REDESCRIPTION AND ECOLOGICAL NICHE OF A LAND SNAIL *DICHARAX STRANGULATUS* (L. PFEIFFER, 1846) IN THE HIMALAYA (GASTROPODA: CYCLOPHOROIDEA: ALYCAEIDAE)

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Abstract *The operculate land snail family, Alycaeidae is comprised of species often <10mm in diameter and most species are known to be narrow-range endemics. Most Indian alycaeid species are known to be distributed in the Eastern Himalaya and the Western Ghats, whereas only a single species,* Dicharax strangulatus *(L. Pfeiffer, 1846), is known to be distributed in the western Himalaya. Most of the reports on this species in India and Nepal originate from the literature published during the British India colonial period. The species remains poorly understood and no studies exist regarding its ecology or habitat. The present study redescribes* Dicharax strangulatus *from Great Himalayan National Park (GHNP) with high resolution photomicrographs scanning electron microscope images and projected an ecological niche model to explore the possible climatic distribution of the species.*

Key words *taxonomy, systematics, redescription, India*

INTRODUCTION

The family Alycaeidae (often assigned as a subfamily of the Cyclophoridae) consists of approximately 370 species, distributed in Asia, from India to Japan (Godwin-Austen, 1882–1920; van Benthem Jutting, 1948, 1959; Minato, 1988; Foon & Liew, 2017; Páll-Gergely *et al*., 2017). In India, three species have been reported from the Western Ghats (Aravind & Páll-Gergely, 2018), and 113 species from the eastern Himalaya (Godwin-Austen, 1882–1920; Godwin-Austen, 1922; Tripathy *et al*., 2018; Aravind & Páll-Gergely, 2018). While the eastern Himalaya region is hotspot for the family, the diversity is unknown from western Himalaya and so far only a single species, *Dicharax strangulatus* (L. Pfeiffer, 1846), is reported from the western Himalaya. During recent field investigations, *D. strangulatus* was collected from Great Himalayan National Park, western Himalaya, India. In this paper, a redescription of *D. strangulatus* along with an ecological niche model is presented.

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MATERIALS AND METHODS

Data collection

Field surveys were conducted in the Great Himalayan National Park (GHNP) during 2016–2018. Visual search methods were followed during the field investigations in moist areas, under litter, stones and forest debris followed by the field protocol Sajan *et al*., 2017. A total of 14 empty shells were collected from soil under rotten leaf litter, while several specimens were also encountered under rocks. All specimens were collected at an elevation above 2000m asl. Additionally, the species distribution was further delimited from previously published records and voucher specimens present in NZSI.

Morphological examination

Shell whorls were counted (to the closest 0.25 whorl) as suggested by Kerney & Cameron (1979: 13). Three regions of the teleoconch were distinguished following Páll-Gergely *et al*. (2017): Region 1 (R1) from the beginning of the teleoconch until the beginning of the differently ribbed region where the sutural tube lies; Region 2 (R2) is the differently ribbed area up to the constriction; and Region 3 (R3) is from the constriction to the peristome.

Abbreviations

AH	aperture height
AW	aperture width
N	number of individual examined
NHMUK and NHM	Natural History Museum (London, United Kingdom)
NZSI	National Zoological Collection of Zoological Survey of India
SH	shell height
SW	shell width
ZSI	Zoological Survey of India (Kolkata, India)

Ecological niche model
Climatically homogenous habitats developed through model projections are predicted to have the same ecological features (Richart *et al*., 2018). Apart from the influence of the climate on the species habitat, studies have found that snail shell forms and structures are very much influenced by the climate of the region in which they reside. Geographic variations in land snail population are well documented and this is due to their adaptations to the regional climate and topography as most of the generations of a population are confined to smaller areas due to lower dispersal rate and slow mobility. In result, elevation, temperature and precipitations have sufficient impacts on the body size, growth rate and reproduction of molluscs (Goodfriend, 1986). Ecological Niche model was developed in MaxEnt software (Ver: 3.4.0) to find out the similar climatic regions within the Himalayan landscape for predicting and specifying habitat for the probable occurrence of *D. strangulatus* populations that reside within this global biodiversity hotspot. A total of eight locations were collated from available literature of the species. Out of the eight locations, only six were found within Himalayan Biodiversity Hotpot. This model was developed by just using these six locations to predict possible climatic requirements for the populations residing within the Himalayan Biodiversity Hotspot. Extent of Himalayan Biodiversity Hotspot was downloaded and used from databasin.org (Mittermeier, *et al*., 2004). Input bioclimatic parameters including precipitation and temperature data at less than 1 kilometre (0.833km^2) precision were used for the present Ecological Niche model. Moreover, the bioclimatic data were downloaded from Worldclim at 30 arcs second of version 2 and 19 bioclimatic variables were used to project the Ecological Niche model (Fick & Hijmans, 2017). Elevation data (CartoDEM Ver: 3 R1) for the Himalaya were extracted from Bhuvan (https://bhuvan-app3.nrsc.gov.in/data/download/index.php). Values for each location data were extracted from all the climatic layers and a correlation study was performed for the data co-linearity between each climatic raster. Values greater than 0.8 were held as highly co-related and therefore excluded from the present study. Annual Mean Temperature (Bio 1), Max Temperature of Warmest Month (Bio 5), Min Temperature of Coldest Month (Bio 6), Temperature Annual Range (Bio 7), Mean Temperature of Wettest Quarter (Bio 8), Mean Temperature of Driest Quarter (Bio 9), Mean Temperature of Warmest Quarter (Bio 10), Precipitation of Driest Quarter (Bio 17) and Precipitation of Warmest Quarter (Bio 18) were used for the final model run after the co-linearity analysis along with the elevation data. MaxEnt cloglog function was used and all the location points were cross validated against each other as the collection points were <10. Richart *et al*. (2018) suggested using cross validation instead of subsample for training and test data to be more effective in cases of inadequate occurrence data. A total of five replicates were generated through the cross validation process. Model validation out of the five generated models was performed through threshold independent evaluation using Receiver operating characteristics (ROC) from Area under ROC curve (AUC) value ranges 0 to 1 where 0.5 resembles completely random model predictions (Phillips *et al.*, 2006).

Systematics

Cyclophoroidea Gray, 1847

Alycaeidae W.T. Blanford, 1864

Genus *Dicharax* Kobelt & Möllendorff, 1900

Dicharax Kobelt & Möllendorff 1900: 186.
Chamalycaeus (*Dicharax*)—Thiele 1929: 108.
Chamalycaeus (*Dicharax*)—Wenz 1938: 478.

Type species *Alycæus hebes* Benson, 1857, by subsequent designation (Gude, 1921).

Remarks The genus *Dicharax* was originally defined on the basis of a swelling between the constriction and the peristome (named R3 here). However, that character is not reliable to delimit genera, because the swelling occurs in species that are probably not closely related and can differ between closely related species (Páll-Gergely *et al.*, 2017). Instead, *Dicharax* is now defined by the lack of spiral striation on the entire shell. Another important character to delimit genera is the morphology of the sutural tube and the breathing tunnels (see Páll-Gergely *et al.*, 2016). Several members of *Dicharax,* including the type species, possess elevated, curved ribs along the sutural tube. However, many species, which probably do not form a monophyletic group, have no elevated and curved ribs. Therefore, their placements to *Dicharax* are somewhat questionable, and are referred to as *Dicharax* (?) species (Páll-Gergely *et al.*, 2017; Aravind & Páll-Gergely, 2018). *Dicharax strangulatus* (L. Pfeiffer, 1846), redescribed herein, also lacks elevated R2 ribs, therefore its generic assignment also requires confirmation.

Dicharax strangulatus (L. Pfeiffer, 1846)
Figs 1 A–B, 2 A–L

Cyclostoma strangulatum (Hutton) Pfeiffer, 1846: 86.
Alycaeus strangulatus.— Gray 1850: 28; Pfeiffer 1851: 147; 1852: 84; Adams 1855: 278; Blanford 1864: 458; Hanley & Theobald 1874: pl. 93; Theobald 1876: 40, figs. 2, 3; Sowerby, in Reeve 1877: pl. 6, fig. 47; Nevill 1878: 290; Godwin-Austen 1914: 337, pl. 136, figs. 1, 1a; Dey & Mitra 2000: 15; Surya Rao & Mitra 2005: 43; Tarruella & Domènech 2011: 73.
Alycaeus (*Charax*) *strangulatus.* — Benson 1859: 177; Kobelt & Möllendorff 1898: 129; 1899: 49.
Alycaeus (*Dicharax*) *strangulatus.* — Kobelt 1902: 376; Gude 1921: 269.
Chamalycaeus (*Dicharax*) *strangulatus.* — Ramakrishna, Mitra & Dey 2010: 66; Budha, Naggs & Backeljau 2015: 5; Tripathy, Sajan & Mukhopadhyay 2018: 789.

Material examined 14 shells, near Shakti Village, 100m away from River Sainj, Great Himalayan National Park, Kullu district, Himachal Pradesh, India 31.78818N, 077.49062E 2258m, coll. Sajan & party, 13 iv 2018, Museum number NZSI M.32318/9.

Diagnosis A small *Dicharax* species with elevated spire, short R2 without elevated ribs, a rounded aperture and a blunt swelling a bit anterior to the middle line of R3.

Redescription Shell brownish-yellowish, 1.33–1.63 times as wide as tall, spire elevated, body whorl in side view rounded. Protoconch low, 1+1/3 whorls, rather glossy without notable sculpture. R1 slightly less than 2 whorls, finely, rather regularly ribbed, with ribs becoming more sparse towards end of R1. Ribbing stronger on dorsal than on ventral side. R2 and R3 c. 80° combined, R2 roughly twice as long as R3. R2 with 20–22 radial lines that are not elevated ribs but indications where the layers of R2 fold over each other, forming microtunnels for breathing. The surface of R2 is nearly smooth, it seems to be the interchanging of slimmer light (= microtunnels) and wider dark (= area between microtunnels) stripes. Cross section of these “ribs” was not examined. R2 and R3 separated by a very shallow constriction. R3 rather irregularly wrinkled with a blunt main swelling, which is situated anterior to the middle of R3. Aperture rounded; peristome relatively thin. Inner peristome rather blunt, slightly protruding anteriorly; outer peristome rather sharp, slightly expanded and not reflected; umbilicus relatively narrow.

Operculum Proteinaceous (“horny”), colour similar to shell, strongly concave; inner surface with a small, blunt, central nipple; outer surface, multispiral, with a slightly elevated, easily eroded lamina (except for nucleus).

Dimensions SH=2.09–2.73, SW=3.32–3.78, AH=1.15–1.51, AW=1.42–1.6. (n=10).

Habitat *Dicharax strangulatus* was most often encountered on moist soil in the sub-alpine climatic zone at 2200–2500m a.s.l. (Fig. 3A–D).

Distribution India: Bilaspur, Simla, Kullu (present study) district in Himachal Pradesh (Gude, 1921); Dehradun, Almora, Nainital district in Uttarakhand (Gude, 1921); also reported from Nepal (Shivapuri-Nagarjun National Park, Kathmandu Valley, Kathmandu, see Budha *et al.*, 2015), but those specimens have not been examined by us (Fig. 4).

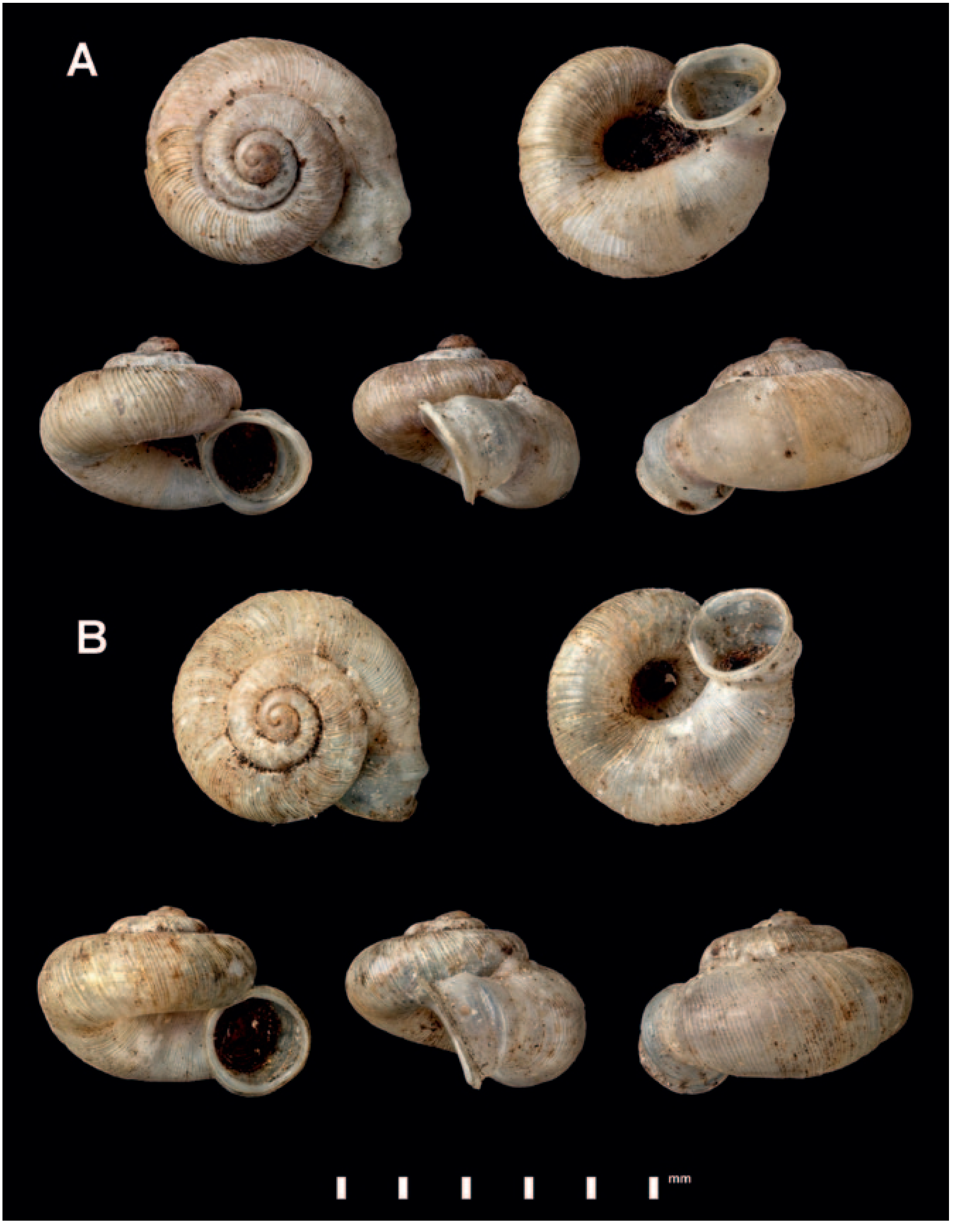

Figure 1 *Dicharax strangulatus* (L. Pfeiffer, 1846). **A:** "possible syntype" NHMUK 1856.9.15.18; **B:** NHMUK 1928.7.28.85–104 (from general lots).

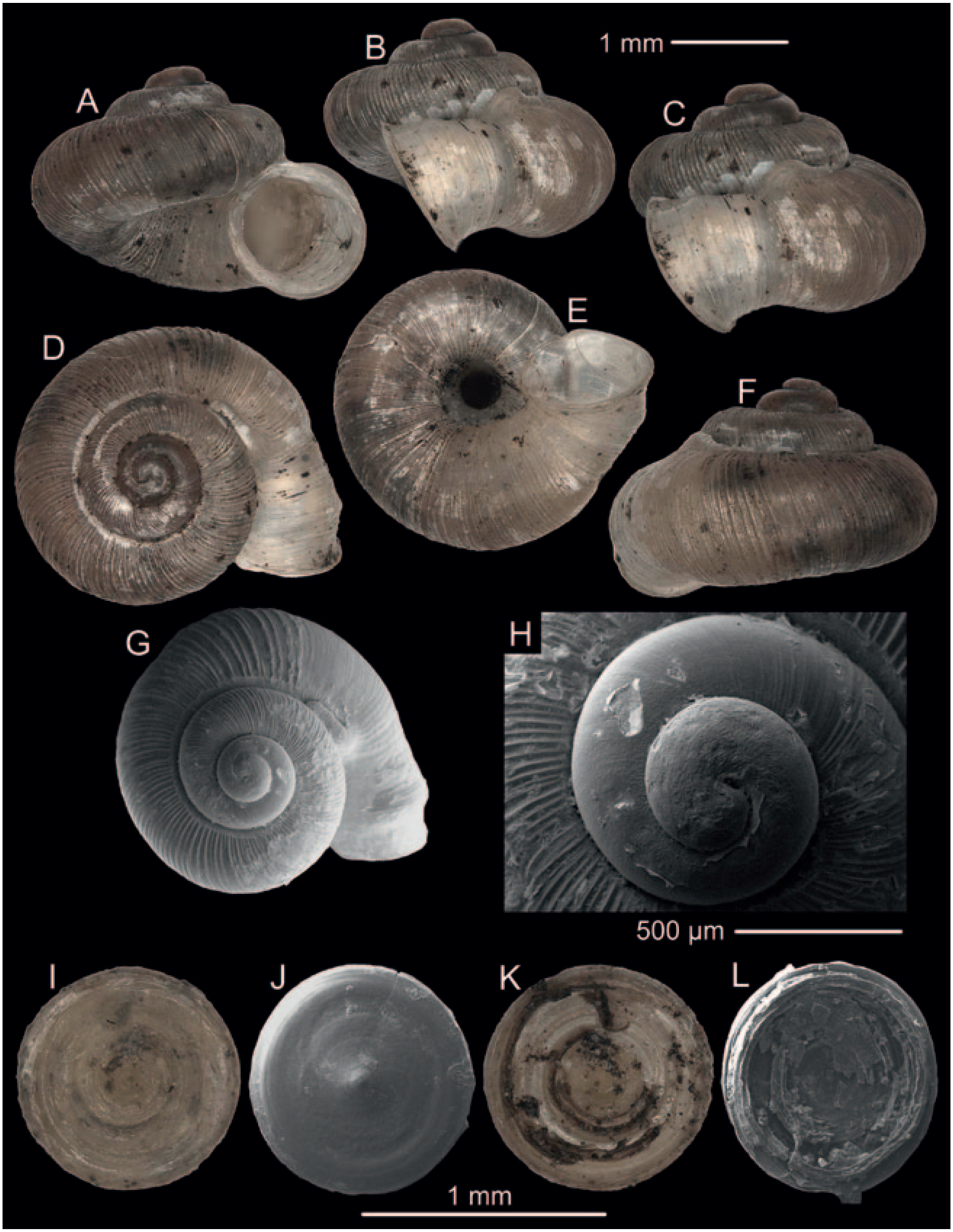

Figure 2 Shell and operculum of *Dicharax strangulatus* (L. Pfeiffer, 1846). **A–F:** specimens from Kullu, Himachal Pradesh; **G:** SEM image, shell; **H:** SEM image, protoconch; **I, K:** operculum; **J, L:** SEM images, operculum. **I–J:** show the inner, **K–L:** show the outer surface.

Figure 3 Suitable habitat of *Dicharax strangulatus* (L. Pfeiffer, 1846) in the Great Himalayan National Park, western Himalaya, India (**A–D**).

Discussions

Climate Niche Model

Species distribution models in MaxEnt are projected not only to understand the distribution of a species, but also the climatic requirements of the species (Phillips *et al*., 2017). The model predicted that 30.3% of the western Himalaya, parts of central Himalaya and Brahmaputra valley of eastern Himalaya within the entire extent of Himalayan Biodiversity Hotspot include highly suitable habitat for this species (Rodgers & Panwar, 1988) (Fig. 5). Out of the 10 parameters used for analysis, two parameters have shown to be the most contributing to the model projection, *viz*. 62.4% annual temperature range and 36.6% precipitation during the driest quarter. The model predicted the availability of this species to be between the temperature range of 16.2–43.6°C and the chances of availability are to be reduced as temperature increases. Regions with cooler and wet climate would provide better nourishment for juvenile snails allowing them to reach maturity earlier and before the dry season (Lee *et al*., 2012). Although there are no specific studies on *Dicharax stangulatus* mortality rate and its relation to any of the environmental parameters, studies on other snail species have recorded higher adult mortality rates during the dry seasons and egg clutch size to be related with the temperature. Egg clutch sizes have been noted to increase as temperature increases (Wolda, 1963). Precipitation of the driest quarter varies from 0–193mm and the availability potential of the species increases with the increased precipitation during the driest season. Moisture is essential for the Cyclophoroidea species as it helps in the respiration of the individuals by the moisturization of the mantle cavity surface which is why most of the species of this superfamily are restricted to wet or moist areas (Tan *et al*., 2012). Soil or litter moisture is the most evident feature for the snail species residing in the temperate, broadleaf and conifer forests as it helps in the movement

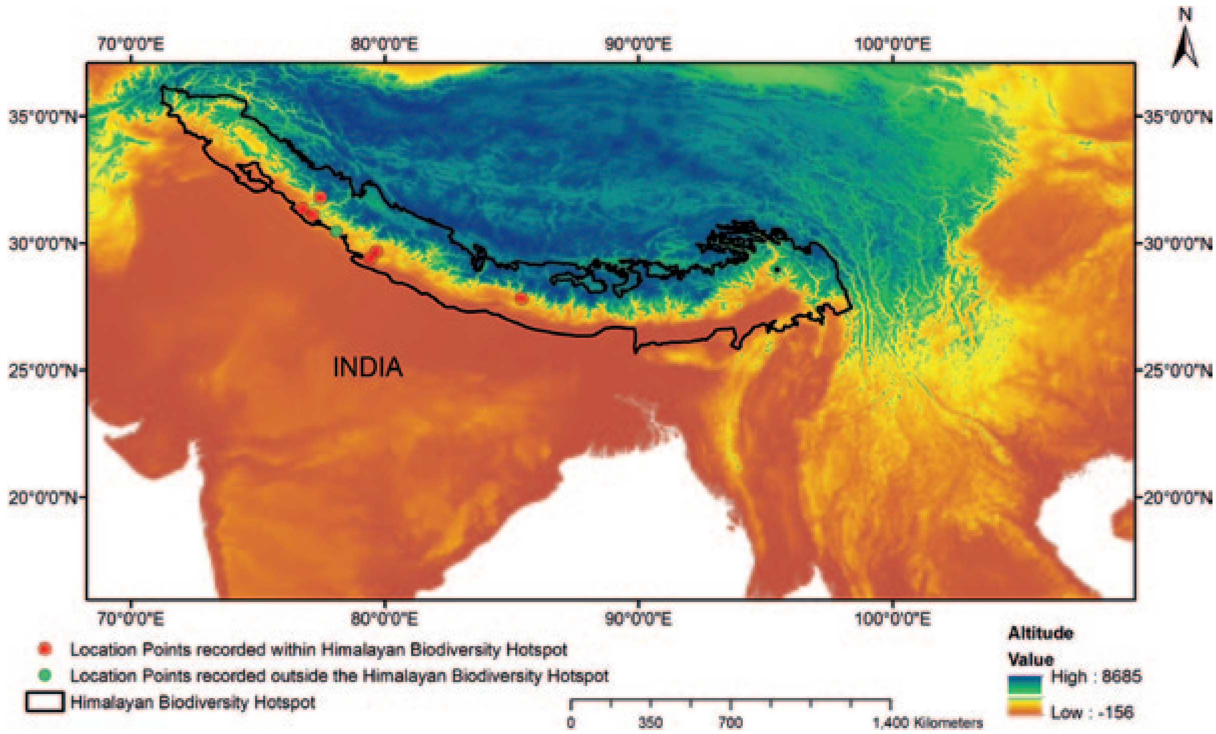

Figure 4 Collection locality points of *D. strangulatus* (L. Pfeiffer, 1846). Red points show the locality areas within the Himalayan Biodiversity Hotspot, whereas the Green points are outside the Himalayan Biodiversity Hotspot.

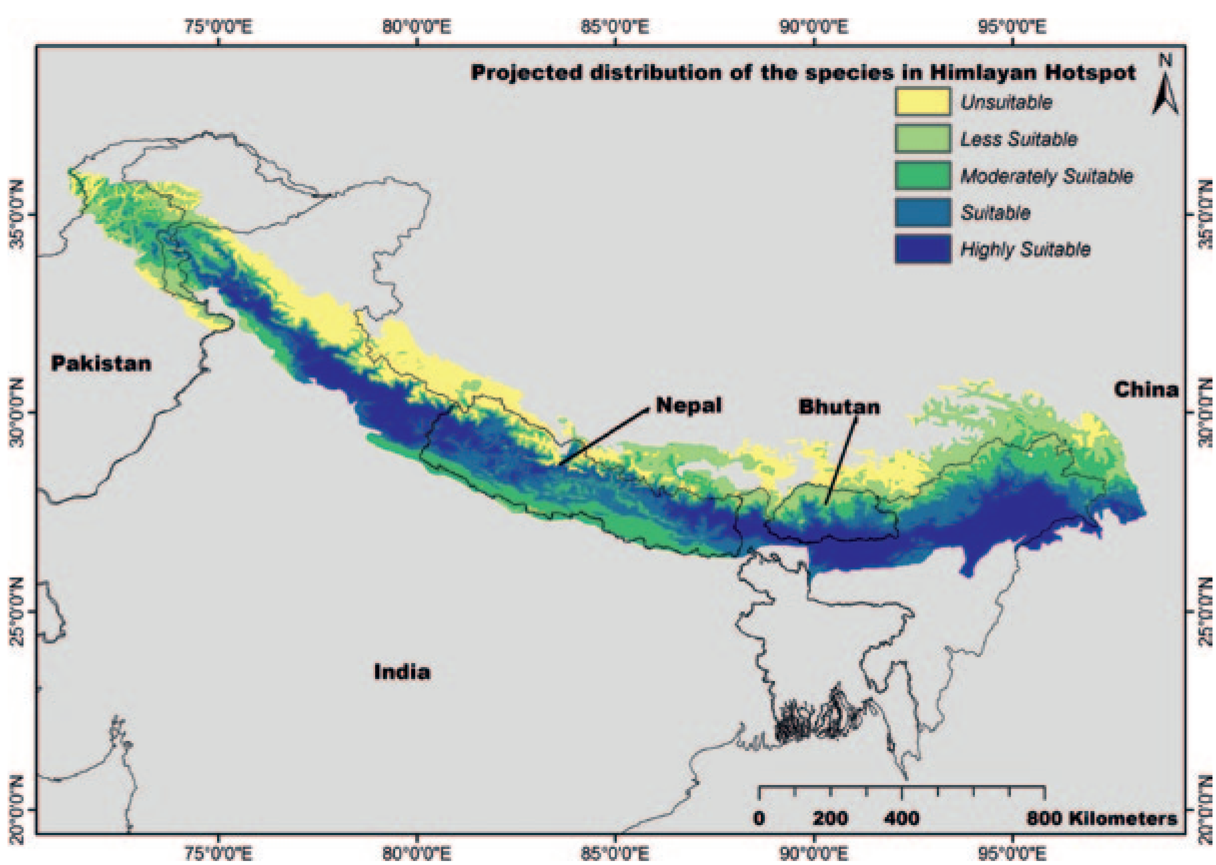

Figure 5 The ENMs shows the possible climatic range areas of *D. strangulatus* (L. Pfeiffer, 1846) distribution in Himalayan biodiversity hotspot.

of the individuals (Bishop, 1977; Getz & Uetz, 1994; Martin & Sommer, 2004). The predicted MaxEnt model for this species distribution was very similar to the actual recorded collection sites of the species in the western Himalaya, i.e., Uttarakhand and Himachal Pradesh. The model predicted the Nepal region as a less suitable climatic niche. This may have been from fewer actual collecting sites in that area or from the Inhomogeneous Poisson Process (IPP) of the cloglog function in MaxEnt or both (Phillips *et al*., 2017). The majority of the suitable areas predicted in the model are ecoregions with prevailing subtropical broadleaf pine forests, and the specimens examined during the present study were collected from these same habitats. This species has not been recorded from the central or eastern parts of the Himalaya and this may be because fewer mollusc surveys have been made in those areas, particularly in the east. Pandit *et al*. (2006) indicates that as much as 90% of the dense forest cover of the Himalaya will be destroyed by the year 2100. Endemic species such as *D. strangulatus* may not survive this habitat devastation during the present anthropogenic climate change period and therefore suggests further surveys to implement conservation measures.

Acknowledgements

The authors are grateful to the Director, Zoological Survey of India, Kolkata for providing necessary facilities and encouragement for the preparation of this manuscript. Thanks are due to the National Mission on Himalayan Study (NMHS) Grant No: NMHS-LG-2016/0011/8509–8, Dated 31.03.2016 funded by Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India. Our sincere thanks to PCCF, Environment and Forests Department (Himachal Pradesh) for issuing the research permit. The authors are thankful to the staff of the Mollusca section of the Zoological Survey of India for their help during the materials examination and Kaushik Mallick for help on field. Furthermore, we are grateful to Jonathan Ablett for granting access to the collection of the Natural History Museum, London and providing photographs. We are thankful to G.P. Mandal and Srabani Kayal for helping us with SEM images. This study was also supported by the MTA (Hungarian Academy of Sciences) Premium Post Doctorate Research Program for BPG. We are thankful to the editor and two anonymous reviewers for their constrictive comments and suggestions in improving the manuscript.

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