REDESCRIPTION AND RANGE EXTENSION OF TWO CARNIVOROUS MICRO-SNAIL SPECIES OF THE GENUS *SINOENNEA* (GASTROPODA: STREPTAXOIDEA: DIAPHERIDAE) FROM NORTHEAST INDIA

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Abstract *This paper provides new records and redescribes two carnivorous micro snail species, viz.,* Sinoennea austeni *(Peile, 1929) and* Sinoennea vara *(Benson, 1859), belonging to the family Diapheridae. Redescriptions are based on shell morphology and include ecological notes and new localities including the first record of S. austeni in 92 years. While* Sinoennea austeni *is endemic to Northeast India,* S. vara *has been recorded from Bhutan and Northeast India.*

Key words *Shell morphology, taxonomy, hotspot, land snail, carnivorous snail, ecology, Mizoram*

INTRODUCTION

Members of the carnivorous land snail genus *Sinoennea* Kobelt, 1904 (family Diapheridae) are widely distributed from northeast India, Nepal to northern Borneo in the south and Japan in the east (Budha *et al.,* 2015; Páll-Gergely *et al*., 2020). There are over 80 species reported from this genus to date (www.molluscabase.org, Páll-Gergely *et al.,* 2020). The shells of *Sinoennea* range mostly between 2 and 12mm in size and are cylindrical to ovoid in shape. The most important conchological characteristics to identify them are the density of ribs and the morphology of apertural barriers. In India, there are eight species of *Sinoennea*, of which seven were described from northeast India, while the remaining one was described from Nicobar Island (Table 1). Known species of *Sinoennea* were found to be associated with different habitats, including forests with calcium-rich soils (Vermeulen, 2007), limestone hills (Maassen, 1999; Tanmuangpak *et al*., 2015), limestone caves (Maassen, 1999; Dumrongrojwattana and Wongkamhaeng, 2013). Thus, although these snails are not obligate rock-dwellers, they are quite abundant in calcium-rich soils.

Initially, Kobelt (1904) erected the genus *Sinoennea* based on the shell morphology, mainly aperture features, followed by *Indoennea* Kobelt, 1904. However, Peile (1935) synonymized them based on the close similarity in the shell and aperture (shape, folds arrangement) between type species of *Indoennea* with *Sinoennea*. Formerly, the genus *Sinoennea* was placed within the family Streptaxidae, however, Sutcharit *et al.* (2010) erected the family Diapheridae based on integrative taxonomy involving shell morphology, reproductive anatomy and molecular data and placed *Sinoennea* therein. However, so far, no morphological synapomorphies of the Diapheridae are known. In this paper we redescribe two poorly known species of *Sinoennea* from northeast India, *S. austeni* (Peile, 1929) and *S. vara* (Benson, 1859) and provide ecological notes along with new distribution data for these species.

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MATERIAL AND METHODS

Samples were collected across Mizo hills, including the Blue Mountain range, located in south-eastern parts of Mizoram, Northeast India, in January 2019 (Fig. 1). The current collection was part of a large project entitled "Bioresources and Sustainability Livelihood of Northeast India" (http://nebiores.atree.org/) on the inventory of the biodiversity of the Northeastern states of India. Approximately 4 to 5 kg of top soil-leaf

Table 1 Checklist of *Sinoennea* species with their geographical ranges

Species	Distribution	Altitude (m)	Reference
Sinoennea austeni (Peile, 1929)	Burrail Range (=Barail Range), Naga Hills; Blue mountains, Mizoram (This study), India	1900 (this study)	Peile, 1929; Páll-Gergely *et al*., 2020
Sinoennea blanfordiana (Godwin-Austen, 1872)	Mahadeo Peak, near Asalu, North Cachar Hills, among rocks at 5700ft., India. A smaller variety was found in Hemeo Peak in the same district; Nepal	1736	Godwin-Austen, 1872; Blanford & Godwin-Austen, 1908; Budha *et al*., 2015
Sinoennea latens (Peile, 1935)	Khasi and Naga Hills, India; Bhutan (District Trashigang: Kharang La, 20km of Trashigang, 2,300m a.m.s.l., 27°09'38.0"N, 91°34'27.3"E)	2300	Peile, 1935; Gittenberger *et al*., 2021
Sinoennea (?) *milium* (Godwin-Austen, 1876)	Shengorh Peak, 7000ft., Dafla hills, Toruputu Peak, 5000ft. north of Assam, India	1524–2134	Blanford & Godwin-Austen, 1908; Páll-Gergely *et al*., 2020
Sinoennea moerchiana (Nevill, 1881)	Centre of Great Nicobar, India		Nevill, 1881; Blanford & Godwin-Austen, 1908
Sinoennea nagaensis (W.T. Blanford, 1899)	Naga Hills, India		Blanford, 1899; Blanford & Godwin-Austen, 1908
Sinoennea stenopylis (Benson, 1860)	Sikhim (=Sikkim), about 4000ft., near Darjeeling, in the valleys 'Rungnu' and 'Rimmau', 1200m a.m.s.l.; Dafla Hills, Khasi Hills, Naga Hills; Manipur, India; Nepal	1200–1219	Blanford & Godwin-Austen, 1908; Gittenberger *et al*., 2021
Sinoennea vara (Benson, 1859)	ad Nauclai (25°15'N, 92°30'E), Cherrapunji (=Cherrapunjee, Meghalaya), Assam; Near Khawzawl, on the way from Champhai to Khawzawl, after crossing the Tuipui Bridge, Mizoram (This study), India; Bhutan (District Zhemgang: between Duenmang Tsachu and Gonphu Zero Point, 24km SE of Zhemgang, 335m a.m.s.l., 27°02'N 90°48'E, scree in warm broadleaf Forest)	335, 874 (this study)	Blanford & Godwin-Austen, 1908; Gittenberger *et al*., 2021

litter samples were collected and stored in polyethene bags for sorting in the laboratory. Samples were then manually searched for snails in a white enamel coated tray. The shells were stored in vials and deposited in the Mollusca collection at ATREE Museum (Ashoka Trust for Research in Ecology and the Environment, Bangalore).

Microscopy and Identification The specimens were washed carefully with water to remove dirt from the shells and air-dried prior to identification. Subsequently, microscopic examinations were conducted using a Keyence Digital Microscope (VHX-6000 series) and Zeiss stereomicroscope (Zeiss Stemi 508) attached with an Axiocam ERc5s camera. The images were stacked with using Helicon Focus (version 7.7.4 ProLifetime) software for taxonomic plate preparation. Identification of the shells was carried out using established literature (Peile, 1928,1929,1935; Páll-Gergely, 2020).

Morphometry ImageJ (version 1.8.0_112) software was used for morphometric measurements of various shell parameters. All terminology of shell characters follows Páll-Gergely *et al*. (2020) and measurements of the shell characters follow Das *et al*. (2021).

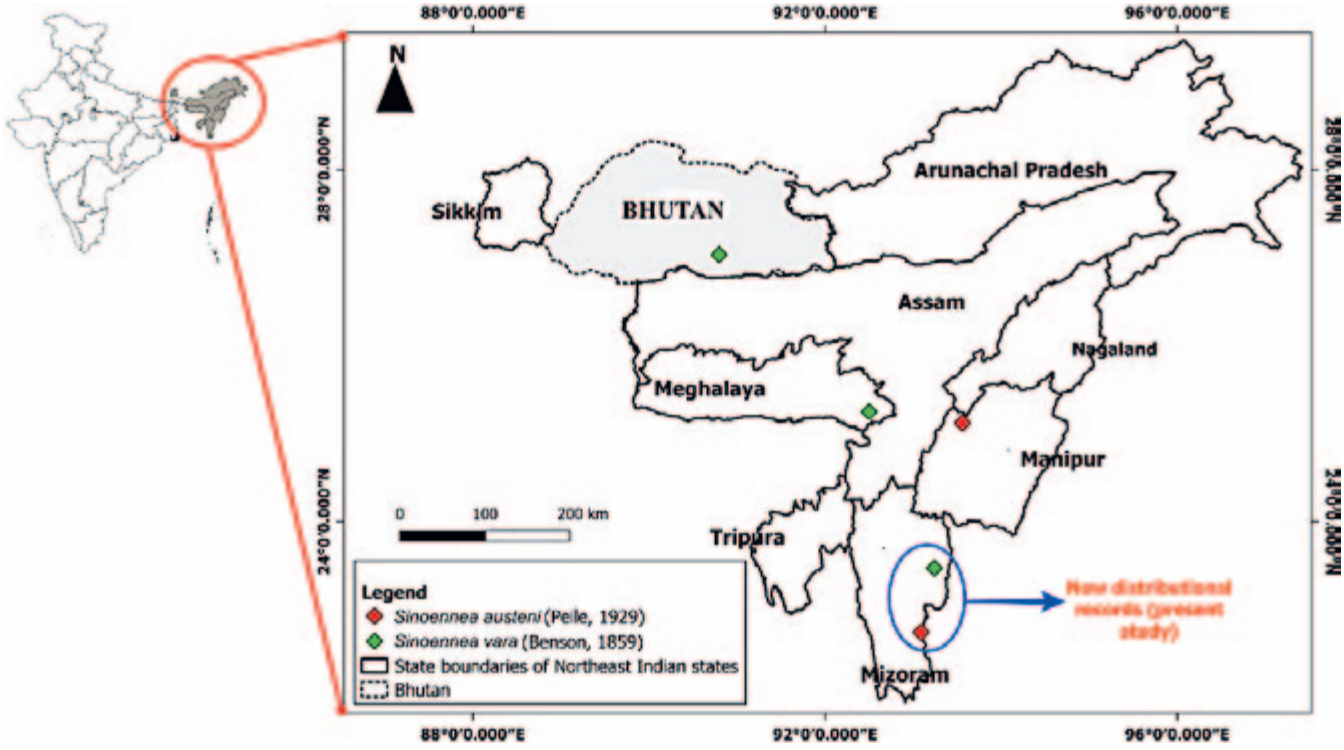

Figure 1 Distributional map for the *S. austeni* Peile, 1929 and *S. vara* Benson, 1859 from the literature and the present study.

ABBREVIATIONS

ATREE:	Ashoka Trust for Research in Ecology and the Environment, Bangalore, India.
S.H.:	Shell Height
S.W.:	Shell Width
A.H.:	Aperture Height
A.W.:	Aperture Width
SpH:	Spire Height
SpW:	Spire Width
LWH:	Last Whorl Height
LWW:	Last Whorl Width
PWH:	Penultimate Whorl Height
PWW:	Penultimate Whorl Width
AWH:	Antepenultimate Whorl Height
AWW:	Antepenultimate Whorl Width
WSABW:	Width of the suture above body whorl
WSAPW:	Width of the suture above penultimate whorl
WSAAW:	Width of the suture above antepenultimate whorl
SI:	Suture Inclination
SD:	Standard Deviation
SE:	Standard Error.

SYSTEMATICS

SUPERFAMILY STREPTAXOIDEA Gray, 1860
FAMILY DIAPHERIDAE Panha & Naggs, 2010
in Sutcharit *et al.*, 2010:5.
Genus *Sinoennea* Kobelt, 1904

Ennea (*Sinoennea*) Kobelt, 1904:27.

Type species *Pupa strophiodes* Gredler, 1881, O.D.

Remarks Traits of the reproductive anatomy and molecular information are known in very few species only. Therefore, the inclusion of genera other than *Diaphera* and *Sinoennea* in the Diapheridae is questionable due to the lack of anatomical and molecular evidence (Sutcharit *et al.*, 2010; Páll-Gergely *et al.*, 2020).

Sinoennea austeni (Peile, 1929)
(Figs 2A–K)

Indoennea austeni Peile, 1929:271, fig 3. Type locality: "Burrail Range, Naga Hills".
Sinoennea austeni Richardson, 1988:154.
Sinoennea austeni Páll-Gergely *et al.*, 2020:704.

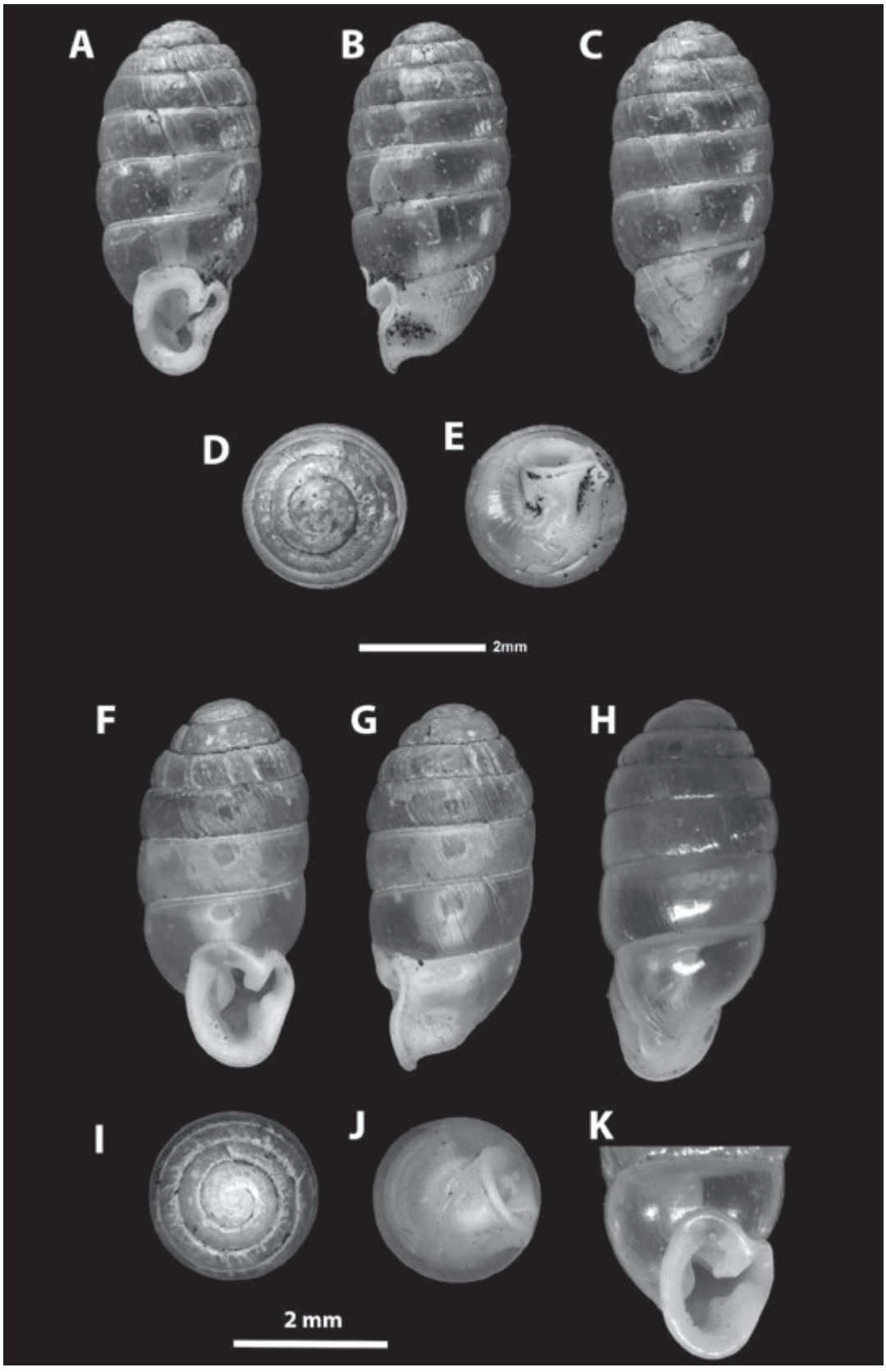

Figure 2 *Sinoennea austeni* Peile, 1929; A- Apertural or ventral view, B- Lateral view, C- Dorsal view, D- Apical or protoconch view, E- Basal or umbilical view of Syntype of *S. austeni* from Burrail Range, (NHMUK 1903.07.01.779); F- Apertural or ventral view, G- Lateral view, H- Dorsal view, I- Apical or protoconch view, J- Basal or umbilical view, K- slanted aperture of *S. austeni* collected from Blue Mountains, Mizoram (AT/2019/LS4011).

Table 2 Shell measurements of the collected specimens of *S. austeni* (Peile, 1929) and *S. vara* (Benson, 1859)

		S. *austeni*					*S. vara*
	Shell parameters (in mm)	**AT/2019/ LS4011**	**AT/2019/ LS4012**	**AT/2019/ LS4013**	**AT/2019/ LS4014**	**AT/2019/ LS4015**	**AT/2019/ LS4016**
Shell	Shell Height (SH)	4.38	4.48	4.03	4.44	4.88	4.75
	Shell Width (SW)	2.02	2.06	2.04	2.06	2.43	2.12
	SH/SW	2.17	2.17	1.97	2.16	2.01	2.24
Aperture	Aperture Height (AH)	1.51	1.61	1.42	1.43	1.71	1.82
	Aperture Width (AW)	1.29	1.32	1.32	1.29	1.49	1.27
	AH/AW	1.17	1.22	1.07	1.11	1.15	1.43
Spire	Spire Height (SpH)	3.04	3.14	2.70	3.14	3.33	3.42
	Spire Width (SpW)	2.02	2.06	2.07	2.06	2.43	2.12
Body/Last whorl	Height (LWH)	2.27	2.30	2.23	2.29	2.52	2.38
	Width (LWW)	1.89	1.9	2.03	1.96	2.29	2.08
Penultimate	Height (PWH)	2.90	2.99	2.87	2.94	3.30	3.07
whorl	Width (PWW)	2.02	2.06	2.09	2.06	2.42	2.12
Antepenultimate	Height (AWH)	3.46	3.55	3.34	3.54	3.87	3.59
whorl	Width (AWD)	1.98	2.02	1.96	2.07	2.35	1.87
Suture	Width of the suture above the body whorl (WSABW)	1.83	1.85	1.93	1.89	2.22	1.92
	Width of the suture above the penultimate whorl (WSAPW)	1.90	1.93	1.93	1.97	2.30	1.81
	Width of the suture above the antepenultimate whorl (WSAAW)	1.75	1.86	1.68	1.82	2.08	1.47
	Suture inclination (SI) (in degree)	11.60	11.19	6.95	8.63	6.93	9.18

Materials Examined 5 shells AT/2019/LS4011 to AT/2019/LS4015, Blue mountains, Mizoram, India, 22.671223°N, 93.045593°E, altitude 1900m a.m.s.l., 30th January 2019, coll. N.A.Aravind; 1 example, Syntype *Sinoennea austeni*, NHMUK1903.07.01.779, Burrail Range, coll. Godwin-Austen.

Measurements (in mm; n=5) SH 4.44 (SD 0.30, SE 0.13), SW 2.12 (SD 0.17, SE 0.08), SH/SW 2.09 (SD 0.10, SE 0.04), AH 1.53 (SD 0.12, SE 0.05), AW 1.34 (SD 0.08, SE 0.04), AH/AW 1.14 (SD 0.06, SE 0.02), SpH 3.07 (SD 0.23, SE 0.10), SpW 2.13 (SD 0.17, SE 0.07), LWH 2.32 (SD 0.11, SE 0.05), LWW 2.01 (SD 0.16, SE 0.07), PWH 2.99 (SD 0.17, SE 0.08), PWW 2.13 (SD 0.16, SE 0.07), AWH 3.55 (SD 0.20, SE 0.09), AWD 2.07 (SD 0.16, SE 0.07), WSABW 1.94 (SD 0.16, SE 0.07), WSAPW 2.01 (SD 0.16, SE 0.07), WSAAW 1.84 (SD 0.15, SE 0.07), SI 9.06° (SD 2.24, SE 1.00). See Table 2 for the measurements of all the five individual shells.

Redescription Shell small (height 4.03–4.87mm, and width 2.02–2.43mm), elongate, and ovoid with cylindrical sides; obtuse apex, dorsal side domed; colour yellowish, vitreous, and transparent; whorls 6–7, suture slightly impressed; all whorls smooth except for occasional fine growth interruptions or varices; umbilicus imperforate; aperture somewhat oval, deformed heart-shaped; peristome white, strongly reflected; parietal lamella long, strong and well developed, divided into internal and external parts which differ in orientation (outer part slightly turns towards palatal wall, inner part slightly turns in the other direction); palatal wall with two conjoined teeth, the upper palatal tooth occurs on the peristome edge and faces the parietal lamella, the lower palatal tooth located deeper than the upper one;

a deep depression on the right lateral side behind the peristome corresponds with the lower palatal tooth; columellar lamella prominent, rounded, sharp, blade-like, situated deeply on the columellar side of aperture, vertical (parallel with shell axis); basal swelling distinct and well developed.

Distribution According to Peile (1929), the type specimen of this species was collected by Godwin-Austen from Burrail Range (=Barail Range), Naga Hills, northeast India. While this study shows their presence in the Mizo Hills (Lushai Hills), also known as the Blue mountain range of Mizoram state, which is over 300km south of the Naga Hill range.

Habitat and Natural History The species was found in the soil-leaf litter sample rich in lime collected from the forest floor of Blue Mountain regions, Mizoram. Snails were collected from a thick layer of leaf litter with almost 100 per cent canopy cover. The Blue mountain range comprises of Temperate forests (DEFCC,2021) and also the region has a highest elevation peak of 2157m a.m.s.l.

Sinoennea vara (Benson, 1859)
(Figs 3A–G)

Pupa (*Ennea*) *vara* Benson, 1859:188 (India: Assam, Meghalaya, Khasi Hills, "ad Nauclai (25°15' N, 92°30' E, Godwin-Austen, 1872:516, pl.30, fig.6. (Cherrapunji, Meghalaya)
Ennea (Huttonella) vara—Nevill, 1878:7.
Ennea (*Indoennea*) *vara*—Kobelt, 1904:160, not pl.20, fig.24 [aperture simple].
Indoennea vara—Peile, 1929: fig.3 (drawings show the dentate juvenile shell)
Sinoennea vara—Richardson, 1988:162.
Ennea vara—W.T. Blanford & Godwin-Austen, 1908:16, fig.10.
Ennea vara—Subba Rao *et al*., 1995:66, pl.13, figs 1–2.
Ennea vara—Ramakrishna *et al*., 2010:191.
Sinoennea vara—Páll-Gergely *et al*., 2020:710.
Sinoennea vara—Gittenberger *et al*., 2021:78.

Materials Examined 1 example, AT/2019/LS4016, Near Khawzawl, on the way from Champhai to Khawzawl, after crossing the Tuipui Bridge, Mizoram, India, 23.47356°N, 93.24174°E, altitude 874m a.m.s.l., 31st January 2019. coll. Nipu Kumar Das; Many shells (NHMUK), Cherrapunji, Assam, coll. Godwin-Austen.

Measurements (in mm; n=1) SH 4.75, SW 2.12, SH/SW 2.24, AH 1.82, AW 1.27, AH/AW 1.43 (AT/2019/LS4016). See Table 2.

Redescription Shell small (height 4.75mm and width 2.24mm), fusiform; apex obtuse; imperforate; sculpture with strong radial ribs in all the whorls except the apical whorls, more specifically the protoconch; whorls 6.25, convex, body whorl and penultimate whorl almost equal in diameter; aperture suboval, and vertical (parallel with shell axis), with distinct columellar callus extending beyond central line of last whorl; peristome whitish, expanded, strongly reflected, continuous; parietal lamella strongly elevated, outer part strongly turns towards palatal side, inner part gradually becomes lower; palatal lip with two conjoined teeth, the upper palatal tooth broader and smaller (in height) than lower palatal tooth; as hollow depression on the right lateral side behind the peristome corresponds with the lower palatal tooth; columellar lip with a very minute columellar denticle; columellar lamella prominent, elongate, rounded, sharp, blade-like, situated deeply on the columellar side of aperture, vertical (parallel with shell axis); basal swelling slight.

Distribution Earlier distribution data suggested that *S. vara* is found in the Khasi Hills of Meghalaya, India (Benson, 1859) and the Zhemgang district of Bhutan (Gittenberger *et al*., 2021). Also, Benson (1859) suggested that the species was rare. The present study recorded this species from the Khawzawl district of Mizoram, India, neighbouring Myanmar. Further extensive surveys may reveal a true distribution of this particular species across this biodiversity-rich region of the Himalayas and Indo-Burma hotspots.

Habitat and Natural History The shells were found in the soil-leaf litter sample collected adjacent to a dry waterfall from Champhai-Khawzawl Road of Mizoram. The litter depth of the collection site was about 0.5cm with 70–80 per cent canopy cover, and 17°C soil temperature. In addition, we observed the shell of *Chloritis*

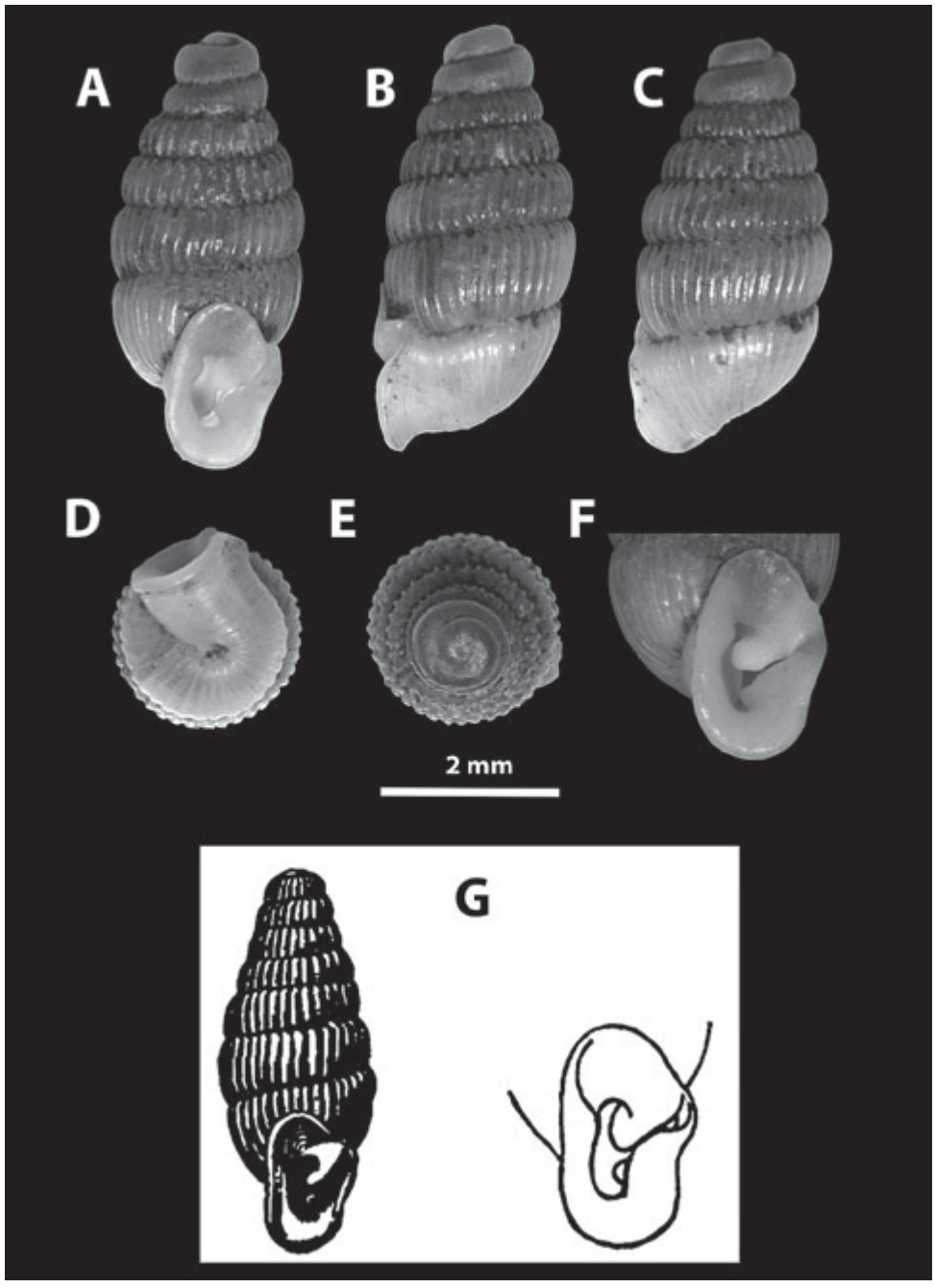

Figure 3 *Sinoennea vara* Benson, 1859; A- Apertural or ventral view, B- Lateral view, C- Dorsal view; D- Basal or umbilical view, E- Apical or protoconch view, F- Slanted aperture of *S. vara* shell collected in this study (AT/2019/LS4016); G- Illustration of ventral view and slanted aperture view of *S. vara*, taken from the book entitled 'The Fauna of British India, Including Ceylon and Burma: Mollusca (Testacellidae and Zonitidae)' by WT Blanford & Godwin Austen (1908), Fig. 10, page 16.

delibrata Benson, 1836 (Camaenidae) in the same collection site.

Discussion

The present study reports the occurrence of the carnivorous micro snails from the Mizo Hills of Mizoram, which was reported earlier only from the Barail Range of Naga Hills for *S. austeni*, and Khasi hills, Meghalaya, India and Bhutan for *S. vara*. In addition, this study also has recorded the range extensions of both the species from Mizoram for the first time which is more than 300km from previously reported localities. This

suggests that the species might be widely distributed in the Northeast region of India. Due to their minute size and lack of intense surveys, these species were not reported. There is a high possibility of finding both these species from much larger areas including neighbouring Myanmar. We redescribe both the species of *Sinoennea* based on their shell morphology. Due to the unavailability of live individuals, anatomy and molecular studies were not possible. However, a future study using these methods for *Sinoennea* will help in understanding the relationship with other carnivorous snails. In addition, we have included natural history notes for both species where available. A recent study from Bhutan suggested the collection of *S. vara* specimens from scree in warm, broadleaf forest (Gittenberger *et al*. 2021), while in the present study, we collected the specimens from the soil-leaf litter samples collected near a dry waterfall. This paper provides the first records of *S. austeni* in 92 years.

In the case of micro-snails, the sampling of soil-leaf litter is very effective (Aravind, 2005; Aravind *et al.,* 2008; Páll-Gergely *et al*., 2020). Our study indicates that there is an urgent need to study the terrestrial micro-snail diversity of this biologically important region that comes under the Indo-Burma biodiversity hotspot (Myers *et al*., 2000). The two collection sites also fall under fire-prone forest areas (ISFR, 2019). Recent incidences like the wild forest fire of 2021 (ENVIS, 2021), and other anthropogenic factors increase threats to their habitats resulting in a decline in molluscan communities. However, there are no conservation assessments and/or policies for these micro-snails due to the lack of knowledge. Therefore, it is important to do further research to assess the conservation status of these carnivorous species.

Acknowledgements

The study was financially supported by the Department of Biotechnology, Government of India under the project 'Bioresources and Sustainability Livelihood of Northeast India' (File no. B.T./01/17/NE/TAX). We are indebted to Mizoram Forest Department for allowing us to carry out research (No.A.33011/4/2017-CWLWNOI-III/224). We would like to thank Dr. Jonathan Ablett, NHM London, for providing us with the syntype image of *S. austeni*. NKD is thankful to Anushree Jadhav, Radhakrishnan Cheran, Samadhan Pardhi for their help in field work, and our driver Mr Daniel for his local help in exploring pristine landscape of Mizoram. We are grateful to Dr Priyadarsanan Dharmarajan (ATREE Bangalore) and the Insect Lab for providing permission and space to do microscopy. We are thankful to the two anonymous reviewers for their constructive comments on the earlier draft of this paper.

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