

A new species of *Sphaerotheca* Gunther, 1859 (Amphibia : Anura : Dicroglossidae) from the agro ecosystems of Chota Nagpur Plateau, India

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Abstract

Members of the genus *Sphaerotheca* are known to have the distribution in the low to mid elevation landscapes of South Asia. Most of the descriptions are either from homestead areas or from agro ecosystems except for a couple of species described from the mid elevated forest areas. The taxonomic uncertainties prevalent in the group was attended very recently, limiting the descriptions of five species to India, two species to Nepal and one each to Pakistan and Sri Lanka (one undescribed species from Myanmar). Here a new species assignable to the morphological 'Breviceps group' is described from the agro ecosystems of Jharkhand based on a combination of morphological, phylogenetic and geographical studies using integrated taxonomic approach. Besides, the distribution status of *Sphaerotheca pashchima* is discussed and the possibility of a new species occurring in Myanmar is pointed out.

Keywords: Agro Ecosystem, Jharkhand, New Species, Plateau, *Sphaerotheca*

Introduction

The genus *Sphaerotheca* Günther under the sub-family Dicroglossinae of the family Dicroglossidae Anderson is represented by nine extant species having predominant distribution in India, Sri Lanka, Nepal, Pakistan and Myanmar (Frost, 2018). The chaos and uncertainties in the taxonomy of this genus has been attended to certain limits in the works of Dahanukar *et al.*, (2017) and Padhye *et al.*, (2017) recently.

Among the extant nine species of *Sphaerotheca*, type localities of five species lie in the political boundaries of India (*Sphaerotheca breviceps*, *S. pluvialis*, *S. dobsonii*, *S. leucorhynchus* and *S. pashchima*) (Dinesh *et al.*, 2019), two in Nepal (*S. swani* and *S. maskeyi*) and one each in Pakistan (*S. strachani*) and Sri Lanka (*S. rolandae*). But the range of distribution and reports of many species in this group are somewhat unreliable due to morphological

character variations and occurrence of different colour morphs among the species complexes.

In India, among the five species described in the past, four species (*Sphaerotheca breviceps*, *S. pluvialis*, *S. dobsonii* and *S. pashchima*) are described either from low lying homestead areas or from disturbed vegetation except for the species *S. leucorhynchus* which was described from the forested areas. The fact that four species were described in the past from homestead areas highlights the importance of exploration of frogs in the homestead areas, agro ecosystems and disturbed vegetation for frogs of the family Dicroglossidae.

During one of the anuran explorations in the agro ecosystems of Nawadih village, Koderma, Jharkhand VKP and team encountered medium sized dicroglossid frogs having distinct shovel shaped inner metatarsal tubercle fitting the generic diagnosis of *Sphaerotheca* but

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not matching the description of any of the extant species of *Sphaerotheca*. Upon following the morphological groupings proposed by Dahanukar *et al.*, (2017) our set of collections were falling under the morphological 'Breviceps group' with the presence of tibio tarsal tubercle but not matching the descriptions of *Sphaerotheca rolandae* species described from Sri Lanka.

Material and Methods

Sampling was done by VKP and team as a part of anuran explorations in the agro ecosystems of his native Nawadih village in Koderma since the year 2015. Collections were made during the breeding period to ensure the sex of the males (calling male) and females (from the amplexed pair). Photography was done in controlled condition followed by euthanization in MS222. Tissues were extracted and fixed in ethanol for further studies followed by specimen fixing and preservation.

DNA extraction, PCR amplification and sequencing were followed as methods described in Dinesh *et al.*, 2015. For the phylogenetic reconstruction with our sample for 16S rRNA, we used the sequences from Dahanukar *et al.*, (2017) and sequences from NCBI GenBank (See Appendix I). Species of *Indirana* was used as out group (Pyron and Weins, 2011) with the available sequences of *Sphaerotheca* from south Asia. For generating Maximum Likelihood (ML) tree RaxML (Silvestro & Michalak, 2012) was used with data partitioned by gene under GTR+GAMMA+I model by running 1000 thorough bootstraps. In the final tree the species *S. strachani*, *S. leucorhynchus*, *S. swani*, *S. rolandae* and *S. maskeyi* were not included due to lack of sequence data. Initial new lineage diagnosis was done using multiple criteria including phylogeny (Figure 1), genetic distance, geographical isolation (Figure 5) and morphological grouping (Figure 4) following Vijayakumar *et al.*, (2014).

Morphological measurements were taken by Mitutoyo vernier caliper (to the nearest 0.1 mm) and Leica EZ4HD 8x magnification. Multiple field visits were made for collecting onsite details for natural history information.

For the multivariate Principal Components Analysis (PCA), we considered our data and the data provided by Padhye *et al.*, (2017) during their revisionary studies and Dahanukar *et al.*, (2017) in new species description. A total of 20 morphometric characters (marked with an

asterisk in Table 1) were transformed to their ratio to SVL and taken into consideration for PCA analysis in the PAST software version 3.16c (Hammer *et al.*, 2001). Abbreviations used for the morphometry are followed after Dinesh *et al.*, (2017).

Results

Generic Allocation

The individuals collected were assignable to the genus *Sphaerotheca* based on the diagnosable morphological characters assigned to the genus by Günther (1859) and the work of Dahanukar *et al.*, (2017) and Padhye *et al.*, (2017).

Species Description

Sphaerotheca magadha sp. nov.

Holotype: ZSI/WRC/A/2178, an adult male (SVL 34.2 mm) collected by Vishal Kumar Prasad and team in July 2015 from semi urbanized agricultural land of Nawadih village (N 24.4179; E 85.4680, 380 meters asl), Koderma, Jharkhand.

Paratypes: ZSI/WRC/A/2179, an adult male (SVL 30.2 mm) and ZSI/WRC/A/2180, an adult female (SVL 41.0 mm) collected by Vishal Kumar Prasad and team July 2015 from semi urbanized agricultural land in Nawadih village (N 24.4179; E 85.4680, 380 meters asl), Koderma, Jharkhand.

Lineage diagnosis: *Sphaerotheca magadha* sp. nov. can be diagnosed phylogenetically as a member of the *Sphaerotheca* clade (Figure 1), showing a sister relationship to *Sphaerotheca breviceps* and exhibiting moderate genetic divergence (16S rRNA - 1.8% to 2.1 %).

Field Diagnosis

Morphology: In the field, *Sphaerotheca magadha* sp. nov. does not have any morphologically similar congeneric sympatric species, and it can be easily identified on the basis of the combination of morphological characters like medium size, stumpy and squat body, wider head width than head length, rounded snout, angled canthus rostralis, first finger longer than the second (and sub equal to third finger), short hind limbs which do not touch when folded at right angles to the body, tibio-

Table 1. Morphometric data (in mm) for the type series of *Sphaerotheca magadha* sp. nov. Prefix ZSI/WRC/A for holotype and paratypes

| ZSI | 2178# | 2179\$ | 53& | 52& | 51& | 49& | 48& | Average \pm SD (Range) |
|---------|-------|--------|------|------|------|------|------|----------------------------|
| Sex | Male | Male | Male | Male | Male | Male | Male | Male |
| SVL* | 34.2 | 30.2 | 32.5 | 32.0 | 30.4 | 29.9 | 28.5 | 31.1 \pm 1.9 (28.5-34.2) |
| HW* | 13.2 | 11.5 | 12.6 | 12.3 | 12.4 | 10.8 | 9.1 | 11.7 \pm 1.4(9.1-13.2) |
| HL* | 9.6 | 9.5 | 9.6 | 9.5 | 9.5 | 8.3 | 8.4 | 9.2 \pm 0.6 (8.3-9.6) |
| IN* | 3.8 | 2.3 | 3.3 | 3.1 | 3.2 | 3.0 | 2.2 | 3.0 \pm 0.6 (2.2-3.8) |
| NE* | 2.9 | 1.5 | 2.8 | 2.6 | 1.6 | 2.0 | 1.4 | 2.1 \pm 0.6 (1.4-2.9) |
| MN | 8.9 | 7.3 | 8.8 | 8.6 | 7.0 | 6.7 | 6.6 | 7.7 \pm 1.0 (6.6-8.9) |
| MFE | 6.8 | 6.7 | 6.3 | 6.2 | 6.1 | 5.8 | 5.7 | 6.2 \pm 0.4 (5.7-6.8) |
| MBE | 4.6 | 4.8 | 4.2 | 4.0 | 4.6 | 4.1 | 3.2 | 4.2 \pm 0.6 (3.2-4.8) |
| SL* | 5.2 | 4.4 | 5.0 | 4.8 | 4.2 | 4.0 | 4.0 | 4.5 \pm 0.5 (4.0-5.2) |
| EL* | 5.4 | 4.5 | 5.0 | 4.8 | 4.1 | 4.1 | 4.6 | 4.6 \pm 0.5 (4.1-5.4) |
| IUE* | 4.0 | 2.5 | 3.5 | 3.4 | 2.2 | 3.0 | 2.4 | 3.0 \pm 0.7 (2.2-4.0) |
| UEW* | 3.9 | 3.1 | 3.0 | 3.1 | 3.2 | 2.8 | 3.1 | 3.2 \pm 0.3 (2.8-3.9) |
| IFE | 6.4 | 4.8 | 5.8 | 5.9 | 4.4 | 5.1 | 4.2 | 5.2 \pm 0.8 (4.2-6.4) |
| IBE | 10.6 | 9.3 | 9.8 | 9.9 | 9.0 | 9.5 | 9.0 | 9.6 \pm 0.6 (9.0-10.6) |
| TYD* | 1.2 | 1.8 | 1.2 | 1.1 | 1.6 | 1.1 | 1.2 | 1.3 \pm 0.3 (1.1-1.8) |
| FLL* | 6.9 | 6.2 | 6.2 | 6.8 | 6.0 | 5.9 | 5.2 | 6.2 \pm 0.6 (5.2-6.2) |
| HAL* | 8.8 | 6.4 | 8.2 | 8.0 | 6.2 | 7.0 | 6.0 | 7.2 \pm 1.1 (6.0-8.8) |
| FL1* | 4.9 | 2.8 | 4.6 | 4.5 | 3.6 | 4.8 | 2.6 | 4.0 \pm 1.0 (2.6-4.9) |
| FL2* | 3.9 | 2.5 | 3.4 | 3.2 | 2.0 | 3.6 | 1.9 | 2.9 \pm 0.8 (1.9-3.9) |
| TFL* | 5.2 | 3.8 | 4.7 | 4.9 | 3.5 | 4.8 | 3.2 | 4.3 \pm 0.8 (3.2-5.2) |
| AGL | 13.2 | 13.5 | 13.0 | 12.8 | 13.2 | 12.3 | 12.5 | 12.9 \pm 0.4 (12.3-13.5) |
| WBS | 13.8 | 12.8 | 12.0 | 11.9 | 12.2 | 12.3 | 11.7 | 12.4 \pm 0.7 (11.7-13.8) |
| WFG | 7.4 | 9.8 | 9.0 | 9.1 | 9.4 | 8.0 | 9.7 | 8.9 \pm 0.9 (7.4-9.8) |
| ShL/FL* | 15.1 | 11.6 | 14.2 | 13.8 | 12.8 | 13.3 | 10.5 | 13.0 \pm 1.6 (10.5-15.1) |
| TiL* | 13.9 | 10.9 | 13.2 | 12.6 | 11.8 | 12.2 | 10.3 | 12.1 \pm 1.3 (10.3-13.9) |
| Tal | 6.4 | 6.1 | 5.2 | 5.4 | 6.0 | 5.6 | 5.2 | 5.7 \pm 0.5 (5.2-6.4) |
| FOL* | 15.9 | 12.7 | 14.9 | 15.2 | 12.2 | 14.0 | 12.1 | 13.9 \pm 1.5 (12.1-15.9) |
| FTL* | 6.9 | 6.7 | 6.0 | 6.1 | 6.5 | 6.4 | 6.2 | 6.4 \pm 0.3 (6.0-6.9) |
| ITL* | 0.8 | 0.8 | 1.0 | 0.8 | 0.6 | 0.9 | 0.6 | 0.8 \pm 0.1(0.6-1.0) |
| IMT* | 3.2 | 3.1 | 3.0 | 3.1 | 2.9 | 2.6 | 2.9 | 3.0 \pm 0.2 (2.6-3.2) |

Contd Table 1.

| ZSI | 2180\$ | 56& | 55& | 58& | 57& | Average ± SD (Range) |
|---------|--------|--------|--------|--------|--------|----------------------|
| Sex | Female | Female | Female | Female | Female | Female |
| SVL* | 41.0 | 38.0 | 36.9 | 34.8 | 32.4 | 36.6±3.3 (32.4-41.0) |
| HW* | 16.0 | 14.8 | 13.6 | 12.8 | 13.0 | 14.0±1.3 (12.8-16.0) |
| HL* | 11.8 | 12.5 | 11.0 | 9.2 | 9.4 | 10.8±1.5 (9.2-12.5) |
| IN* | 3.4 | 4.2 | 3.4 | 3.6 | 3.2 | 3.6±0.4 (3.2-4.2) |
| NE* | 2.6 | 3.6 | 2.8 | 3.0 | 2.6 | 2.9±0.4 (2.6-3.6) |
| MN | 8.8 | 9.7 | 9.0 | 9.0 | 8.4 | 9.0±0.5 (8.4-9.7) |
| MFE | 8.1 | 7.7 | 6.7 | 7.0 | 6.1 | 7.1±0.8 (6.1-8.1) |
| MBE | 4.8 | 5.8 | 5.1 | 5.0 | 4.0 | 4.9±0.6 (4.0-5.8) |
| SL* | 5.1 | 5.4 | 5.0 | 5.4 | 4.8 | 5.1±0.3 (4.8-5.4) |
| EL* | 5.8 | 5.4 | 5.3 | 5.2 | 5.0 | 5.3±0.3 (5.0-5.8) |
| IUE* | 3.6 | 3.0 | 3.5 | 4.2 | 3.3 | 3.5±0.4 (3.0-4.2) |
| UEW* | 3.8 | 3.2 | 3.2 | 4.0 | 3.2 | 3.5±0.4 (3.2-4.0) |
| IFE | 7.6 | 6.8 | 6.8 | 6.4 | 5.4 | 6.6±0.8 (5.4-7.6) |
| IBE | 12.6 | 10.8 | 10.6 | 10.8 | 9.2 | 10.8±1.2 (9.2-12.6) |
| TYD* | 1.6 | 1.8 | 1.8 | 1.0 | 1.1 | 1.5±0.4 (1.0-1.8) |
| FLL* | 7.2 | 7.4 | 7.2 | 6.8 | 6.0 | 6.9±0.6 (6.0-7.4) |
| HAL* | 9.2 | 9.4 | 8.1 | 9.0 | 7.8 | 8.7±0.7 (7.8-9.4) |
| FLI* | 4.3 | 4.9 | 5.4 | 5.0 | 4.2 | 4.8±0.5 (4.2-5.4) |
| FL2* | 3.6 | 3.6 | 4.2 | 3.8 | 3.0 | 3.6±0.4 (3.0-4.2) |
| TFL* | 5.1 | 5.9 | 5.3 | 5.4 | 4.2 | 5.2±0.6 (4.2-5.9) |
| AGL | 18.4 | 15.6 | 16.5 | 13.4 | 12.8 | 15.3±2.3 (12.8-18.4) |
| WBS | 17.2 | 12.8 | 13.1 | 14.0 | 11.8 | 13.8±2.1 (11.8-17.2) |
| WFG | 10.8 | 7.2 | 10.1 | 7.8 | 9.2 | 9.0±1.5 (7.8-10.8) |
| ShL/FL* | 18.2 | 16.9 | 15.0 | 15.4 | 14.0 | 13.9±3.4 (14.0-18.2) |
| TiL* | 16.0 | 15.9 | 14.1 | 13.5 | 13.0 | 14.5±1.4 (13.0-16.0) |
| Tal | 7.9 | 7.2 | 6.8 | 6.2 | 5.0 | 6.6±1.1 (5.0-7.9) |
| FOL* | 17.2 | 17.4 | 16.8 | 15.9 | 14.4 | 16.3±1.2 (14.4-17.4) |
| FTL* | 8.4 | 7.6 | 9.7 | 6.8 | 6.2 | 7.7±1.4 (6.2-9.7) |
| ITL* | 1.4 | 1.0 | 1.4 | 0.8 | 0.8 | 1.1±0.3 (0.8-1.4) |
| IMT* | 3.8 | 3.6 | 3.3 | 3.0 | 2.8 | 3.3±0.4 (2.8-3.8) |

*data used for PCA analysis; #holotype; \$paratypes; &other referred specimens

tarsal articulation reaching front of shoulders, moderate webbing, distinct shovel shaped inner metatarsal tubercle and a prominent tarsal tubercle. For comparisons of the new species *Sphaerotheca magadha* sp. nov. with its phylogenetic sister species *Sphaerotheca breviceps* and its congeners, see section below.

Geography: This species is known from low to mid elevation (380 m) agricultural lands of semi urbanized Nawadih village, Jharkhand (Figure 5). This species is geographically 1600 km away (aerial distance) from the type locality of the phylogenetic sister species *S. breviceps* and 1800 km away (aerial distance) from the type locality of the morphologically similar species *S. rolandae*. Additional sampling and genetic studies are required to establish the range limits of the phylogenetic sister (*S. breviceps*) and the morphologically similar species (*S. rolandae*).

Description of Holotype (ZSI/WRC/A/2178) (Figure 2)

A medium sized burrowing frog (SVL = 34.2 mm) with robust, stumpy and squat body; head width wider than

head length (HW = 13.2 mm; HL = 9.6 mm); snout rounded (SL = 5.2 mm) and sub equal to eye diameter (EL = 5.4 mm); canthus rostralis angled, loreal region flat, inter orbital space flat (IUE = 4.0 mm) sub equal to upper lid (UEW = 3.9 mm) and internarial distance (IN = 3.8 mm); distance between back of eyes 1.6 times more than front of eyes (IFE = 6.4 mm; IBE = 10.6 mm); nostrils oval, nearer to tip of snout; symphyial knob moderate; tympanum distinct, minute visible below the supratympanic fold (TYD = 1.2 mm) and close to eye; vomerine ridges present; tongue bifid without a papilla.

Fore arm robust and short (FLL = 6.9 mm) slightly shorter than hand (HAL = 8.8 mm); finger short and thin without any dermal fringes, first finger longer than the second and sub equal to third finger (TFL = mm), tips blunt without any enlarged discs, webbing between fingers absent; subarticular tubercles distinct, rounded and pre-pollex tubercle distinct, supernumerary tubercles absent.

Hind limbs short, do not touch when folded at right angles to the body and tibio-tarsal articulation reaches front of shoulders; femur length sub equal to tibia length (FL = 15.1 mm; TiL = 13.9 mm); foot length is 2.4 times tarsus length (FOL = 15.9 mm, TAL = 6.4 mm), relative

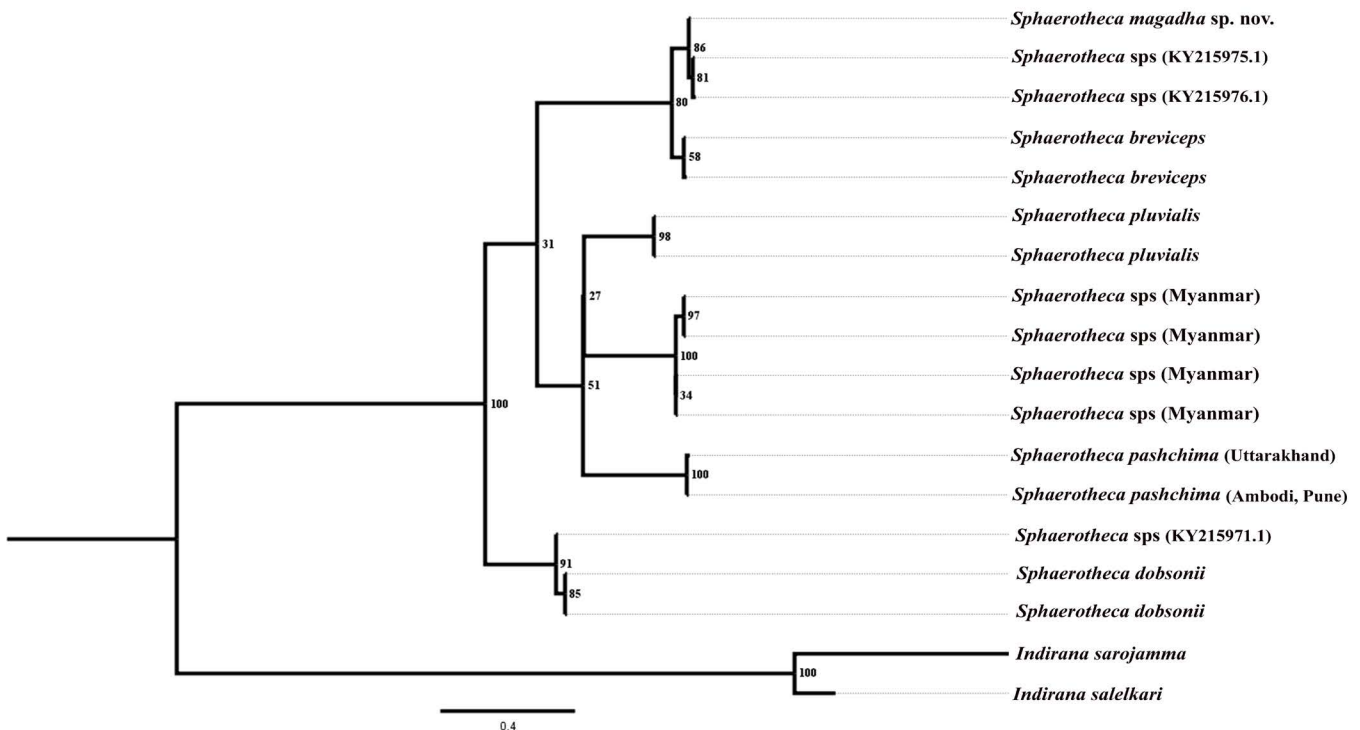


Figure 1. Maximum Likelihood (ML) tree for the species of *Sphaerotheca* based on 6518 bp of mitochondrial (16S, 12S, COI and Cytb) and nuclear genes (BDNF, CXCR4, NCX1, RAG1, RAG2, Rhod and Tyro).

toe length $I < II < III < V < IV$ (FTL = 6.9 mm); inner toe minute (ITL = 0.8 mm), webbing moderate (I 1-2 II 1½-2½ III 2-2½ IV 2½-1½ V) ; inner metatarsal tubercle (IMTL = 3.2 mm) distinct and shovel shaped, outer metatarsal tubercle and supernumerary tubercles absent, tarsal tubercle prominent.

In preservative, skin on the dorsum with dotted raised glandular folds; ventrally smooth on throat and belly but granular at the region of back of thighs. Colour on the dorsum washed stone black, surrounding the raised glandular folds blackish giving an overall appearance of blotches on the entire dorsal surface of body, fore arm and hind legs; lateral sides of the body with wider blotches; region of supratympanic fold and canthus rostralis dark; tip of snout with cream white spot; upper lip barred and lower lip and region of rictal gland uniform cream white; fore and hind limbs barred (Figure 2).

In life, dorsum light greenish brown, region surrounding the raised glandular folds blackish, creamish arch shaped band at the both the sides of the body starting from the region of groin diverging towards the center of dorsum (bands do not meet) at the region of shoulder; at the lateral sides of the body creamish blotches separate the dorsal light greenish brown and the ventral whitish skin; region below the eye, below tympanum creamish and snout tip with a creamish spot; fore arm and hind legs barred; back of thighs and front of groin chocolaty brown without any yellow spots. Eye, diamond shaped pupil black, iris golden brown with fine blackish reticulations (Figure 3).

Secondary Sexual Characters

Adult males have a pair of external vocal sac at the region of throat which is mostly black in colour.

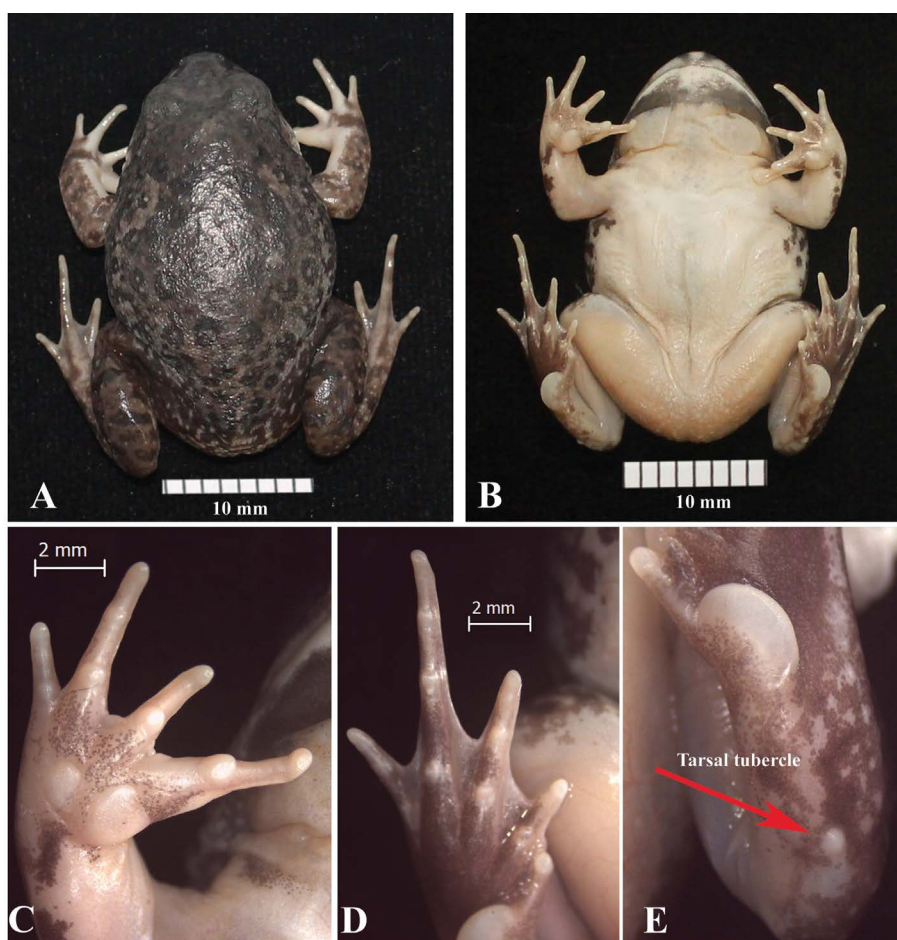


Figure 2. Holotype of *Sphaerotheca magadha* sp. nov. (a) dorsal view; (b) ventral view; (c) ventral view of right hand; (d) ventral view of right foot; (e) arrow showing tarsal tubercle.

Additional Information from Paratypes, Other Reference Collections and Variations

Morphological data are given in Table 1. Paratypes range from 30.2 to 41.0 mm in SVL; all the males in the collections were ranging from 28.5 to 34.2 mm in SVL and females were ranging from 32.4 to 41.0 mm in SVL. In all the external morphological characters, holotype and paratypes were similar to the reference collections.

Etymology

The specific epithet is derived from the term 'Magadha', an ancient kingdom located on the Indo-Gangetic plains in the eastern Indian state Jharkhand. Suggested common name: 'Magadha burrowing frog' species epithet is treated as noun in apposition to generic name.

Distribution and Natural history

Sphaerotheca magadha sp. nov. is known specifically from Joungi and Nawadih village of Koderma district of Jharkhand in Chota Nagpur Plateau. Chota Nagpur Plateau is having geological significance in terms of the continental drift theory (Mani, 1974; Ghosh *et al.*, 2015). We found this species to be common locally on the road side muddy puddles and it was observed calling and breeding during pre-monsoon showers of June.



Figure 3. *Sphaerotheca magadha* sp. nov. in life.

Comparisons

Sphaerotheca magadha sp. nov. can be easily distinguished morphologically from its congeners by its combination of characters like medium size, stumpy and squat body, wider head width than head length, rounded snout, angled canthus rostralis, first finger longer than the second (and sub equal to third finger), short hind limbs which do not touch when folded at right angles to the body, tibio-tarsal articulation reaching front of shoulders, moderate webbing, distinct shovel shaped inner metatarsal tubercle and a prominent tarsal tubercle. As of now, none of the species of *Sphaerotheca* are found to be sympatric in distribution with *Sphaerotheca magadha* sp. nov. The new species being a member of burrowing frog group showing wide range of distribution, *Sphaerotheca magadha* sp. nov. is compared with all the known nine species of *Sphaerotheca* for convenience based on the data from original descriptions.

Multivariate Principal Component Analysis (PCA) was carried out for the six species of *Sphaerotheca* (male samples only from Padhye *et al.*, (2017)) with the new species. Twenty morphological characters for the male individuals of five species were size corrected by SVL. During the analysis for the male specimens, six different clusters representing *Sphaerotheca pluvialis*, *Sphaerotheca dobsonii*, *Sphaerotheca breviceps*, *Sphaerotheca maskeyi* and *Sphaerotheca pashchima* (Figure 4) could be discerned on the PC2 (22.7 % variance) and PC5 (6.4 % variance) axis.

Sphaerotheca magadha sp. nov. can be distinguished from *S. breviceps*, in having a relatively smaller adult male size of SVL 31.1 mm \pm 1.9, n=7 (vs relatively larger adult male size SVL 33.4 mm \pm 7.5, n=6 in *S. breviceps*); lower HL/SVL ratio of 0.281 to 0.313, n=7 (vs higher HL/SVL ratio of 0.317 to 0.392, n=6 in *S. breviceps*); lower FLL/SVL ratio of 0.182 to 0.213, n=7 (vs higher FLL/SVL ratio of 0.219 to 0.274, n=6 in *S. breviceps*); moderate webbing (I 1-2 II 1½-2½ III 2-2½ IV 2½-1½ V) (vs rudimentary webbing (I 1-2 II 1½-2½ III 2-3½ IV 4-2 V) in *S. breviceps*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. breviceps*); in life dorsum with creamish arch shaped band at the both the sides of the body (vs no band pattern on the dorsum in *S. breviceps*); back of thigh and front of groin chocolaty brown (vs back of thigh and front of groin with light yellow blotches in *S. breviceps*); type locality and

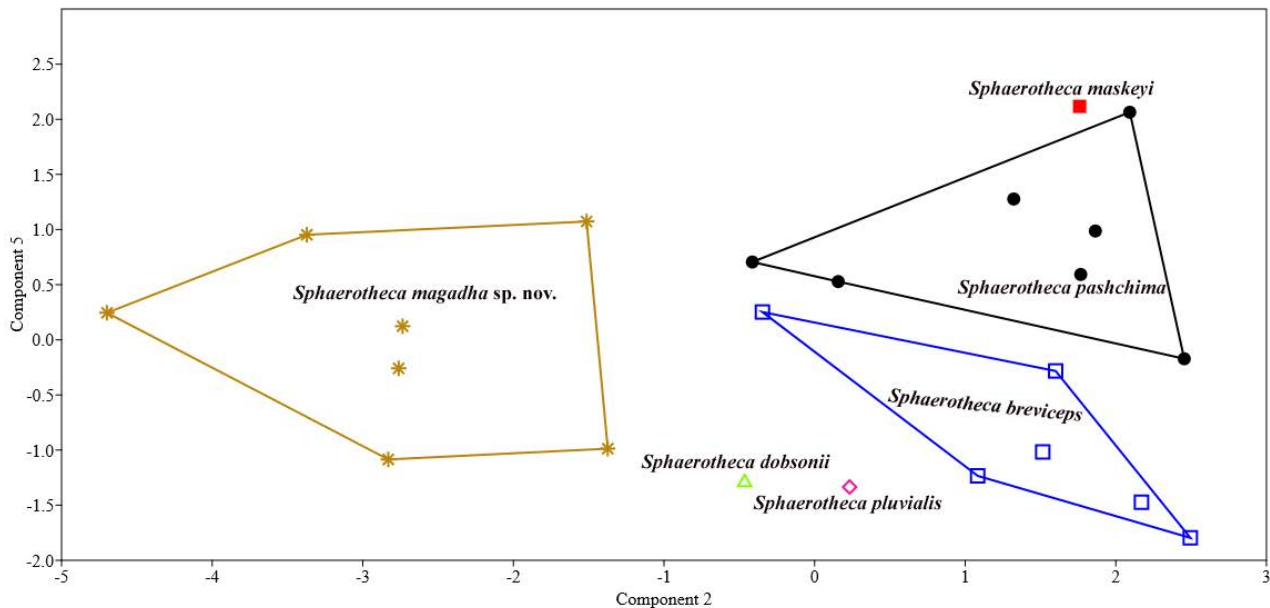


Figure 4. Multivariate Principal Component Analysis for six species of *Sphaerotheca* (data from Padhye *et al.*, (2017) and with *Sphaerotheca magadha* sp. nov. (14 morphometric characters marked as * in Table 1 transformed to their ratio to SVL).

predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the east coast of India in *S. breviceps*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. pluvialis* in having a relatively smaller adult male size of SVL 31.1 mm±1.9, n=7 (vs relatively larger adult male size SVL 43.7, n=1 in *S. pluvialis*); lower HL/SVL ratio of 0.281 to 0.313, n=7 (vs higher HL/SVL ratio of 0.327, n=1 in *S. pluvialis*); lower HW/SVL ratio of 0.319 to 0.388, n=7 (vs higher HW /SVL ratio of 0.403, n=1 in *S. pluvialis*); higher IUE/SVL ratio of 0.072 to 0.117, n=7 (vs lower IUE /SVL ratio of 0.067, n=1 in *S. pluvialis*); lower TYD/SVL ratio of 0.034 to 0.061, n=7 (vs higher TYD/SVL ratio of 0.075, n=1 in *S. pluvialis*); lower FLL/SVL ratio of 0.182 to 0.213, n=7 (vs higher FLL/SVL ratio of 0.247, n=1 in *S. pluvialis*); lower T4L/SVL ratio of 0.185 to 0.223, n=7 (vs higher T4L /SVL ratio of 0.320, n=1 in *S. pluvialis*); moderate webbing (I 1-2 II 1½-2½ III 2-2½ IV 2½-1½ V) (vs rudimentary webbing (I 1-2 II 1-3 III 2-3½ IV 4-2 V) in *S. pluvialis*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. pluvialis*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the east coast of India in *S. pluvialis*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. dobsonii* in having a relatively smaller adult male size of SVL 31.1 mm±1.9, n=7 (vs relatively larger adult male size SVL 55.1 mm, n=1 in *S. dobsonii*); lower HL/SVL ratio of 0.281 to 0.313, n=7 (vs higher HL/SVL ratio of 0.336, n=1 in *S. dobsonii*); lower HW/SVL ratio of 0.319 to 0.388, n=7 (vs higher HW /SVL ratio of 0.403, n=1 in *S. dobsonii*); lower TYD/SVL ratio of 0.034 to 0.061, n=7 (vs higher TYD/SVL ratio of 0.064, n=1 in *S. dobsonii*); lower FLL/SVL ratio of 0.182 to 0.213, n=7 (vs higher FLL/SVL ratio of 0.254, n=1 in *S. dobsonii*); moderate webbing (I 1½-2 II 1½-3 III 2½-4 IV 4-2 V) (vs rudimentary webbing (I 1½-2 II 1½-3 III 2-2½ IV 2½-1½ V) in *S. dobsonii*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. dobsonii*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the west coast of India in *S. dobsonii*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. strachani* in having wider head than long (vs head longer than wide in *S. strachani*); snout rounded (vs snout obtuse in *S. strachani*); skin on the back with rounded glandular spots (vs skin on the back with short longitudinal folds in *S. strachani*); finger 1 longer than finger 2 (vs finger 1

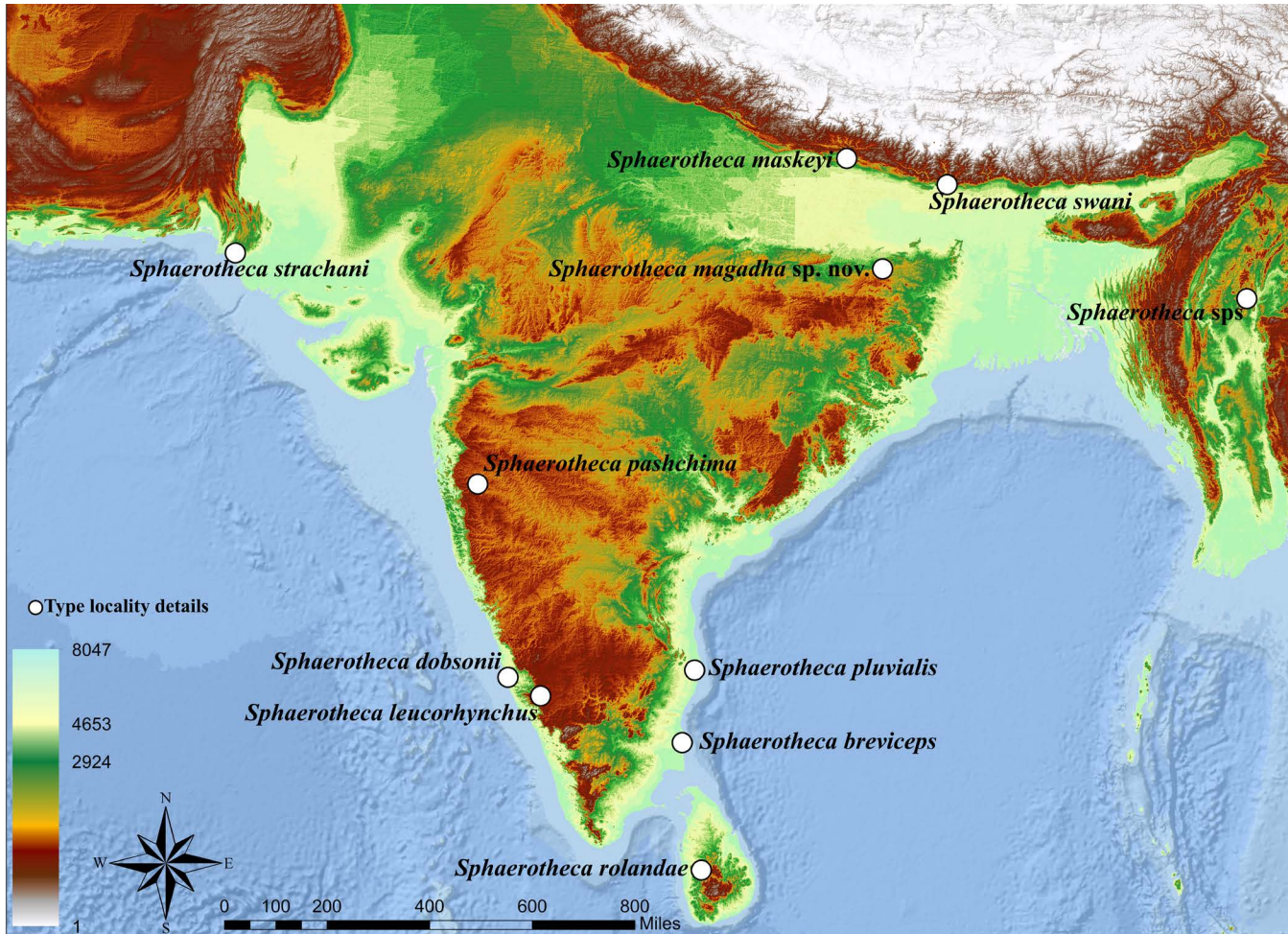


Figure 5. Map showing type localities of extant species of *Sphaerotheca* in South Asia.

and 2 are equal in *S. strachani*); metatarsal articulation reaches back of eyes (vs metatarsal articulation reaches tip of snout in *S. strachani*); outer metatarsal tubercle absent (vs outer metatarsal tubercle present in *S. strachani*); toes moderately webbed (vs toes half webbed in *S. strachani*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. strachani*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the Sindh province of Pakistan in *S. strachani*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. leucohrynus* having a relatively smaller adult male size of SVL 31.1 mm±1.9, n=7 (vs relatively larger adult male size SVL 35.0 mm in *S. leucohrynus*); having wider head than long (vs head longer than wide in *S. leucohrynus*); snout rounded (vs snout obtuse in *S. leucohrynus*); snout

length sub-equal to eye length (vs snout length longer than eye length in *S. leucohrynus*); tibio-tarsal articulation reaches front of shoulders (vs tibio-tarsal articulation reaches eye in *S. leucohrynus*); toes moderately webbed (vs toes 1/3rd webbed in *S. leucohrynus*); outer metatarsal tubercle absent (vs outer metatarsal tubercle present in *S. leucohrynus*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. leucohrynus*); type locality and predominant distribution in the Jharkhand landscapes (vs. known only from the type locality ‘Wattakole, Coorg’ mid elevations of Western Ghats in *S. leucohrynus*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. swani* in having a relatively smaller adult male size of SVL 31.1 mm±1.9, n=7 (vs relatively larger adult male size SVL 42.3 mm, n=1 in *S. swani*); inter orbital distance equal to upper eyelid width (vs inter orbital distance 3/4

of upper eyelid width in *S. swani*); tympanum small about $\frac{1}{4}$ th of eye length (vs tympanum large about $\frac{2}{3}$ rd of eye length in *S. swani*); tibio-tarsal articulation reaches front of shoulders (vs tibio-tarsal articulation reaches eye in *S. swani*); moderate webbing (I 1-2 II $1\frac{1}{2}$ - $2\frac{1}{2}$ III 2- $2\frac{1}{2}$ IV $2\frac{1}{2}$ - $1\frac{1}{2}$ V) (vs rudimentary webbing (I 1-2 II 1-3 III 2- $3\frac{1}{2}$ IV $3\frac{1}{2}$ -2 V) in *S. swani*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. swani*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the lower elevations of eastern Nepal in *S. swani*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. rolandae* in having nostrils nearer to tip of snout (vs. nostrils equidistant from eye to snout tip in *S. rolandae*); inter orbital space equal to upper lid (vs. inter-orbital width broader than that of upper eyelid in *S. rolandae*); diameter of the eye nearly four times of the tympanum (vs. tympanum nearly half the diameter of the eye *S. rolandae*); first finger longer than the second finger (vs first finger shorter than the second finger in *S. rolandae*); tibio-tarsal articulation reaches front of shoulders (vs. tibiotarsal articulation reaches posterior corner of the eye in *S. rolandae*); moderate webbing (I 1-2 II $1\frac{1}{2}$ - $2\frac{1}{2}$ III 2- $2\frac{1}{2}$ IV $2\frac{1}{2}$ - $1\frac{1}{2}$ V) (vs rudimentary webbing (I 1-2 II $1\frac{1}{2}$ - $2\frac{1}{2}$ III 2- $3\frac{1}{2}$ IV $4\frac{1}{2}$ -2 V) in *S. rolandae*); in life, dorsum light greenish brown, fore arm and hind legs barred, back of thighs and front of groin chocolaty brown without any yellow spots (vs. in life dorsum uniformly grey limbs with or without darker cross bands; upper surface of thigh black spotted or marbled with white in *S. rolandae*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in Sri Lanka for *S. rolandae*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. maskeyi* in having a relatively smaller adult male size of SVL $31.1 \text{ mm} \pm 1.9$, $n=7$ (vs relatively larger adult male size SVL 43.7 mm , $n=1$ in *S. maskeyi*); lower HL/SVL ratio of 0.281 to 0.313, $n=7$ (vs higher HL/SVL ratio of 0.343, $n=1$ in *S. maskeyi*); lower HW/SVL ratio of 0.319 to 0.388, $n=7$ (vs higher HW/SVL ratio of 0.448, $n=1$ in *S. maskeyi*); lower EL/SVL ratio of 0.135 to 0.160, $n=7$ (vs higher EL/SVL ratio of 0.162, $n=1$ in *S. maskeyi*); lower SL/SVL ratio of 0.134 to 0.154, $n=7$ (vs higher SL/SVL ratio of 0.161, $n=1$ in *S. maskeyi*); lower TYD/SVL ratio of 0.034 to 0.061, $n=7$ (vs higher TYD/SVL ratio of

0.078, $n=1$ in *S. maskeyi*); lower F2L/SVL ratio of 0.066 to 0.114, $n=7$ (vs higher F2L/SVL ratio of 0.118, $n=1$ in *S. maskeyi*); lower FL/SVL ratio of 0.369 to 0.442, $n=7$ (vs higher FL/SVL ratio of 0.471, $n=1$ in *S. maskeyi*); lower TL/SVL ratio of 0.361 to 0.408, $n=7$ (vs higher TL/SVL ratio of 0.412, $n=1$ in *S. maskeyi*); lower T1L/SVL ratio of 0.020 to 0.031, $n=7$ (vs higher T1L/SVL ratio of 0.042, $n=1$ in *S. maskeyi*); T4L/SVL ratio of 0.185 to 0.223, $n=7$ (vs higher T4L/SVL ratio of 0.328, $n=1$ in *S. maskeyi*); moderate webbing (I 1-2 II $1\frac{1}{2}$ - $2\frac{1}{2}$ III 2- $2\frac{1}{2}$ IV $2\frac{1}{2}$ - $1\frac{1}{2}$ V) (vs rudimentary webbing (I 1-2 II $1\frac{1}{2}$ -3 III 2- $3\frac{1}{2}$ IV $3\frac{1}{2}$ -2 V) in *S. maskeyi*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. maskeyi*); type locality and predominant distribution in the Jharkhand landscapes (vs. type locality and predominant distribution in the lower elevations of central Nepal in *S. swani*).

Sphaerotheca magadha sp. nov. can be distinguished from *S. pashchima*, in having a relatively smaller adult male size of SVL $31.1 \text{ mm} \pm 1.9$, $n=7$ (vs relatively larger adult male size SVL $44.5 \text{ mm} \pm 5.1$, $n=7$ in *S. pashchima*); lower HL/SVL ratio of 0.281 to 0.313, $n=7$ (vs higher HL/SVL ratio of 0.317 to 0.353, $n=7$ in *S. pashchima*); lower TYD/SVL ratio of 0.034 to 0.061, $n=7$ (vs higher TYD/SVL ratio of 0.061 to 0.068, $n=7$ in *S. pashchima*); lower FLL/SVL ratio of 0.182 to 0.213, $n=7$ (vs higher TYD/SVL ratio of 0.223 to 0.289, $n=7$ in *S. pashchima*); moderate webbing (I 1-2 II $1\frac{1}{2}$ - $2\frac{1}{2}$ III 2- $2\frac{1}{2}$ IV $2\frac{1}{2}$ - $1\frac{1}{2}$ V) (vs rudimentary webbing (I 1-2 II 1-3 III 2- $3\frac{1}{2}$ IV $3\frac{1}{2}$ -2 V) in *S. pashchima*); tarsal tubercle present and distinct (vs tarsal tubercle absent in *S. pashchima*); type locality and predominant distribution in the Jharkhand landscapes (vs type locality from Western Ghats and predominant distribution in the mid elevations of Western Ghats to Uttarakhand in *S. pashchima*).

Discussion

Padhye *et al.*, (2017) and Dahanukar *et al.*, (2017) had sorted out the taxonomic ambiguity and species identity for the species of *Sphaerotheca* (except for *S. leucohrynus*) described from India, to a greater extent. However the identity of the *Sphaerotheca* species outside the Indian political boundaries still warrants further studies (specifically phylogenetic studies).

Now, *S. breviceps* is known specifically from parts of Karnataka, Andhra Pradesh and Tamil Nadu regions of south India. Report of *S. breviceps* from Jharkhand by

Dahanukar *et al.*, (2017) should be treated as *Sphaerotheca magadha* sp. nov. as the sequences of *S. breviceps* from Jharkhand (GenBank number: KY215977 and KY215977) matches with the new species (see comparison section above). As the samples from Jharkhand (WILD-16-AMP-647 and BNHS 6006) were sub adults, the presence of tarsal tubercle could not have been noticed by Dahanukar *et al.*, (2017) during their morphological grouping. Report of *S. breviceps* from Pakistan and Sri Lanka in Frost (2018) warrants genetic studies.

After the work of Dahanukar *et al.*, (2017) distribution range for *S. pluvialis* is resolved and restricted to South India and Sri Lanka (Frost, 2018).

Range of distribution for *S. dobsonii* is considered as west coast of Karnataka and Maharashtra (Dahanukar *et al.*, 2017; Frost, 2018). The *S. dobsonii* collection from Tamhini, Maharashtra is having considerable genetic divergence from the populations of Bankot and Hasool in Maharashtra and Mangalore coast in Karnataka. Mangalore, Bankot and Hasool falls in the coastal plains of West Coast and Tamhini lies in the middle elevated hill ranges of Western Ghats. With this backdrop, collections of *S. dobsonii* from Tamhini warrants further morphological studies since there could be phylogeographic structuring within the populations of *S. dobsonii*.

The species *S. strachani* is known only from the type locality and original description, where as reports of *S. breviceps* from Pakistan (aerially 2000 km away from the type locality of *S. breviceps*) in the following web links could be *S. strachani* which needs further studies:

(https://calphotos.berkeley.edu/cgi/img_query?seq_num=788267&one=T;

https://calphotos.berkeley.edu/cgi/img_query?seq_num=268841&one=T and

https://calphotos.berkeley.edu/cgi/img_query?seq_num=111863&one=T).

From the central Western Ghats hill ranges, *S. leucorhynchus* was described from Coorg and there are no further reports of this species since its original description by Rao (1937). Interestingly among the nine extant species of *Sphaerotheca* only *S. leucorhynchus* and *S. pashchima* are described / known from middle to higher elevation (above 700 asl) hill ranges (Table 2).

From Nepal two species were described *S. swani* from eastern Nepal and *S. maskeyi* from central Nepal (aerially around 300 km apart from the type localities) (Figure 5) and these two species are resurrected from the synonymy

by Dahanukar *et al.*, (2017). With this backdrop the report of *S. breviceps* and *S. rolandae* from Nepal by Schleich and Rai (2012); *S. breviceps* by Bhattarai *et al.*, (2017) from Beeshazar and *S. breviceps* by Bhattarai *et al.* (2018) from Parsa National Park could be erroneous (aerially 1800 km away from the type locality of *S. breviceps* and aerially 2000 km away from the type locality of *S. rolandae*). Further systematic sampling with genetic studies is warranted for the species of *Sphaerotheca* from Nepal.

The species *S. rolandae* was described from Kurunegala, Sri Lanka (Figure 5) and there are reports of *S. rolandae* from India. Since there is no genetic information from Sri Lanka for this species, studies are warranted to confirm the range of distribution of this species in India. With the available information now *S. pluvialis* is known to be available in India and Sri Lanka (Dahanukar *et al.*, 2017) and in other terms Sri Lanka is known to have two species of *Sphaerotheca* (Dahanukar *et al.*, 2017; Frost, 2018), *S. rolandae* and *S. pluvialis*, which needs genetic confirmation as the morphological characters are too cryptic to identify the congeneric species of this group.

In the description of *S. pashchima*, Padhye *et al.*, (2017) have signified the confirmed distribution of this species in the region of Western India with an indication of this species from Rajasthan. During our phylogenetic analysis we found that the sequences (GenBank number: KX815435.1, KX815436.1, KX815437.1, KX815438.1 and KX815439.1) (Figure 1) from Uttarakhand (N 30.28476; E 77.97365, 590 m asl) were closely matching with the sequences of *S. pashchima* (GenBank number: KY21599.1) indicating the presence of *S. pashchima* from Uttarakhand (aerially 1300 km away from the type locality). This confirms the distribution range of *S. pashchima* from the mid elevated hill ranges of Western Ghats to Himalayan foot hills of Uttarakhand.

Upon close scrutiny of the species discovery pattern in the genus *Sphaerotheca*, of the nine valid species described from South Asia, seven species are described from the lower elevations (*S. breviceps*, *S. pluvialis*, *S. dobsonii*, *S. strachani*, *S. swani*, *S. rolandae* and *S. maskeyi*) and two species from medium to higher elevated landscapes (*S. leucorhynchus* and *S. pashchima*) (Figure 5). Interestingly the species *S. strachani*, *S. breviceps*, *S. pluvialis*, *S. dobsonii* and *S. rolandae* are either described or known from the low elevated homestead and disturbed landscapes in close proximity to the Arabian Sea shore lines. The species *S. swani* and *S. maskeyi* are described from the low elevated

Table 2. Extant valid species of *Sphaerotheca* in South Asia

| Sl. No. | Extant species of <i>Sphaerotheca</i> | Type locality | Latitude (N) | Longitude (E) | Altitude |
|---------|--|--|--------------|---------------|-------------------------|
| 1 | <i>Sphaerotheca breviceps</i> (Schneider, 1799)* | Tranquebar, Tamil Nadu, India | 11.0628 | 79.8134 | Lower elevation (15 m) |
| 2 | <i>Sphaerotheca pluvialis</i> (Jerdon, 1853)* | Thirudisoolam near Pattaravakkam, Tamil Nadu: | 13.1084 | 80.1664 | Lower elevation (15 m) |
| 3 | <i>Sphaerotheca dobsonii</i> (Boulenger, 1882)* | Mangalore, Karnataka, India | 12.9071 | 74.8989 | Lower elevation (30 m) |
| 4 | <i>Sphaerotheca strachani</i> (Murray, 1884) | Sind (Mulleer) (= Malir, near Karachi), Pakistan | 24.8669 | 67.2085 | Lower elevation (30 m) |
| 5 | <i>Sphaerotheca leucorhynchus</i> (Rao, 1937) | Wattakole, Coorg, Karnataka, India | 12.3799 | 75.8220 | Mid elevation (1000 m) |
| 6 | <i>Sphaerotheca swani</i> (Myers and Leviton, 1956) | Dharan, eastern Nepal | 26.7943 | 87.2880 | Lower elevation (300 m) |
| 7 | <i>Sphaerotheca rolandae</i> (Dubois, 1983) | Kurunegala, Sri Lanka | 7.4710 | 80.3549 | Lower elevation (100 m) |
| 8 | <i>Sphaerotheca maskeyi</i> (Schleich and Anders, 1998) | Royal Chitwan National Park, Central Nepal | 27.5336 | 84.4552 | Lower elevation (220 m) |
| 9 | <i>Sphaerotheca pashchima</i> Padhye, Dahanukar, Sulakhe, Dandekar, Limaye, and Jamdade, 2017* | Ambodi, Pune, Maharashtra, India | 18.3519 | 74.0449 | Mid elevation (750 m) |
| 10 | <i>Sphaerotheca magadha</i> sp. nov.* | Nawadih village, Koderma, Jharkhand | 24.417985 | 85.4680 | Lower elevation (380 m) |
| 11 | <i>Sphaerotheca</i> sps* | Chatthin, Kanbular Township, Sagaing, Myanmar | 23.5794 | 95.7405 | Lower elevation (200 m) |

*species included in the phylogenetic analysis

Terai Valleys of Nepal. The species *S. leucorhynchus* and *S. pashchima* are the only two species known from high lands of the Western Ghats and the foot hills of Himalaya (Figure 1, 5). With this backdrop the species *Sphaerotheca magadha* sp. nov. described from the Nawadih village of Chota Nagpur Plateau (Mani, 1974; Ghosh *et al.*, 2015) falls under the Eastern Plateau and Hills Region Agro-Climatic Zones of India (Mandal *et al.*, 2016) is showing medium to shallow genetic divergence with distinct morphological characters and there could be a sort of phylogeographic structuring within and among the species of *Sphaerotheca* which should be explored at the greater extent with large field sampling and genetic studies.

Due to morphological character variations and occurrence of different colour morphs, identification

of the species of *Sphaerotheca* seems to be difficult by morphological characters alone. Most of the records of species of *Sphaerotheca* in the past needs to be scrutinized in view of the recent work by Padhye *et al.*, (2017) and Dahanukar *et al.*, (2017). Genetic information is available only for the four species of *Sphaerotheca* described from India (except for *S. leucohrynus*) and there is a need for generating genetic information for the species described from Pakistan (one species), Nepal (two species) and Sri Lanka (one species). Interestingly the population of *Sphaerotheca* from Myanmar (GenBank number MG935992.1, MG935698.1, DQ283816.1, DQ282927.1 and MG935993.1) (Table 3) is substantially divergent from the known (available) genetic information (Figure 1) of this group, which requires further taxonomic studies.

Table 3. GenBank accession numbers for the *Sphaerotheca* taxa used in the construction of Maximum-likelihood tree based on 6518 bp of mitochondrial (16S, 12S, COI and Cytb) and nuclear genes (BDNF, CXCR4, NCX1, RAG1, RAG2, Rhod and Tyro)

| | 16s | 12s | COI | Cytb | BDNF | CXCR4 | NCX1 | RAG1 | RAG2 | Rhod | Tyro |
|--------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| <i>Sphaerotheca magadha</i> sp. nov. | MK694738.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Sphaerotheca</i> sps (Iharkand) | KY215975.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Sphaerotheca</i> sps (Iharkand) | KY215976.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. breviceps</i> | KY215977.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. breviceps</i> | KY215978.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. pluvialis</i> | AF215418.1 | AF161039.1 | ----- | AF249077.1 | ----- | ----- | ----- | DQ347214.1 | ----- | AF249110.1 | AF249173.1 |
| <i>S. pluvialis</i> | AF249042.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Sphaerotheca</i> sps (Mayanmar) | AF215417.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Sphaerotheca</i> sps (Mayanmar) | DQ283100.1 | DQ283100.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Sphaerotheca</i> sps (Mayanmar) | MG935992.1 | ----- | MG935698.1 | ----- | ----- | ----- | ----- | ----- | ----- | DQ283816.1 | DQ282927.1 |
| <i>Sphaerotheca</i> sps (Mayanmar) | MG935993.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. pashchima</i> | AB277305.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. pashchima</i> (Uttarakhand) | KX815435.1 | ----- | KX831615.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S.cf. dobsonii</i> | KY215971.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>S. dobsonii</i> | AB277305.1 | AB277290.1 | ----- | AB488855.1 | AB489064.1 | AB277318.1 | AB277330.1 | AB488959.1 | AB488999.1 | AB489040.1 | AB277357.1 |
| <i>S. dobsonii</i> | AB530608.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Indirana salelkari</i> | KP826825.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| <i>Indirana sarojamma</i> | KX641796.1 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |

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