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ARTICLE

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IDENTITY OF *SPHAEROTHECA PLUVIALIS* (JERDON, 1853) AND OTHER AVAILABLE NAMES AMONG THE BURROWING FROGS (ANURA: DICROGLOSSIDAE) OF SOUTH ASIA

Neelesh Dahanukar¹, Shauri Sulakhe² & Anand Padhye³

¹Indian Institute of Science Education and Research (IISER), G1 Block, Dr. Homi Bhabha Road, Pashan, Pune, Maharashtra 411008, India

¹Systematics, Ecology and Conservation Laboratory, Zoo Outreach Organization (ZOO), No. 12 Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road, Saravanampatti, Coimbatore, Tamil Nadu 641035, India

^{2,3}Institute of Natural History Education and Research (INHER), C26/9 Ketan Heights, Kothrud, Pune, Maharashtra 411038, India

³Department of Zoology, Abasaheb Garware College, Karve Road, Pune, Maharashtra 411004, India.

¹n.dahanukar@iiserpune.ac.in, ²shaurisulakhe@gmail.com, ³anand.padhye@mesagc.org (corresponding author)

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Abstract: Species diversity of South Asian burrowing frogs within the genus *Sphaerotheca* is still obscure because of lack of taxonomic review. There are taxonomic issues within the genus *Sphaerotheca* with several names being synonymized to *S. breviceps* and names, such as *S. pluvialis*, being available without proper diagnosis. To resolve the taxonomic confusion, we describe and diagnose *S. pluvialis* by designating a neotype from Carnatic region of southern India, from where the original species was described, and make *S. fodiens* as its objective synonym. We designate lectotype of *S. breviceps* and provide diagnosis for separating the species from its congeners. We clarify the identity of *S. dobsonii* and resurrect *S. swani* and *S. maskeyi*. Based on morphology we define three groups within genus *Sphaerotheca* and provide key to the groups and eight valid species in the genus. We assign genetic barcodes to *S. pluvialis*, *S. dobsonii* and *S. breviceps*.

Keywords: Amphibia, molecular phylogeny, *S. breviceps*, *S. dobsonii*, *S. fodiens*, *S. maskeyi*, *S. swani*, taxonomy.

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For **Author Details** and **Author Contribution** see end of this article.

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INTRODUCTION

South Asian burrowing frogs have a long taxonomic history. Schneider (1799) described *Rana breviceps* from eastern India, followed by Gravenhorst (1829) who described *Rana variegata*, without providing the type locality. Tschudi (1838) transferred *Rana breviceps* to genus *Systema*. Subsequently, Jerdon (1853) described *Pyxicephalus fodiens*, *P. rufescens* and *P. pluvialis* from southern India and Sri Lanka. Günther (1859) proposed a new genus *Sphaerotheca* while describing *S. strigata* from Madras, southern India, which was later synonymized to the genus *Tomopterna* by Günther (1860). Günther (1864) provided the first revision of South Asian burrowing frogs and placed the species under Genus *Pyxicephalus*. He considered two valid species, namely *Pyxicephalus breviceps* and *P. rufescens*, with *Sphaerotheca striata*, *P. fodiens* and *P. pluvialis* as synonyms of *P. breviceps*. Boulenger (1882) shifted the two valid species to *Rana* and described a new species *Rana dobsonii*. Murray (1884) described *Tomopterna strachani* which was included in *Rana* by Boulenger (1890). Boulenger (1920) retained all the valid species under *Rana* subgenus *Tomopterna* owing to their burrowing habit. Rao (1937) described *Rana (Tomopterna) leucorhynchus* from southern India; Myers and Leviton In Leviton et al. (1956) described *Rana swani* from Nepal, and Dubois (1983) described *Rana (Tomopterna) breviceps rolandae* from Sri Lanka. Dubois (1987) defined tribe Tomopternini under family Ranidae and considered only two species valid from South Asia, namely *Tomopterna (Sphaerotheca) breviceps* and *T. (S.) rolandae* while he considered other species, namely *Rana dobsonii*, *Pyxicephalus fodiens*, *Rana leucorhynchus*, *Pyxicephalus pluvialis*, *Tomopterna strachani*, *Sphaerotheca strigata*, *Rana swani* and *Rana variegata*, as 'incertae sedis et synonymes' without providing any rationale for doing so. He also transferred *Rana (Tomopterna) rufescens* under *Limnonectes (Fejervarya)*. Subsequently, Schleich & Anders (1998) described *Tomopterna maskeyi* from Nepal. Marmayou et al. (2000) and Vences et al. (2000) provided genetic support to raise the subgenus *Sphaerotheca* to genus level. Vences et al. (2000) considered seven species from South Asia valid under *Sphaerotheca*, namely *S. breviceps*, *S. dobsonii*, *S. leucorhynchus*, *S. maskeyi*, *S. rolandae*, *S. strachani* and *S. swani*.

Major confusion regarding the valid species under genus *Sphaerotheca* was due to the following publications—Dubois (1999, 2000, 2004) made the name *Sphaerotheca pluvialis* available without

properly resurrecting the species as he did not provide diagnostic characters to identify it and separate it from other available names. Further, Dubois (1999) synonymized *Tomopterna maskeyi* and Dubois (2000) synonymized *Rana variegata*, *Pyxicephalus fodiens*, *Sphaerotheca strigata*, *Rana dobsonii*, *Tomopterna strachani*, *Rana (Tomopterna) leucorhynchus* and *Rana swani* to *Sphaerotheca pluvialis* without providing any justification. In addition, Marmayou et al. (2000) provided genetic sequence for *Sphaerotheca pluvialis*, from Myanmar, without clearly defining the species. Moreover, the type locality of *S. pluvialis* by original description is southern India and not Myanmar, which are biographically well separated areas.

Therefore, in this communication we try to resolve the taxonomic confusions in available names under *Sphaerotheca*. We validate the resurrection of *S. pluvialis* by Dubois (1999), by designating a neotype. We designate a lectotype for *S. breviceps* and clarify the identity of *S. dobsonii*, *S. swani* and *S. maskeyi*. We define morphological groups within the genus *Sphaerotheca* and provide a key to the groups and species. Further, we assign genetic barcodes to *S. pluvialis*, *S. dobsonii* and *S. breviceps*.

MATERIALS AND METHODS

Specimen studied and museum details

Specimens in the Indian museum collections of Bombay Natural History Society (BNHS, Mumbai), the Zoological Survey of India (ZSI, Kolkata), the Zoological Survey of India, Western Regional Centre (ZSI-WRC, Pune), the Wildlife Information Liaison Development (WILD, Coimbatore), and the Institute of Natural History Education and Research (INHER, Pune), were studied. Photographs of syntypes of *Sphaerotheca breviceps* were studied from the Museum für Naturkunde (ZMB), Berlin, Germany. Photographs of holotype of *Sphaerotheca swani* were studied from California Academy of Sciences, Stanford University collection (CAS-SU), San Francisco, USA. Photographs of holotype of *Sphaerotheca maskeyi* were studied from Zoologische Staatssammlung München, Germany (available online at <http://www.biologie.uni-ulm.de/cgi-bin/herbar.pl?herbid=109475&sid=T&lang=d>, accessed on 17 February 2017). Photographs of holotype of *Sphaerotheca rolandae* were studied from the Natural History Museum (BMNH), London, UK.

Morphometry

Measurements were taken to the nearest 0.1mm using a digital caliper (Ocean Premium measuring instruments) and include: Length of specimen from snout to the visible tip of urostyle (SUL), head length (HL), head width (HW), nasal snout distance (SN), inter nasal distance (IN, measured between the centre of the nares), diameter of the eye (EL), eye snout distance (SL), eye to nasal distance (EN), shortest distance between eyes (IUE), upper eyelid width (UEW), tympanum diameter (TYD), distance from tympanum to the back of the eye (TYE), length of hand (HAL), F1 to F4 (Finger 1 to Finger 4 length from the base of the sub-articular tubercle), length of forelimb (FLL), length of femur (FL), length of Tibia (TL), foot length (FoL, measured from the base of the inner metatarsal tubercle to the tip of the toe), T1 to T5 (Toe1 to Toe5 length from the base of the respective sub-articular tubercle), and Inner metatarsal tubercle length (IMT). Webbing formula was determined following the method provided by Savage & Heyer (1967) with modifications by Myers & Duellman (1982).

Statistical analysis

All characters showed positive linear correlation with SUL. Therefore, to remove size bias, statistical analysis of the morphometric data was performed on size adjusted measurements by taking all measurements as percent of SUL. Multivariate normality of the data was checked using Doornik & Hansen (2008) omnibus. Discriminant Analysis (DA) was performed to understand whether related species form significantly different clusters (Huberty & Olejnik 2006) in the genus *Sphaerotheca*. Wilks' Lambda statistic was used to test the null hypothesis that the mean vectors of different clusters are equal (Harris 2001). Mahalanobis distances (Harris 2001) between pair of individuals were calculated and were used for computing Fisher's distances (distance between the centroids of the clusters, divided by the sum of their standard deviations) between two clusters to check if the clusters were significantly different. Statistical analysis was performed in PAST 3.12 (Hammer et al. 2001).

Molecular analysis

Thigh muscle tissue was harvested from two specimens of putative topotypes of *S. breviceps* (BNHS 6005, WILD-16-AMP-645), two specimens of *S. breviceps* from Maithon, Jharkhand (BNHS 6006 and WILD-16-AMP-647), three specimen of *S. dobsonii* from Tamhini, Maharashtra (BNHS 6007, INHER-Amphibi-86, ZSI-WRC

A/1548), two specimens of *S. dobsonii* from Devi-Hasol, Maharashtra (BNHS 6008, WILD-16-AMP-651) and one specimens of *S. dobsonii* from Bankot, Maharashtra (WILD-16-AMP-653). We could not collect topotypes for *Sphaerotheca leucorhynchus* for molecular analysis despite our best efforts for three consecutive years (2013 to 2016) to visit the type locality of the species. Further, we could not study topotypes of *S. maskeyi*, *S. rolandae*, *S. swani* and *S. strachani* for molecular analysis because of logistic and legal reasons due to their presence outside India. Tissues were preserved in absolute ethanol. DNA extraction, PCR amplification of 16S rRNA gene and sequencing protocols followed Padhye et al. (2014). Sequences were analysed by the BLAST tool (Altschul et al. 1990) for similar sequences in NCBI Genbank database (www.ncbi.nlm.nih.gov). Sequences generated in the current study are deposited in GenBank under the accession numbers (KY215969–KY215978). Additional 16S gene sequences were retrieved from the NCBI GenBank database. Gene sequences were aligned using MUSCLE (Edgar 2004). Pair-wise raw phylogenetic distances were calculated in MEGA6 (Tamura et al. 2013). Maximum likelihood phylogenetic tree was built using IQ-TREE software (Nguyen et al. 2015) where the best nucleotide substitution model was analysed based on the minimum Bayesian Information Criterion (BIC) value (Schwarz 1978; Nei & Kumar 2000). Reliability of the phylogenetic tree was estimated with ultrafast bootstrap support (Minh et al. 2013) for 1000 iterations. Phylogenetic tree was edited in FigTree v1.4.2 (Rambaut 2009).

Comparative material and data sources

Sphaerotheca breviceps: Lectotype, ZMB 55005, male (29.9mm SUL) and paralectotype, ZMB 3351 (33.9mm SUL), Indes orientales (only photographs examined); BNHS 6004, male (29.6mm SUL), BNHS 6005, female (33.5mm SUL), WILD-16-AMP-645, male (31.6mm SUL), WILD-16-AMP-646, female (34.8mm SUL), ZSI-WRC A/1546, male (31.7mm SUL), ZSI-WRC A/1547, female (30.0mm SUL), INHER-AMPHIBIA-46, female (34.4mm SUL) and INHER-AMPHIBIA-49, male (27.8mm SUL), 15.xi.2015, India: Tamil Nadu: Nagapattinam District, Tranquebar (=Tharangambadi), Karaikal (11.062°N, 79.813°E, elevation 16m), coll. N. Dandekar and S. Sulakhe; WILD-16-AMP-647, sub adult (26.6mm SUL) and BNHS 6006, sub adult (24.8mm SUL), 26-ix-2014, India: Jharkhand: Dhanbad District, Maithon (23.776°N, 86.809°E, 150m), coll. A.D. Padhye; ZSI 18744, male (48.3mm SUL), Madras, coll. J. Henderson.

Sphaerotheca dobsonii: WILD-16-AMP-648, female

(43.0mm SUL), ZSI-WRC A/1548, female (38.0mm SUL) and BNHS 6007, female (45.5mm SUL), 1-vi-2000, India: Maharashtra: Pune District, Tamhini (18.477°N, 73.427°E, 897m), coll. A. D. Padhye; INHER-Amphibia-86, male (55.1mm SUL), 25-vi-2016, India: Maharashtra: Pune District, Tamhini (18.477°N, 73.427°E, 897m), coll. N. Dandekar & M. Ketkar; INHER-Amphibia-151, female (35.0mm SUL), WILD-16-AMP-651, female (34.3mm SUL) and BNHS 6008, female (42.5mm SUL), 31-vii-2016, India: Maharashtra: Ratnagiri District, Devi-Hasol (16.742°N, 73.432°E, 159m), coll. A.D. Padhye; 5 ex., INHER-Amphibia-144, female (37.0mm SUL), WILD-16-AMP-652, female (41.5mm SUL), WILD-16-AMP-653, female (46.0mm SUL), BNHS 6009, female (42.9mm SUL) and BNHS 6010, female (31.7mm SUL), 29.vii.2016, India: Maharashtra: Ratnagiri District, Bankot (17.980°N, 73.065°E, 46m), coll. S. Sulakhe et al. Additional data from Boulenger (1920).

Sphaerotheca swani: Holotype, CAS-SU 15371, male (42.3mm SUL), 22.vi.1954, Dharan, eastern Nepal, at an altitude of 1,000 feet, coll. L.W. Swan (only photographs examined). Additional data from Leviton et al. (1956).

Sphaerotheca maskeyi: Holotype, ZSM 106/91-2, 8.vii.1991, Chitwan Jungle Lodge, Royal Chitwan National Park, Central Nepal, at an altitude of approx. 300m, coll. H.H. Schleich and T.M. Maskey (only photographs examined); ZSI 16127, female, 43.7mm SUL, Chainpur (=Chainpur) Nepal. Additional data from Schleich & Anders (1998).

Sphaerotheca rolandae: Holotype, BMNH 1973.3024, Kurunegala, Sri Lanka, altitude 60m, latitude 7°29'N, longitude 80°22'E (only photographs examined); ZSI 17630 and ZSI 17632, Bangalore, India, coll. C.R. Narayan Rao (only photographs examined). Further details from Dubois (1983) and Dutta & Manamendra-Arachchi (1996).

Data for *Sphaerotheca leucorhynchus* from Rao (1937) and *S. strachani* from Murray (1884). Among the current synonyms of *S. breviceps*, data for *Rana variegata* was obtained from Gravenhorst (1829) and *Sphaerotheca strigata* from Günther (1859) and Boulenger (1920).

RESULTS AND DISCUSSION

Identity of *Sphaerotheca pluvialis* (Jerdon, 1853)

Jerdon (1853) made two names available, namely *Pyxicephalus fodiens* and *P. pluvialis*, from Carnatic region of southern India based on scanty descriptions. Nevertheless, he acknowledged that the two species are very similar and preferred to call them different just

based on the different vernacular names used by the natives. Günther (1859) further mentioned that he has seen the “coloured figures of Mr. Jerdon’s *Pyxicephalus fodiens* and *P. pluvialis*, in the possession of Walter Elliot, Esq., from which it is evident that they are identical”. Thus, it can be suggested that *Pyxicephalus fodiens* and *P. pluvialis* are indeed the same species. Although, the name *P. fodiens* appears before *P. pluvialis*, Dubois (2000) gave preference for the name *P. pluvialis* over *P. fodiens* as the first reviser, owing to slightly more detailed original description of *P. pluvialis*. We designate ZSI A9074 as a neotype of both *P. fodiens* and *P. pluvialis* and consider *P. pluvialis* as a valid species under the genus *Sphaerotheca* with *P. fodiens* as its objective synonym. It is also essential to note that the neotype is collected from within the Carnatic region, the type locality of both the species, which is the part of southern India that includes Tamil Nadu, south-eastern Karnataka, north-eastern Kerala and southern Andhra Pradesh in modern India. We choose this specimen ZSI A9074 because it also has 16S rRNA gene sequence AF215418, which is the genetic barcode for the neotype of *Sphaerotheca pluvialis*. Designation of a neotype is necessary for three reasons. First, there are no known types for *P. fodiens* and *P. pluvialis* and the types were reported as lost (Jerdon, 1870) and colored figures of the two species, as mentioned by Günther (1859), are also not traceable. Second, the original description is not adequate to identify and diagnose the species. Third, the species has often been confused with other sympatric congeners in the past.

Sphaerotheca pluvialis (Jerdon, 1853) (Image 1)

Synonyms:

Pyxicephalus pluvialis Jerdon (1853): p. 534

Pyxicephalus fodiens Jerdon (1853): p. 534 (objective synonym)

Sphaerotheca strigata Günther, 1859: p. 20, Plate II fig. A

Pyxicephalus (Tomopterna) fodiens—Peters (1860, p. 186)

Tomopterna (Sphaerotheca) pluvialis—Dubois (2000, p. 334)

Sphaerotheca dobsonii (non Boulenger, 1882)—Vences et al. (2000, p. 240)

Tomopterna (Sphaerotheca) breviceps (non Schneider, 1799)—Bossuyt & Milinkovitch (2000, p. 6586)

Suggested common name: Jerdon’s Burrowing Frog

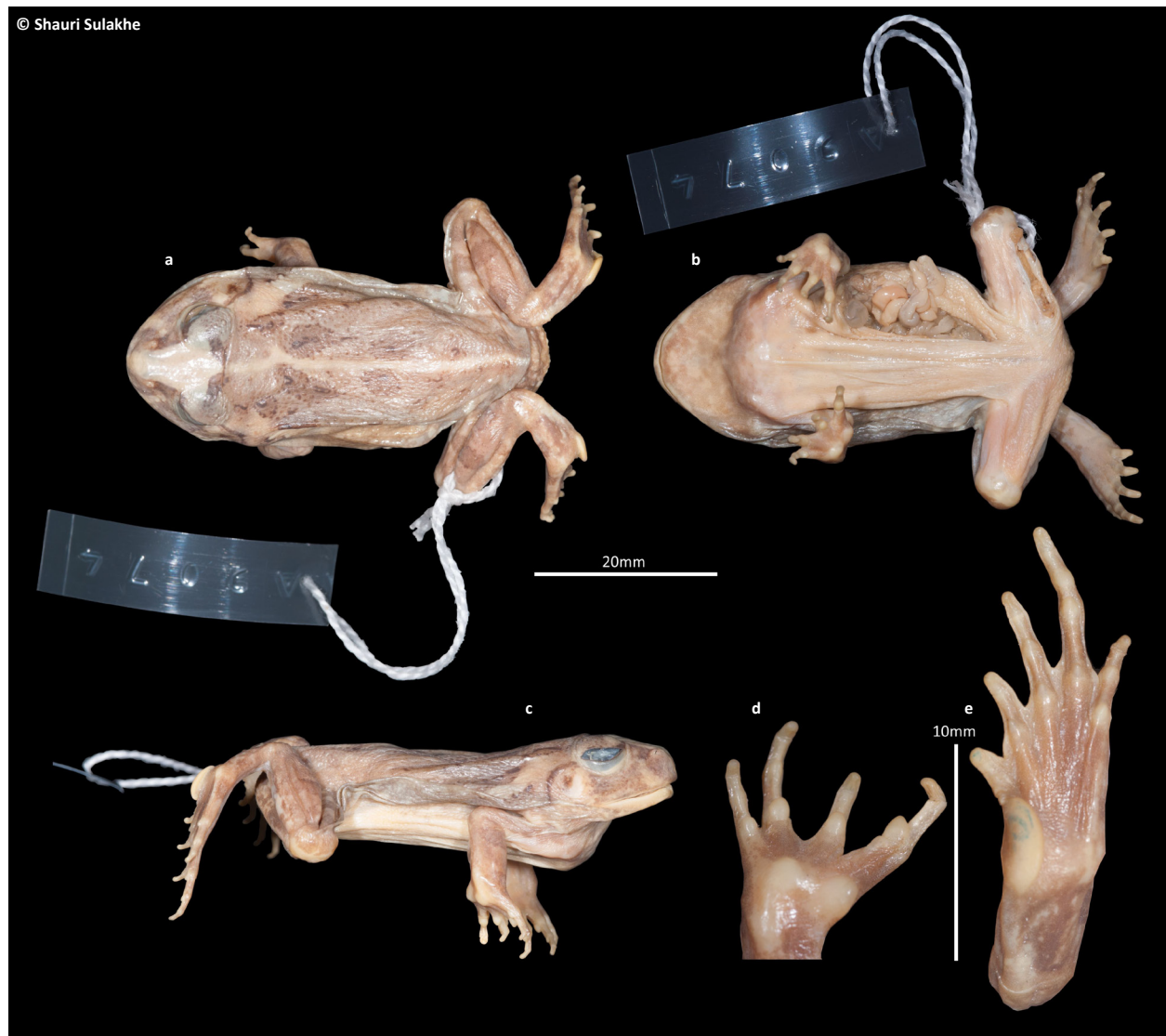


Image 1. *Sphaerotheca pluvialis* neotype (ZSI A9074, 45.1 mm SUL) from Pattaravakkam, Tamil Nadu, India. (a) dorsal view, (b) ventral view, (c) lateral view, (d) right hand, and (e) right foot.

Neotype: ZSI A9074, 10.vi.1998, female, 45.1mm SUL, India: Tamil Nadu: Thiruadisoolam near Pattaravakkam (12.696°N, 80.030°E), coll. Romulus Whitaker.

Comparative material: ZSI 18743, female, 51.9mm SUL, Madras, coll. J. Henderson; ZSI 12515, male, 46.5mm SUL, southern India, coll. E. Gerard; ZSI 2681, female, 45.4mm SUL, Sri Lanka, coll. E.F. Kelaart.

Genetic barcode: 16S rRNA sequence AF215418 of the neotype ZSI A9074.

Diagnosis: *Sphaerotheca pluvialis* differs from all other congeners based on the following combination of characters: medium sized frog with slightly warty dorsum; snout as long as eye diameter; tympanum large, vertically oval, its horizontal diameter less than ½ of the eye diameter; inter-narial width slightly greater

than inter orbital distance, which is less than the width of upper eyelid; first finger longer than second and fourth; first finger almost equal to or slightly less than third finger; second finger longer than fourth; outer metatarsal tubercle absent; tibio-tarsal tubercle absent; inner metatarsal tubercle elongated, crescentic, more than 1.5 times but less than two times in length as compared to length of first toe; heels do not touch each other when legs are folded at right angles to the body axis; tibio tarsal articulation barely reaching the tympanum; and webbing formula I1⁻2⁺II1⁺-3III2⁺-3½IV3-2V (See species groups and species comparisons section below for species wise comparison.)

Description of the Neotype (ZSI A9074, female, Image 1) (all measurements in mm): Medium sized frog (SUL



Image 2. *Sphaerotheca pluvialis* comparative material. (a) ZSI 18743, 51.9mm SUL from Madras, India, (b) ZSI 12515, 46.5mm SUL from southern India, and (c) ZSI 2681, 45.4mm SUL from Sri Lanka.

45.1); head wider than long (HW 18.8 > HL 15.1); snout shorter than horizontal diameter of eye (SL 6.3 < EL 6.6); outline of snout rounded dorsally, truncated laterally; snout slightly protruding beyond the mouth ventrally; nostrils nearer to eye than to snout (SN 3.6 > EN 3.2); tympanum less than $\frac{1}{2}$ the diameter of eye (TYD = 2.5; EL = 6.6); supra-tympanic fold distinct; upper eyelid width about $\frac{2}{3}$ rd the horizontal diameter of eye (UEW = 4.2; EL = 6.6); upper eyelids warty; Inter narial width slightly greater than shortest distance between eyes (IN 3.7 > IUE 3.6); canthus rostralis distinct; loreal region slightly concave and oblique; buccal cavity shallow, vomerine teeth in two sharply oblique rows at the anterior border of choanae; tongue thin, bifid, without papilla; dorsal skin granulated or slightly warty; ventral and lateral skin smooth.

Length of Forelimb slightly greater than length of hand (FLL 10.8 > HAL 10.5); finger lengths from shortest to longest—F4 (3.4) < F2 (4.1) < F1 (5.9) < F3 (6.1); palmar tubercles present, outer palmar tubercle single, sub-articular tubercles moderate, supernumerary tubercles present, single; fingers without web or fringe of skin.

Hind limbs long; femur longer than tibia (FL 19.1 > TL 17.4); foot longer than tibia (FoL 18.3 > TL 17.4); toe lengths from shortest to longest are—T1 (2.8) < T2 (5.8) < T3 (9.2) < T5 (9.8) < T4 (14.6); inner metatarsal tubercle large, very prominent, compressed, inserted obliquely at the base of the first toe, which it exceeds in

length—T1 (2.8) < IMT (4.0); outer metatarsal tubercle absent; supernumerary tubercles absent; sub-articular tubercles moderate; tarsal fold and outer phalangeal fringe absent; webbing formula I1-2II1-3III2-3 $\frac{1}{2}$ IV4-2V.

Coloration: In alcohol preservation (Image 1), creamish-brown above with dark brown patches, dorso-lateral creamish patches on shoulders and above supratympanic fold, mid-dorsal creamish line starting from middle of eyes till vent; inverted V-shaped mark on the back interrupted by mid-dorsal line; creamy white triangular patch starting from snout to middle of the eyes followed by a dark band continuing on the upper eyelids on either side; limbs cross barred, canthal region dark brown with two vertical creamy white bands starting from anterior as well as posterior margins of the eye extending to upper jaw, posterior band covers anterior portion of tympanum, tympanum dark brown in posterior half; supra tympanic fold distinctly marked with dark brown edge; ventral side creamy brown with mottling on throat.

Variation: Morphometric variation is provided in Table 1. Morphological and color variation as per Image 2.

Morphometric analysis: Size corrected morphometric data was not significantly different from multivariate normal (Ep = 55.44, P = 0.3464). *Sphaerotheca breviceps*, *S. dobsonii* and *S. pluvialis* formed distinct clusters in DA (Fig. 1). *Sphaerotheca pluvialis* formed a distinct cluster

Table 1. Morphometric data (in mm) of *Sphaerotheca pluvialis* Neotype [N] and comparative material of *S. pluvialis*, *S. dobsonii*, *S. breviceps* and *S. maskeyi*. Vouchers with asterisk were used in genetic analysis. Gender is indicated in parenthesis as male (M), female (F) and sub adult (SA).

Species / Voucher	SUL	HL	HW	SN	IN	EL	SL	EN	IUE	UEW	TYD	TYE	HAL	F1L	F2L	F3L	F4L	FLL	FL	TL	FoL	T1L	T2L	T3L	T4L	T5L	IMT	
<i>Sphaerotheca pluvialis</i>																												
ZSI A9074 (F) [N]*	45.1	15.1	18.8	3.6	3.7	6.6	6.3	3.2	3.6	4.2	2.5	1.4	10.5	5.9	4.1	6.1	3.4	10.8	19.1	17.4	18.3	2.8	5.8	9.2	14.6	9.8	4.0	
ZSI 18743 (F)	51.9	16.7	19.8	3.7	3.3	6.8	7.7	3.3	3.2	5.1	3.1	2.6	11.2	6.6	4.4	6.8	3.6	11.7	21.2	19.1	22.0	2.6	5.0	10.1	15.8	9.3	4.5	
ZSI 2681 (F)	45.4	16.2	19.9	3.2	3.4	6.3	6.0	3.7	2.7	3.5	2.2	2.7	--	--	--	--	--	9.4	19.0	18.3	--	3.3	--	--	--	--	4.3	
ZSI 12515 (M)	46.5	15.2	19.4	3.9	3.3	6.9	6.9	3.2	3.1	5.2	3.5	2.0	11.2	6.4	4.7	6.4	3.9	11.5	18.4	17.7	21.1	2.6	5.1	9.0	14.9	10.0	4.4	
<i>Sphaerotheca dobsonii</i>																												
WILD-16-AMP-648 (F)	43.0	13.7	17.7	2.2	3.8	5.9	6.1	2.9	2.9	4.3	2.9	2.3	10.2	4.2	4.1	5.2	3.3	11.9	20.1	19.0	21.5	2.3	3.4	6.0	11.3	5.9	4.4	
ZSI-WRC A/1548 (F)*	38.0	12.0	15.1	1.9	3.9	5.4	5.2	3.1	3.1	3.8	2.8	1.6	9.8	3.4	3.0	5.1	2.7	10.4	17.4	16.5	18.1	2.2	3.4	4.8	10.0	4.9	4.1	
BNHS 6007 (F)*	45.5	15.2	18.5	2.3	4.3	5.6	6.3	3.9	3.9	3.7	2.8	2.5	10.3	4.1	4.8	5.7	4.1	11.4	19.3	18.7	20.8	2.2	3.1	5.7	10.0	4.8	3.8	
INHER-Amphibia-151 (F)	35.0	12.4	14.9	2.7	3.2	5.4	5.5	3.4	2.0	3.1	2.2	1.6	8.8	4.5	3.8	5.4	3.2	8.6	15.8	15.2	17.3	1.9	3.1	5.0	8.8	4.6	2.6	
WILD-16-AMP-651 (F)*	34.3	13.2	15.0	3.1	3.7	5.8	6.4	3.2	2.8	3.8	2.3	1.5	7.9	3.9	3.1	4.4	2.6	6.7	13.0	14.9	14.9	1.4	2.9	4.5	8.2	4.1	2.6	
BNHS 6008 (F)*	42.5	14.6	17.7	3.3	4.6	5.9	7.3	3.9	3.4	3.9	2.3	1.8	10.4	5.4	4.1	6.0	3.7	9.5	17.5	18.0	19.8	1.8	3.6	6.0	9.8	4.8	3.4	
INHER-Amphibia-144 (F)	37.0	12.4	16.2	2.8	3.2	5.3	5.9	3.1	2.7	3.1	1.9	1.4	9.6	4.5	3.5	5.7	3.0	8.8	16.1	15.8	17.1	1.3	2.8	5.0	8.9	4.6	2.5	
WILD-16-AMP-652 (F)	41.5	16.0	18.2	2.9	4.1	5.7	6.9	3.7	3.6	3.5	2.3	1.7	10.3	5.1	4.1	6.1	3.7	9.3	18.6	18.2	19.2	2.0	3.7	5.4	9.6	5.9	3.1	
WILD-16-AMP-653 (F)*	46.0	15.2	18.3	3.4	4.4	6.1	7.3	3.7	3.7	3.7	2.1	1.7	11.4	5.9	4.5	6.6	4.1	10.6	18.4	20.1	21.3	2.5	4.1	6.7	10.7	5.6	3.8	
BNHS 6009 (F)	42.9	15.2	17.6	3.4	4.0	5.5	7.0	3.7	4.0	3.2	2.3	1.8	10.0	4.2	4.0	6.1	3.5	9.0	20.0	17.8	19.2	2.0	3.8	6.2	10.8	4.9	3.5	
BNHS 6010 (F)	31.7	11.8	12.7	2.9	3.1	4.9	4.9	2.5	2.6	2.9	1.9	0.9	7.9	3.5	3.1	4.4	2.5	6.5	13.9	12.5	13.9	1.5	2.1	3.8	6.9	3.6	2.2	
INHER Amphibia-86 (M)*	55.1	18.5	22.2	2.4	4.6	7.7	7.6	4.3	3.9	5.6	3.5	1.8	12.1	6.5	4.6	7.0	4.2	14.0	22.2	21.4	22.3	2.6	3.7	6.4	11.9	4.6	4.6	
<i>Sphaerotheca breviceps</i>																												
WILD-16-AMP-646 (F)	34.8	11.2	14.6	1.5	2.8	4.6	4.6	2.3	3.6	3.3	1.7	2.1	8.3	3.1	2.7	4.1	1.8	8.3	16.1	13.6	15.9	1.0	1.9	3.5	7.8	3.4	2.9	
ZSI-WRC A/1547 (F)	30.0	9.7	12.1	1.8	2.6	4.6	4.2	2.1	2.6	2.3	1.6	1.6	6.8	2.4	1.9	3.4	1.6	7.3	12.9	11.5	13.5	1.2	2.3	4.1	7.2	3.8	2.6	
INHER-AMPHIBIA-46 (F)	34.4	10.8	14.4	2.2	2.8	4.9	4.7	2.6	3.6	2.9	2.2	2.1	7.2	2.9	2.6	4.0	1.7	7.9	15.0	12.9	14.5	0.8	2.0	4.0	6.9	3.0	2.7	

continued next page...

Table 1 continued...

Species / Voucher	SUL	HL	HW	SN	IN	EL	SL	EN	IUE	UEW	TYD	TYE	HAL	F1L	F2L	F3L	F4L	FLL	FL	TL	FoL	T1L	T2L	T3L	T4L	T5L	IMT
BNHS 6005 (F)*	33.5	11.1	15.0	2.0	2.7	4.9	5.1	3.0	3.5	3.0	2.0	2.1	7.4	2.9	2.2	3.4	1.9	8.0	15.8	13.4	12.4	0.9	2.0	4.2	4.5	3.1	3.4
BNHS 6004 (M)*	29.6	10.0	13.1	2.2	2.7	4.5	4.8	2.5	2.8	2.6	1.6	1.6	7.6	2.4	2.3	3.9	1.9	8.1	14.4	11.9	15.2	0.9	1.9	3.6	8.2	3.8	2.9
ZSI-WRC A/1546 (M)	31.7	10.6	13.6	2.2	3.1	4.4	5.0	2.5	3.1	2.5	1.6	1.3	6.5	2.8	2.0	3.4	1.7	8.2	13.9	12.7	13.5	0.7	2.3	3.4	5.7	2.8	2.8
WILD-16-AMP-645 (M)*	31.6	10.4	13.3	1.9	3.0	4.7	4.7	2.5	3.4	2.7	1.9	1.7	7.1	2.8	2.3	3.6	1.9	8.3	14.0	12.5	14.9	0.9	2.2	4.5	7.9	3.6	3.2
INHER-AMPHIBIA-49 (M)	27.8	10.0	12.4	1.7	2.5	4.4	4.4	2.2	3.0	2.8	1.6	1.6	6.9	2.7	2.0	3.7	1.8	7.4	12.3	11.0	14.1	0.9	2.2	4.0	7.3	2.7	2.8
WILD-16-AMP-654 (M)	31.1	12.2	14.5	1.6	3.0	4.5	4.5	2.3	2.7	2.8	1.5	1.4	7.5	3.3	2.5	4.0	1.9	6.8	14.7	13.6	14.5	1.1	1.9	3.7	7.5	3.6	2.8
ZSI 18744 (M)	48.3	15.3	18.1	3.7	4.0	7.5	7.5	3.4	2.4	5.1	3.6	2.3	10.5	7.0	4.8	6.8	3.3	11.9	20.1	18.4	21.8	2.1	4.3	5.7	11.8	5.6	4.8
BNHS 6006 (SA)	24.8	8.9	10.6	1.3	2.3	4.0	4.0	2.0	2.2	2.2	1.6	1.1	6.3	2.4	2.1	3.2	1.5	5.4	10.8	10.2	11.0	0.9	2.0	2.8	5.2	2.5	2.3
WILD-16-AMP-647 (SA)*	26.6	9.9	11.3	2.0	2.6	4.1	4.2	2.1	2.7	2.9	1.5	1.1	6.4	2.6	2.0	3.0	1.5	6.6	10.3	10.0	10.9	0.7	1.3	2.9	5.3	2.5	2.5
<i>Sphaerotheca maskeyi</i>																											
ZSI 16127 (M)	43.74	14.99	19.6	3.63	4.42	7.08	7.05	3.1	3.85	4.9	3.43	1.96	10.58	6.83	5.17	6.28	3.71	11.09	20.6	18.03	20.41	1.84	5.19	8.6	14.36	7.55	4.87

from *S. breviceps* ($F = 3824.71$, $P = 0.004$) based on longer toes and smaller femur, inter orbital distance, forelimb and head width (Fig. 1). *Sphaerotheca pluvialis* formed a distinct cluster from *S. dobsonii* ($F = 1694.35$, $P = 0.019$) based on longer toes and smaller thigh, foot and inter narial distance (Fig. 1).

Genetic analysis: Model test suggested transition model with gamma distribution (TIM2e+G4, $-lnL = 1686.798$, $df = 31$, $BIC = 3570.69$) as the best fit nucleotide substitution model for the data. *Sphaerotheca pluvialis* formed a distinct clade different from both, the topotypic *S. breviceps* and *S. dobsonii* (Fig. 2). *Sphaerotheca pluvialis* differed from *S. breviceps* by 7.9–8.3 % raw genetic distance, while it differed from *S. dobsonii* by 5.6–8.0 % (Table 2). Specimens identified as *S. pluvialis* by Marmayou (2000) and *S. breviceps* by Frost *et al.* (2006) from Myanmar are conspecific to each other but differ from *S. pluvialis* by 7.1–7.5 % raw genetic distance and from *S. breviceps* by 9.1–9.6 % indicating that they are neither *S. pluvialis* nor *S. breviceps* and they may belong to one of the other available names under *Sphaerotheca*. Gene sequence AF249042 of a specimen identified as *S. breviceps* from Sri Lanka by Bossuyt & Milinkovitch (2000) is similar to the sequence of neotype of *S. pluvialis*. We have not considered five sequences AF249014, DQ346976, AY880442 and GU19112 or specimens identified as *Sphaerotheca* for genetic analysis because they either did not align properly with other sequences of *Sphaerotheca* or were not of good quality. Further, we have not considered GU191123 labelled as *Sphaerotheca* sp. because the sequence is similar to *Hoplobatrachus tigerinus* and not species of *Sphaerotheca*.

Distribution: While both *Pyxicephalus fodiens* and *P. pluvialis* were described from Carnatic region of India, Jerdon (1853) mentioned that *Pyxicephalus fodiens* was also present in Ceylon (= Sri Lanka). Interestingly, we found a specimen in the collection of Zoological Survey of India (ZSI 2681) collected from Sri Lanka, which is conspecific with *S. pluvialis*. Further, 16S rRNA gene sequence AF249042 of a specimen identified as *S. breviceps* from Sri Lanka by Bossuyt & Milinkovitch (2000) is similar to the sequence of neotype of *S. pluvialis*, which further vouch for the presence of *S. pluvialis* from Sri Lanka. Based on the neotype, three comparative specimens and genetic evidence we suggest that *S. pluvialis* is present in southern India and Sri Lanka.

Remarks: Dubois (2000) used the name *Tomopterna (Sphaerotheca) pluvialis* and Dubois (1999; 2004) and Marmayou *et al.* (2000) used the name *S. pluvialis* without actually discussing the proper resurrection

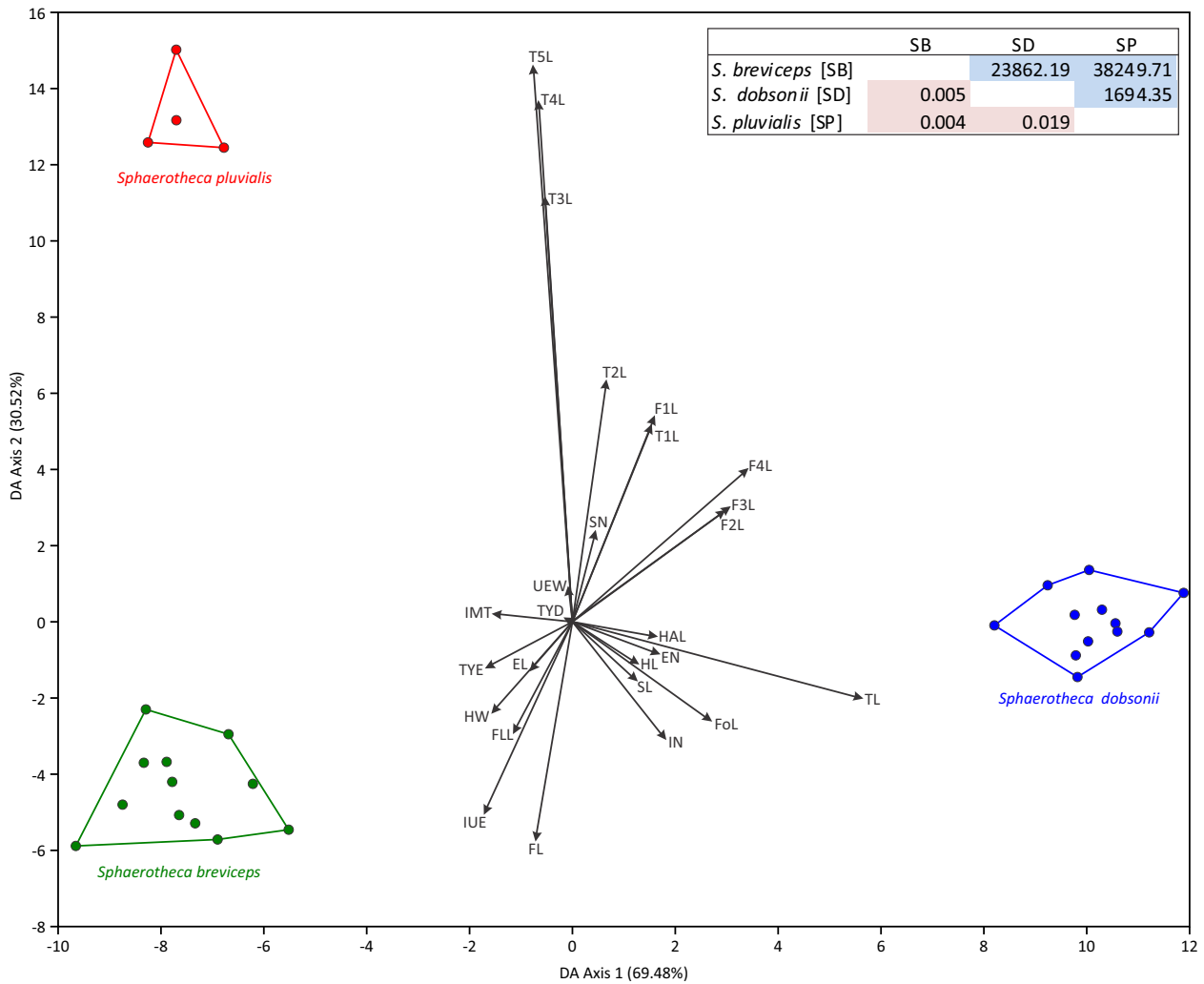


Figure 1. Discriminant analysis biplot of size adjusted morphometric characters. Pairwise Fisher's distances (blue cells) and associated P values (red cells) are provided in the inset in the right hand top corner. Values in parenthesis are percent inertia explained by each discriminant analysis axis.

Table 2. Percent pairwise uncorrected raw distances expressed as minimum–maximum based on 16S rRNA partial gene sequence for *Sphaerotheca* species. Values in square brackets are intra-clade distances. *Sphaerotheca* species comprise of two sequences from Myanmar (AF215417 and DQ283100, see Figure 1).

Species	SB	SD	SP	SS
<i>Sphaerotheca breviceps</i> (SB)	[0.2–2.2]			
<i>Sphaerotheca dobsonii</i> (SD)	7.1–10.9	[0.0–2.0]		
<i>Sphaerotheca pluvialis</i> (SP)	7.9–8.3	5.6–8.0	[0.0]	
<i>Sphaerotheca</i> sp. (SS)	9.1–9.6	8.1–10.5	7.1–7.5	[0.4]

of the species with detailed diagnosis to identify it. Although Dubois (1999; 2000) referred to a manuscript in preparation that will clarify the identity of *S. pluvialis*, such a manuscript has not been published till date. Use of a specimen from Myanmar for genetic analysis

of *S. pluvialis* by Marmayou et al. (2000) is certainly wrong, because of two reasons. First, there was no diagnosis for the species and therefore the identity of the species was not clear, and second, *S. pluvialis* was definitely described from southern India, so a specimen from Myanmar cannot be considered as conspecific with *S. pluvialis* until it is proven that the species is also distributed in southern India. The neotype of *S. pluvialis* described in this study is from Carnatic region and is distinctly different from other valid species (see Species groups and species comparisons section below).

It is essential to note that the type locality of *S. pluvialis* is just south of Madras, the type locality of *Sphaerotheca strigata* described by Günther (1859). We also found a specimen (ZSI 18743) from Madras that is conspecific to *S. pluvialis* neotype. We were not able to examine the types of *S. strigata*; however, the

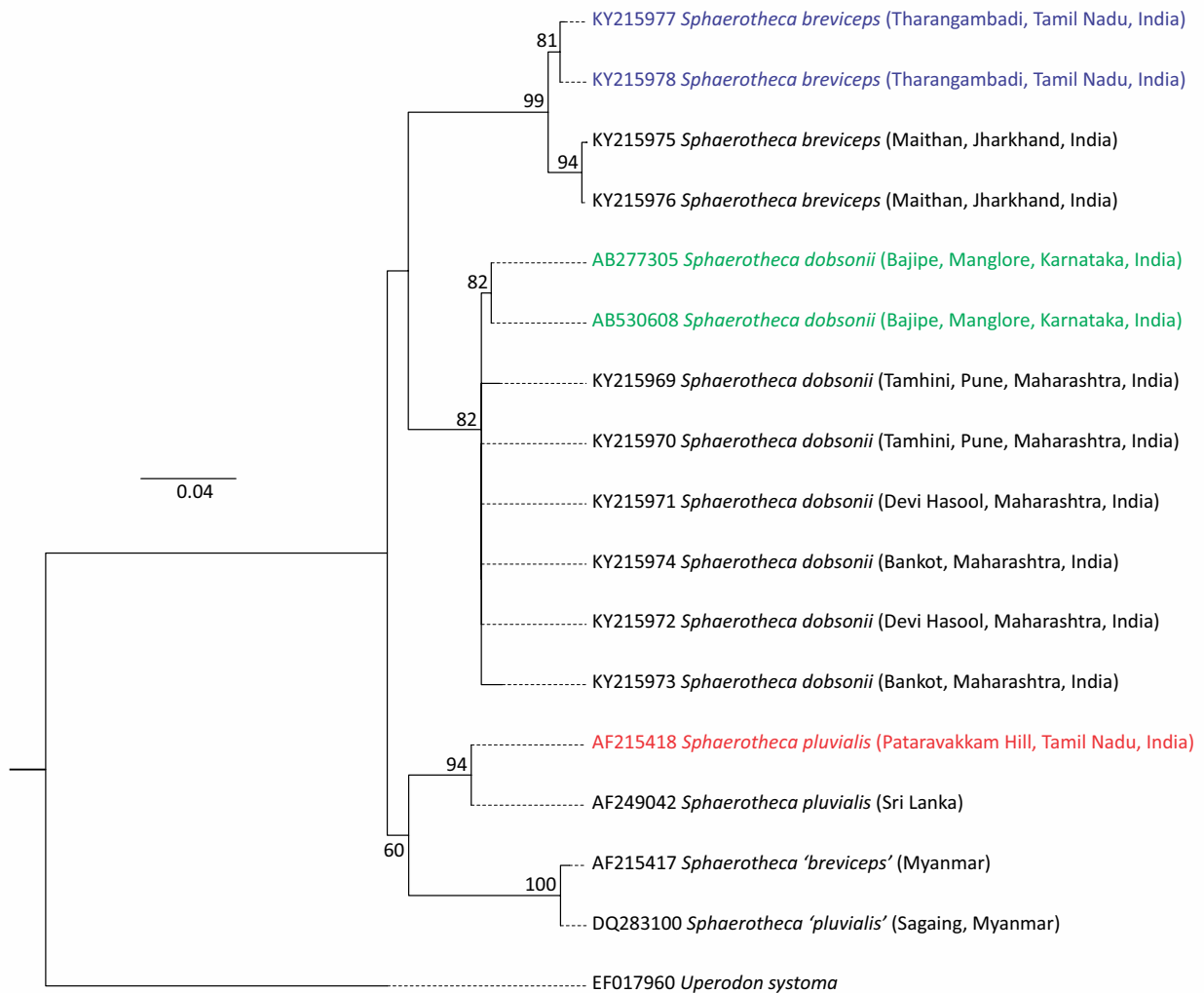


Figure 2. Maximum likelihood analysis of 16S rRNA partial gene sequence. Sequence of *Sphaerotheca pluvialis* neotype is in red. Sequences of topotypic *S. breviceps* are in blue. Sequences of topotypic *S. dobsonii* are in green. Species identifications which are likely to be wrong are in single quotes. *Uperodon systema* is used as an outgroup. Values along the nodes are percent bootstrap for 1000 iterations. Bootstrap values less than 50 are not shown.

original description and morphometry of types provided by Boulenger (1920) clearly indicate that *S. strigata* is conspecific with *S. pluvialis* neotype. We do not use the available name *S. strigata* and prefer to designate the neotype of *S. pluvialis* for following reasons. First, *S. pluvialis* has precedence over *S. strigata*. Second, Günther (1859) mentions that types of *S. strigata* were collected by J.C. Jerdon creating the possibility that they were from the same collection that Jerdon (1853) used for describing *Pyxicephalus fodiens* and *P. pluvialis*. Third, Günther (1864) himself synonymized *Pyxicephalus fodiens*, *P. pluvialis* and *S. strigata* with *S. breviceps*, making all three names available for the species that will be resurrected from *S. breviceps* complex. Thus, we consider *S. strigata* as a junior subjective synonym of *S. pluvialis*, maintaining the synonymy suggested by

Dubois (2000).

Resurrection of *Sphaerotheca maskeyi* (Schleich & Anders, 1998)

Dubois (1999) treated *S. maskeyi* as a synonym of *S. pluvialis* without providing any rationale for the same. We examined the photographs of the holotype of *S. maskeyi*, as well as a specimen from Nepal (ZSI 16127, Image 3) that matches the description of the species and was collected just south of the type locality. On the basis of detailed description of the species provided by Schleich & Anders (1998) and study of the holotype and comparative material we suggest that the species is valid and can be diagnosed as follows.

Sphaerotheca maskeyi can be distinguished from all its congeners based on the combination of following



Image 3. *Sphaerotheca maskeyi* (ZSI 16127, 43.7mm SUL) from Chainpur, Nepal. (a) Dorsal view, (b) lateral view, (c) ventral view, (d) left hand, and (e) left foot.

characters: tympanum about $\frac{1}{2}$ of the eye diameter; interorbital width less than upper eyelid width; snout to nostril distance more than half of eye diameter; nostril nearer to eye than to snout; finger 2 length more than or equal to finger 4 length; finger 1 length more than finger 3 length; tibio tarsal articulation reaching tympanum; outer metatarsal tubercle absent; tibio tarsal tubercle absent; length of inner metatarsal tubercle more than 2 times the inner toe length; and webbing formula $I1-2+II1\frac{1}{2}-3+III2+3\frac{1}{2}IV3\frac{1}{2}-2+V$ (See Species groups and species comparisons section below for species wise comparison).

Resurrection of *Sphaerotheca swani* (Myers & Leviton in Leviton et al., 1956)

Dubois (2000) treated *S. swani* as a synonym of *S. pluvialis* without providing any justification. We

examined the photographs of the holotype of *S. swani* (Image 4). On the basis of detailed description of the species provided by Leviton et al. (1956) and study of the holotype we suggest that the species is valid and can be diagnosed as follows.

Sphaerotheca swani can be distinguished from all its congeners based on the combination of following characters: inter orbital distance about $\frac{3}{4}$ of upper eyelid width; tympanum large, about $\frac{2}{3}$ rd diameter of eye; first finger equal to third; second finger shorter than first and third; fourth finger shortest; tibio tarsal articulation reaching centre of eye; outer metatarsal tubercle absent; tibio tarsal tubercle absent; length of inner metatarsal tubercle slightly more or equal to inner toe length; and webbing formula $I1-2+II1+3+III2+3\frac{1}{2}IV3\frac{1}{2}-2+V$ (See Species groups and species comparisons section below for species wise comparison).

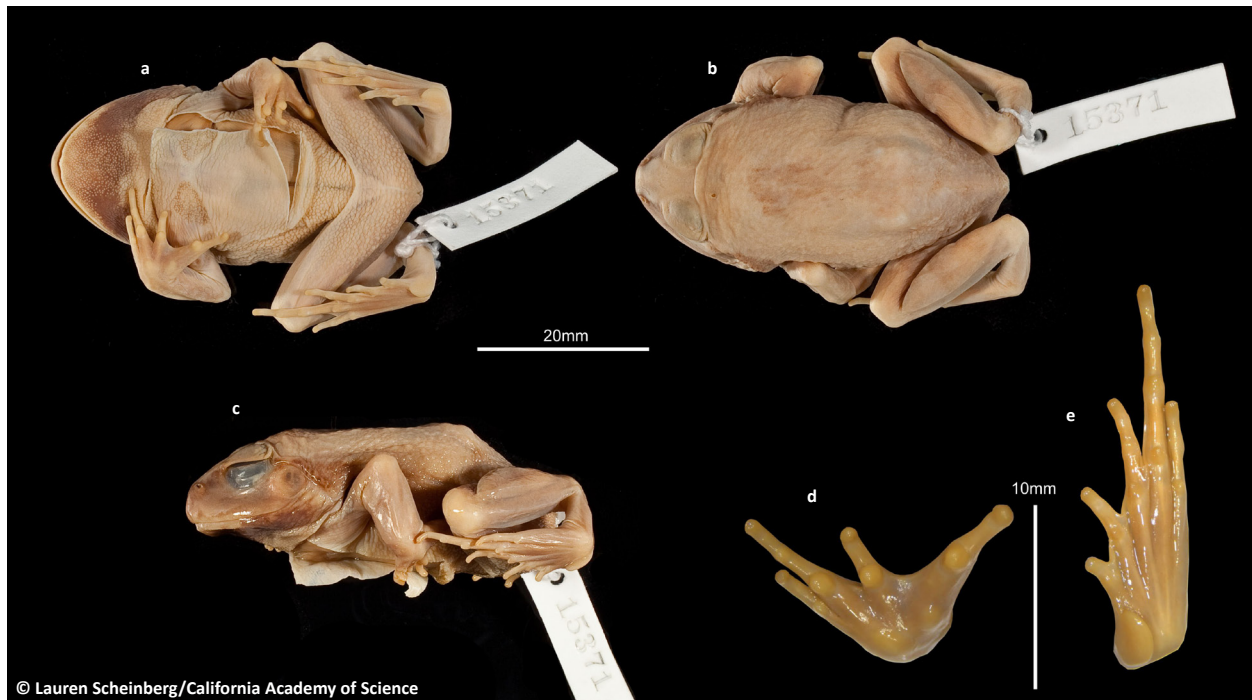


Image 4. *Sphaerotheca swani* Holotype (CAS-SU 15371, 42.3mm SUL) from Dharan, eastern Nepal. (a) Dorsal view, (b) ventral view, (c) lateral view, (d) right hand, and (e) left foot.

Identity of *Sphaerotheca breviceps*

Several species have been considered under the synonymy of *Sphaerotheca breviceps* because of lack of diagnostic characters that separates *S. breviceps* from its congeners. Schneider (1799) does not provide a precise type locality for the species; however, he mentions that the specimens were obtained from eastern India. Because the type locality of *S. pluvialis* is also in eastern coast of southern India, based on the neotype designation, there is a need to clarify the identity of *S. breviceps*. There are two extant syntypes of *S. breviceps*, namely ZMB 3351 and ZMB 55005. For clarifying taxonomy we designate the lectotype from among the syntypes; however, as there is no illustration or special mention of one of the syntypes, we designate the male ZMB 55005 (Image 5) as the lectotype of *S. breviceps* and consider the other specimen ZMB 3351 as the paralectotype. Dubois (1983) suggests that these specimens probably came from Tranquebar (=Tharangambadi), Tamil Nadu, India. We collected several specimens of the species from Tharangambadi and they closely resemble the lectotype based on the diagnostic characters described below. Our specimens from Tharangambadi, therefore, can be considered as putative topotypes of *S. breviceps* and 16S rRNA sequences from these topotypes, namely KY215977 and KY215978, as the genetic barcode for the species.

Sphaerotheca breviceps can be diagnosed from all its congeners based on the combination of following characters: tympanum small, less than $\frac{1}{2}$ of the eye diameter; interorbital width more than or equal to upper eyelid width; snout to nostril distance less than half of eye diameter; nostril nearer to snout than to eye; finger 2 length more than finger 4 length; finger 1 more than finger 2 length but less than finger 3 length; outer metatarsal tubercle absent; tibio tarsal tubercle absent; length of inner metatarsal tubercle more than 2 times the inner toe length; and webbing formula I1-2-II1 $\frac{1}{2}$ -2 $\frac{1}{2}$ III2 $\frac{1}{2}$ -3 $\frac{1}{2}$ IV4-2 $\frac{1}{2}$ V (See Species groups and species comparisons section below for species wise comparison).

We examined a specimen of *S. breviceps* (ZSI 18744) collected from Madras (Image 6). This suggests that both *S. breviceps* and *S. pluvialis* are probably sympatric. We examined two specimens from Jharkhand (BNHS 6006 and WILD-16-AMP-647), which are morphologically similar to *S. breviceps*. Although these specimens formed a distinct clade (Fig. 2), their raw genetic distance from topotypic *S. breviceps* was low (1.8–2.2 %). Therefore, *S. breviceps* is probably widespread along the eastern coast of India.

We tentatively retain *Rana variegata* Gravenhorst, 1829 under the synonymy of *S. breviceps* because we could not trace the type specimens and the figure as

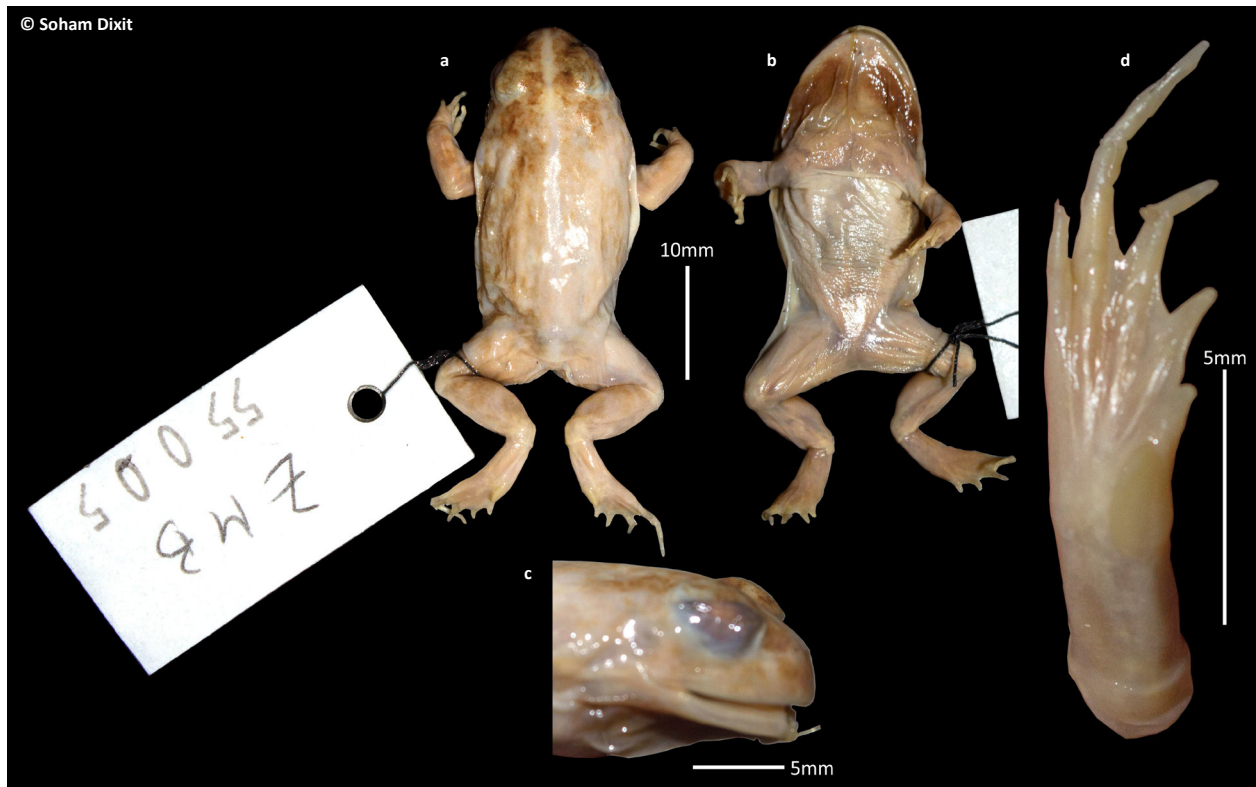


Image 5. *Sphaerotheca breviceps* lectotype (ZMB 55005, 29.9mm SUL). (a) Dorsal view, (b) ventral view, (c) head in lateral view, and (d) right foot.



Image 6. *Sphaerotheca breviceps* (ZSI 18744, 48.3mm SUL) from Madras, India.

well as the description are not enough to diagnose the species. Further, there is no type locality mentioned for *Rana variegata*. Nevertheless, we think that the type of the species could be present in the museum collection of Natural History Museum (UWZM), Wrocław University. This is because, for another species described by Gravenhorst (1829), namely *Rana gracilis*, it was speculated that Gravenhorst did not collect specimens (Biju et al. 2014); however, Padhye et al. (2015) mention a specimen of *R. gracilis* in the collection of UWZM collected by Gravenhorst. We have already stated that specimens misidentified as *S. pluvialis* and *S. breviceps* from Myanmar are not conspecific to either *S. breviceps* or *S. pluvialis*. For these specimens, *Rana variegata* is an available name. It is also essential to note that several of the species described by Gravenhorst (1829) came from Southeast Asia, so a further enquiry into *Sphaerotheca* from Myanmar is essential to resolve the issue with the identity of *Rana variegata* Gravenhorst, 1829.

Identity of *Sphaerotheca dobsonii*

Dubois (1987) considered *Rana dobsonii* Boulenger, 1882 as 'incertae sedis et synonymes' under the genus *Tomopterna* subgenus *Sphaerotheca* without providing any rationale for the same. Similarly, Dubois

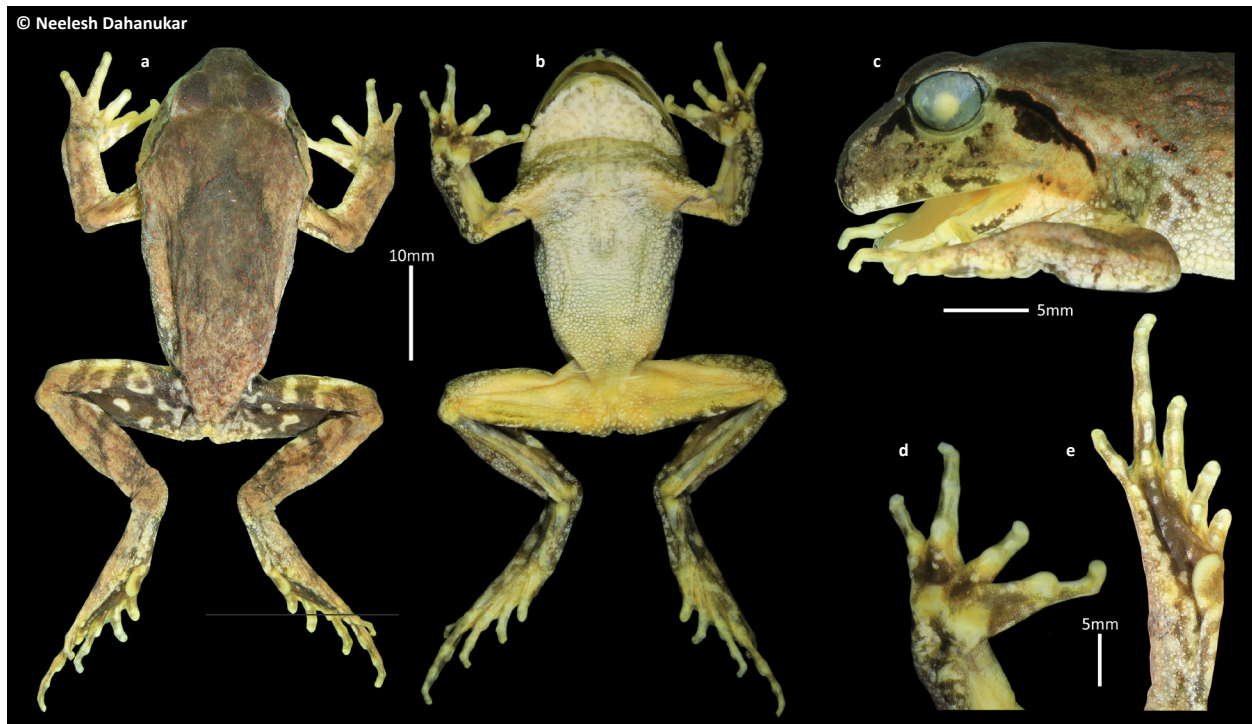


Image 7. *Sphaerotheca dobsonii* (WILD-16-AMP-652, 41.5mm SUL) from Bankot, Maharashtra. (a) dorsal view, (b) ventral view, (c) head in lateral view, (d) right hand, and (e) right foot.

(2000) placed *Rana dobsonii* under the synonymy of *Tomopterna (Sphaerotheca) pluvialis*, a species which he never properly resurrected by providing diagnostic characters to identify it. This makes it important to clarify the identity of *Sphaerotheca dobsonii*. We were not able to examine the holotype of *Sphaerotheca dobsonii*; however, we examined several specimens of the species from wide distributional range in Western Ghats of Maharashtra. Our specimens (for example see Image 7) closely resemble the type description and illustration provided by Boulenger (1882) and morphometry of type specimen provided by Boulenger (1920). Further, Kotaki et al. (2008) and Hasan et al. (2014) provided 16S rRNA gene sequences (AB277305 and AB530608 respectively) for topotypic *Sphaerotheca dobsonii*. These sequences can be considered as genetic barcode for identifying *S. dobsonii*. Our specimens are genetically closer to these sequences further confirming the species identity. Since *S. dobsonii* differs from *S. breviceps* with a raw genetic distance of 7.1–10.9% and from *S. pluvialis* with 5.6–8.0%, it is obvious that *S. dobsonii* is a genetically distinct species. Morphologically, *S. dobsonii* can be diagnosed from its congeners as follows.

Sphaerotheca dobsonii differs from all other congeners based on a combination of characters including: snout equal to or longer than eye diameter; tympanum large,

vertically oval, its horizontal diameter less than or equal to half of the eye diameter; inter-narial width greater than inter orbital distance; first finger length less than third finger length; second finger longer than fourth; outer metatarsal tubercle absent; tibio-tarsal tubercle absent; inner metatarsal tubercle elongated, crescentic, more than 1.5 times but less than or equal to two times in length as compared to length of first toe; tibio tarsal articulation barely reaches eye; heels just touch each other when legs are folded at right angles to the body axis; and webbing formula $I1\frac{1}{2}-2^+II1\frac{1}{2}-3^+III2\frac{1}{2}-4^+IV4^-2^+V$ (See Species groups and species comparisons section below for species wise comparison).

Species groups and species comparisons

Based on morphological comparison of the species under *Sphaerotheca*, we recognize three morphological groups, namely Breviceps group, Dobsonii group and Leucorhynchus group. Diagnostic characters for each group and species comparison within each group are provided below.

Breviceps group: Outer metatarsal tubercle absent and length of inner metatarsal tubercle more than two times the inner toe length. Included species are *Sphaerotheca breviceps* (Schneider, 1799), *S. maskeyi* (Schleich & Anders, 1998) and *S. rolandae* (Dubois,

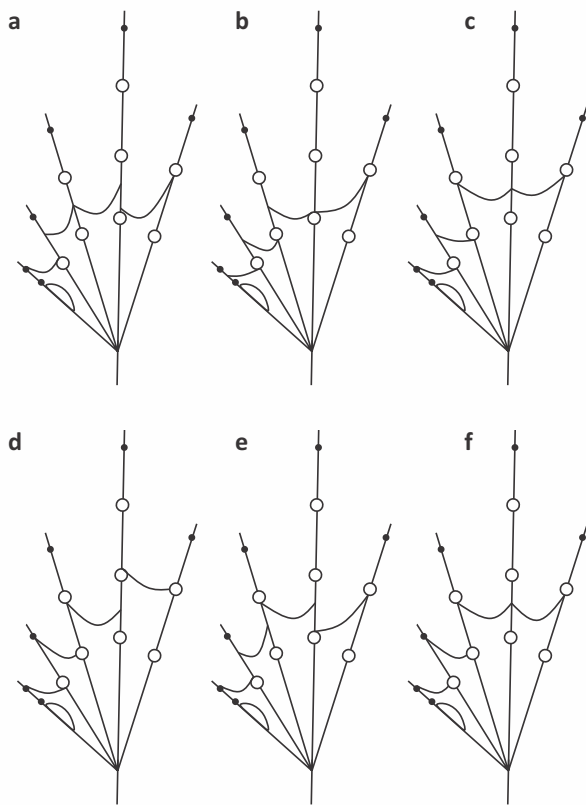


Figure 3. Webbing in (a) *Sphaerotheca breviceps*, (b) *S. dobsonii*, (c) *S. maskeyi*, (d) *S. pluvialis*, (e) *S. swani*, and (f) *S. rolandae*. Solid dots indicate phalangeal articulation without tubercle. Empty circles indicates sub-articular tubercles. Crescentic empty structure on first toe indicate inner metatarsal tubercle.

1983). *Sphaerotheca breviceps* differs from *S. maskeyi* in tympanum length less than half of eye diameter (vs. more than or equal to half), interorbital distance more than or equal to upper eyelid width (vs. less than upper eyelid width), snout to nostril less than half of eye diameter (vs. more than half of eye diameter), nostril closer to snout than to eye (vs. closer to eye than snout) and finger 1 length less than finger three length (vs. more than finger three length). *Sphaerotheca rolandae* differs from both *S. breviceps* and *S. maskeyi* in the presence of tibiotarsal tubercle (vs. absent) (see Image 8). Further, all three species have different webbing extent on foot (Fig. 3).

Dobsonii group: Outer metatarsal tubercle absent and length of inner metatarsal tubercle less than or equal to two times the inner toe length. Included species are *Sphaerotheca dobsonii* (Boulenger, 1882), *S. pluvialis* (Jerdon, 1853) and *S. swani* (Myers & Leviton in Leviton et al., 1956). *Sphaerotheca dobsonii* differs from *S. pluvialis* in tibio tarsal articulation reaching eye (vs. barely reaching tympanum), heels just touch each other when legs are folded at right angles to the body



Image 8. Tibio-tarsal joints of species in *Breviceps* group. Tibio-tarsal tubercle (pointed by arrow) is present in (a) *S. rolandae* (ZSI 17630) and absent in (b) *S. breviceps* (lectotype, ZMB 55005) and (c) *S. maskeyi* (ZSI 16127). © (a & c - Shauri Sulakhe), (b - Soham Dixit).

axis (vs. do not touch); and finger 1 length much lesser than finger 3 length (vs. finger 1 length equal to or slightly lesser than finger 3 length). Further, *S. dobsonii* is genetically distinct from *S. pluvialis* (Fig. 2) with raw genetic distance of 5.6–8.0%. *Sphaerotheca swani* differs from both *S. dobsonii* and *S. pluvialis* in tympanum large about $\frac{3}{4}$ rd of eye diameter (vs. less than or equal to $\frac{1}{2}$), first finger is equal to or longer than third (vs. less than third), inner metatarsal tubercle equal to first toe length (vs. more than 1.5 times first toe length) and tibio tarsal articulation reaching middle of eye (vs. barely reaching tympanum in *S. pluvialis* and reaching eye in *S. dobsonii*). Further, all three species have different webbing extent on foot (Fig. 3).

Leucorhynchus group: Can be diagnosed from *Breviceps* and *Dobsonii* groups by presence of outer metatarsal tubercles. Included species are *Sphaerotheca leucorhynchus* (Rao, 1937) and *S. strachani* (Murray, 1884). *Sphaerotheca leucorhynchus* differs from *S. strachani* in outer metatarsal tubercle small (vs. conspicuous), first finger longer than second (vs. first finger nearly equal to second) and tympanum smaller than eye (vs. as large as eye).

Despite extensive surveys in the type locality of *S. leucorhynchus* in Wattakole, Coorg in Karnataka for three consecutive years (2013–2016), we were unable to record a species of *Sphaerotheca* resembling the description or the figure provided by Rao (1937). Further surveys to locate this species are essential to clarify its identity. Presence of outer metatarsal tubercles makes this species unique from other species of *Sphaerotheca*, except *S. strachani*.

Key to groups

1. Outer metatarsal tubercle present Leucorhynchus group
Outer metatarsal tubercle absent 2
2. Length of inner metatarsal tubercle less than or equal to two times the inner toe length Dobsoni group
Length of inner metatarsal tubercle more than two times the inner toe length Breviceps group

Key to the species of Leucorhynchus group

3. Outer metatarsal tubercle conspicuous, first finger nearly equal to second, tympanum as large as eye
..... *S. strachani*
Outer metatarsal tubercle small, first finger longer than second, tympanum smaller than eye *S. leucorhynchus*

Key to Dobsoni group

4. Length of inner metatarsal tubercle less than 1.5 times inner toe length, tympanum large about $\frac{3}{4}$ rd of eye diameter *S. swani*
Length of inner metatarsal tubercle more than 1.5 times the inner toe length, tympanum about $\frac{1}{2}$ of eye diameter ... 5
5. First finger much smaller than third finger, tibiotarsal articulation reach eye *S. dobsonii*
First finger almost equal to third finger, tibiotarsal articulation barely reach tympanum *S. pluvialis*

Key to Breviceps group

6. Tibio tarsal tubercle present *S. rolandae*
Tibio tarsal tubercle absent 7
7. First finger longer than third finger, interorbital distance less than upper eyelid width, nostril closer to eye than to snout *S. maskeyi*
First finger shorter than third finger, interorbital distance more than or equal to upper eyelid width, nostril closer to snout than to eye *S. breviceps*

Key to groups and species of the genus *Sphaerotheca*

Based on the comparative account provided above, a key to the groups and valid species of *Sphaerotheca* is provided.

CONCLUSIONS

We designate, diagnose and describe the neotype of *Sphaerotheca pluvialis* from Carnatic region, which is a type locality mentioned in the original description of the species. We resurrect *S. maskeyi* and *S. swani* with characters to diagnose the species. We clarify the identity of *S. breviceps* by designating a lectotype, and of *S. dobsonii*, and provide diagnosis for the two species. Based on our study we suggest that genus *Sphaerotheca* has three species groups with eight valid species, viz., Breviceps group: *S. breviceps* (Schneider, 1799), *S. maskeyi* (Schleich & Anders, 1998), and *S. rolandae* (Dubois, 1983); Dobsoni group: *S. dobsonii* (Boulenger, 1882), *S. pluvialis* (Jerdon, 1853), and *S. swani* (Myers & Leviton in Leviton et al., 1956); and Leucorhynchus group: *S. leucorhynchus* (Rao, 1937), and *S. strachani* (Murray, 1884). We consider *Sphaerotheca strigata* Günther, 1859 as a junior subjective synonym of *S. pluvialis* and *Rana variegata* Gravenhorst, 1829 as a junior subjective synonym of *S. breviceps*. We provide genetic delimitation of three species, namely *S. breviceps*, *S. dobsonii* and *S. pluvialis*, based on topotypes and type specimen.

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Author Details: NEELESH DAHANUKAR works in ecology and evolution with an emphasis on mathematical and statistical analysis. He is also interested in taxonomy, distribution patterns and molecular phylogeny of fish and frogs. SHAURI SULAKHE is a Founder Trustee of Institute of Natural History Education and Research (INHER), Pune. He is interested in wildlife photography and natural history. ANAND PADHYE is an Associate Professor working on systematics, ecology, diversity, distribution and evolution of amphibians. He is also Founder Trustee of Institute of Natural History Education and Research (INHER), Pune.

Author Contribution: ND and AP designed the study; ND and AP diagnosed the species; SS and AP collected specimens; AP and SS studied museum specimens and collected morphometric data; ND collected genetic data; ND performed genetic and morphometric analysis; ND and AP wrote the manuscript.





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