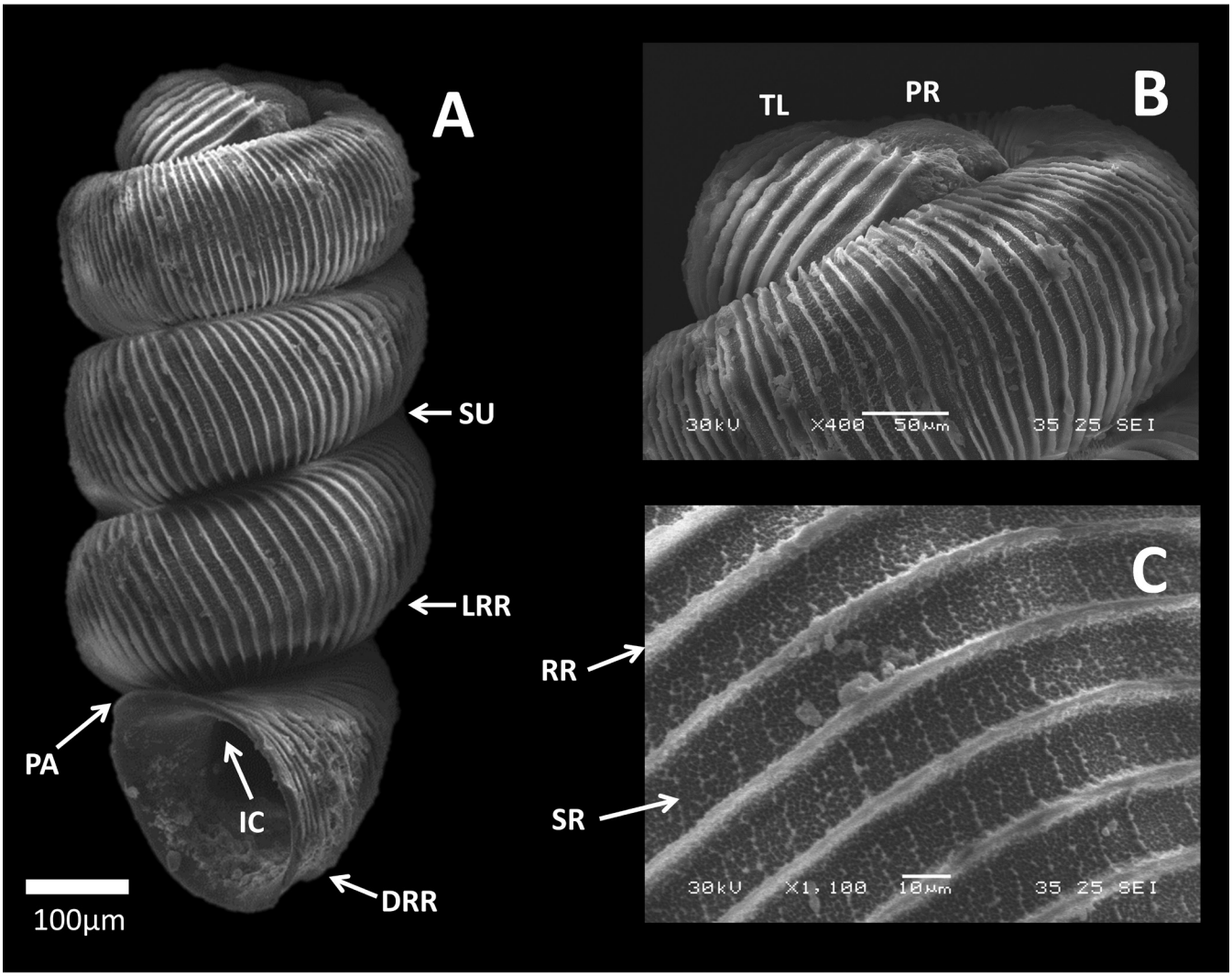

Fig. 2. SEM images of *Arinia* (*Notharinia*) *micro* Marzuki & Foon, new species, holotype (BOR/MOL 6227). A, sub-frontal view of the holotype; B, top whorl of the holotype; C, Radial ribs and spiral ridges on the surface of the holotype shell. Abbreviations: PA = Parietal side of the aperture, IC = Internal constriction, DRR = Dense radial ribs, LRR = Loose radial ribs, SU = Suture, TL = teleoconch, PR = protoconch, RR = Radial rib, SR = Spiral ridges.

peristome not touching the ultimate whorl. Umbilicus deep. Peristome simple, reflected at the parietal area but not the palatal and basal areas.

Description. Shell minute, delicate, dextral. Color dull white, translucent. Suture deeply impressed. Whorls 4.5, convex. Apical whorl depressed conical, width of the antepenultimate, penultimate and ultimate whorl consistent, thus shell appears cylindrical. Periphery rounded for all whorls. Apex somewhat sunken, slightly depressed and concave. Protoconch rounded, smooth, distinctly oblique at 25 degrees to the teleoconch. Teleoconch commences with abruptly sculptured orthoclinic radial ribs. Radial sculpture is present on all whorls except the protoconch and is characterised by dense, straight, pronounced, sharp thin ribs. Radial ribs slightly sinuous particularly on apical and ultimate whorls. Radial rib density varies ontogenically, ribs more loosely spaced at the start of the teleoconch, denser at the apical and antepenultimate whorls (10 ribs per 0.1 mm), less dense at the penultimate and ultimate whorls (6 ribs per 0.1 mm) and very dense towards the terminal of the ultimate whorl (7 ribs in 0.04 mm before the aperture, equivalent to 17.5 ribs per 0.1 mm). Internal constriction present, but not conspicuous. Spiral ridges between radial ribs very fine, evenly-spaced, distinct and are present on all whorls except the protoconch. Shell rimately perforate, last whorl loosely-coiled, slightly detached, revealing a deep umbilicus. Aperture simple, circular, white. Peristome simple, well-rounded, thickened and reflected at the parietal area but not the palatal or basal area, not touching the ultimate whorl. Operculum not examined.

Dimensions (Table 1). Shell height 0.80–0.90 mm, mean 0.85 mm; Shell width 0.34–0.35 mm, mean 0.35 mm; Aperture height 0.24–0.42 mm, mean 0.31 mm (n=3).

Etymology. From the Greek *micro*, meaning small, in reference to the remarkably smaller shell of matured individuals of the species compared to its four known congeners.

Habitat and ecology. *Arinia* (*Notharinia*) *micro* inhabits thickly vegetated lowland rainforest on and near limestone karsts. Living individuals were observed crawling among leaf

Table 1. Shell measurements (mm) for *Arinia* (*Notharinia*) species. Measurements of *Arinia* (*Notharinia*) *attenuata*, *Arinia* (*Notharinia*) *brevior*, *Arinia* (*Notharinia*) *crassilabris*, and *Arinia* (*Notharinia*) *linnei* were sourced from Vermeulen et al. (2007) and Maassen (2008).

Specimen	Shell Height	Shell Width	Aperture Height
Arinia (*Notharinia*) *attenuata* Vermeulen, Phung & Truong, 2007	1.70–1.90	0.75–0.85	0.45–0.50
Arinia (*Notharinia*) *brevior* Vermeulen, Phung & Truong, 2007	1.50–1.60	0.85–0.90	0.50–0.55
Arinia (*Notharinia*) *crassilabris* Vermeulen, Phung & Truong, 2007	1.60–2.05	0.65–0.75	0.50–0.60
Arinia (*Notharinia*) *linnei* Maassen, 2008	1.58–2.16	0.84–0.99	NA
Arinia (*Notharinia*) *micro* Marzuki & Foon, new species			
Holotype (BOR/MOL 6227)	0.90	0.35	0.25
Paratype 1 (BOR/MOL 6228/1)	0.85	0.35	0.26
Paratype 2 (BOR/MOL 6227/2)	0.80	0.34	0.24
Mean (Holotype, Paratype 1 and Paratype 2)	0.85	0.35	0.25

litter and plant debris in sheltered and damp microhabitats near limestone rock outcrops.

Conservation status. This species is vulnerable to habitat loss as the Gunung Rapat karst complex is completely isolated from other natural rainforest and karst habitats because of intensive human developments, such as ex-tin mining ponds, agriculture, roads and residential areas. Although the type locality is within cave temple grounds, which provides the local population of *Arinia* (*Notharinia*) *micro* nominal protection from other land uses, the southern and central parts of the same karst complex are being rapidly subjected to destructive limestone quarrying activities.

Remarks. *Arinia* (*Notharinia*) *micro* notably differs from its congeners by its distinctly smaller shell. Like other *Arinia* (*Notharinia*) species, specimens of *Arinia* (*Notharinia*) *micro* may vary slightly in shell size (see Table 1), which has been suggested to be due to sexual dimorphism by Maassen (2008). Matured shells of *Arinia* (*Notharinia*) *micro* consistently comprise of 4.5 whorls compared to 4.5–5.0 whorls in *Arinia* (*Notharinia*) *linnei*, 5.0–5.4 whorls in *Arinia* (*Notharinia*) *attenuata*, 4.1–4.5 whorls in *Arinia* (*Notharinia*) *brevior* and 5.5 whorls in *Arinia* (*Notharinia*) *crassilabris*.

The radial ribs in *Arinia* (*Notharinia*) *micro* are more pronounced and well-developed compared to *Arinia* (*Notharinia*) *linnei*. The ultimate whorl of *Arinia* (*Notharinia*) *micro* is more loosely coiled and detached than *Arinia* (*Notharinia*) *brevior* and is distinct from the tightly coiled *Arinia* (*Notharinia*) *attenuata*, *Arinia* (*Notharinia*) *crassilabris* and *Arinia* (*Notharinia*) *linnei*. The deep umbilicus is visible in *Arinia* (*Notharinia*) *micro*, a feature not found in other congeners except *Arinia* (*Notharinia*) *linnei*. The umbilicus of *Arinia* (*Notharinia*) *linnei* is only partially visible due to obstruction by the ultimate whorl. The peristome of *Arinia* (*Notharinia*) *micro* is simple, a feature shared by only one other species, *Arinia* (*Notharinia*) *attenuata*. Interestingly, fine spiral ridges between the radial ribs are present in both Peninsular Malaysian species, *Arinia* (*Notharinia*) *micro* and *Arinia* (*Notharinia*) *linnei*, but is absent in the Vietnamese species (see Vermeulen et al., 2007).

DISCUSSION

The familial assignment of *Arinia* (*Notharinia*) has been contentious (e.g., Vermeulen et al., 2007; Maassen, 2008; Egorov, 2013). *Arinia* (*Notharinia*) was placed in the family Pupinidae by Vermeulen et al. (2007), who regarded *Arinia* (*Notharinia*) more akin to the genus *Pseudopomatias* Möllendorff, 1885, on the basis of shared shell characters, such as evenly-spaced radial ribs, simple or doubled and circular aperture as well as smooth protoconch transitioning to ribbed teleoconch at the apical whorls (see Páll-Gergely et al., 2015a). The interspecific variability in radial rib height (pronounced or low) and the variation in radial rib density at each whorl are present in both *Pseudopomatias* and *Arinia* (*Notharinia*) as well (Páll-Gergely et al., 2015a). However, *Arinia* (*Notharinia*) possesses a distinctly oblique apex, which is not known in pupinids, but fairly common in diplommatinids (Webster et al., 2012; Yamazaki et al., 2013, 2015a, b; Liew et al., 2014; Neubert & Bouchet, 2015). *Arinia* (*Notharinia*) *micro*, new species, possesses an internal constriction unlike other known *Arinia* (*Notharinia*) species (see Vermeulen et al., 2007), which is also common in diplommatinids, but not in pupinids (Webster et al., 2012; Yamazaki et al., 2013, 2015a, b; Liew et al., 2014; Neubert & Bouchet, 2015). The sub-cylindrical to cylindrical shell, simple but distinct radial ribs and the occasionally detached last whorl of members of the diplommatinid *Arinia* sensu stricto, Adams & Adams, 1856, is similar to *Arinia* (*Notharinia*) (see Vermeulen, 1996; Egorov, 2013). Despite these similarities, Vermeulen et al. (2007) regards *Arinia* (*Notharinia*) a pupinid because of their lack of longitudinal teeth. However, the absence of longitudinal teeth is not a good diagnostic character for *Arinia* (*Notharinia*) because most *Arinia* sensu stricto species also do not possess longitudinal teeth. Thus, we concur with Maassen (2008) that the absence of longitudinal teeth alone is not a reliable familial character. Egorov (2013) placed *Notharinia* as a subgenus of *Arinia* but did not elaborate reasons for the recombination. We demonstrate above that Egorov's (2013) decision to place *Notharinia* in genus *Arinia* and the family Diplommatinidae is justified.

Some of the smallest terrestrial snails known to science were briefly discussed by Páll-Gergely et al. (2015b). *Arinia* (*Notharinia*) *micro* (shell height = 0.80–0.90 mm) is one of the smallest terrestrial snails ever recorded, following closely behind *Acmella nana* Vermeulen, Liew & Schilthuizen, 2015 (shell height = 0.60–0.79 mm), *Acmella minutissima* (Maassen, 2000) (shell height = 0.8 mm), *Acmella conica* Vermeulen & Junau, 2007 (shell height = 0.85 mm) and *Georissa leucococca* Vermeulen, Liew & Schilthuizen, 2015 (shell height = 0.70–1.05 mm). It is beyond the scope of this paper to cover the ecological and evolutionary implications of such minute snail sizes. However, such extreme body sizes in land snails is well-known and have been attributed to resource and niche partitioning among molluscan communities (McClain & Nekola, 2008; Nekola et al., 2013; Nekola, 2014). This has been alluded to in studies on the micro-snails (shell size <5 mm) of the tropics, although detailed research on such aspects remains to be done (Schilthuizen, 2011).

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