

A new species of *Fejervarya* Bolkay, 1915 from the lateritic plateaus of the Goa parts of the Western Ghats

K. P. Dinesh^{1,3*}, Nirmal U. Kulkarni², Priyanka Swamy³ and P. Deepak⁴

¹Zoological Survey of India (ZSI), Western Regional Centre (WRC), Pune – 411044, Maharashtra, India; kpdinesh.zsi@gmail.com

²Mhadei Research Centre, C/o Hiru Naik Building, Dhuler Mapusa – 403507, Goa, India

³Centre for Ecological Sciences (CES), Indian Institute of Science, Bangalore – 560012, Karnataka, India

⁴Mount Carmel College, Autonomous; No. 58, Palace Road, Vasanth Nagar, Bengaluru – 560052, Karnataka, India

Abstract

Based on a combination of field explorations, morphological characters and molecular studies, a large sized *Fejervarya* species new to science is described using an integrated taxonomic approach. Here, the new species is diagnosed on the basis of distinctness in morphology, genetic distance and geography. The new species is assignable to the *Fejervarya nilagirica* morphological group. In addition, taxonomic problems among the congeners of *Fejervarya* in the Western Ghats are discussed. Finally, we describe the pattern of species representations of different morphological group in the Goa landscape.

Keywords: *Fejervarya*, Goa, Goemchi, Lateritic, New Species, Plateau, Taxonomy, Western Ghats

Introduction

The anuran family Dicroglossidae Anderson, 1871 is represented by 201 species globally (Frost, 2017) and in India by 67 species within 11 genera (Dinesh *et al.*, 2017). In the Western Ghats, this family is represented by 31 species belonging to 4 genera *Euphlyctis* Fitzinger, 1843 (4 species); *Hoplobatrachus* Peters, 1863 (2 species); *Fejervarya* Bolkay, 1915 (20 species) and *Sphaerotherca* Günther, 1859 (5 species) (Dinesh *et al.*, 2017). Generic level ambiguity within this family for the genus *Fejervarya* / *Minervarya* / *Zakerana* has been addressed by Dinesh *et al.*, 2015 showing overlapping distribution range among the members of these 'clades' and the absence of distinct morphological characters to recognize the above said three genera.

Garg and Biju (2017), while describing four new species of *Fejervarya* from the Western Ghats have recognized four morphological groups (see discussion below). However, there still remain many taxonomic ambiguities regarding the identities of the taxon *Fejervarya brevipalmata*,

Fejervarya modesta, *Fejervarya murthii*, *Fejervarya mysorensis*, *Fejervarya parambikulamana* and *Fejervarya sauriceps* where most of these species are known from original descriptions or from type localities only. Of the rest which have clear taxon identity, *Fejervarya caperata*, *Fejervarya cepfi*, *Fejervarya granosa*, *Fejervarya kadar*, *Fejervarya kudremukhensis*, *Fejervarya manoharani*, *Fejervarya mudduraja* and *Fejervarya neilcoxi* lack comprehensive distribution range data. The species *Fejervarya gomantaki*, *Fejervarya keralensis*, *Fejervarya nilagirica*, *Fejervarya rufescens*, *Fejervarya sahyadris* and *Fejervarya syhadrensis* have a broad distribution range (Dinesh *et al.*, 2015; Garg and Biju, 2017; Frost, 2017).

Overall, the taxonomy of this genus in the Western Ghats is not fully resolved, species distribution range data are scanty and morphological character crypticity results in underestimation of species richness. Systematic comprehensive field sampling combined with genetic studies could uncover the species richness of this genus in the Western Ghats resolving the problems associated with the taxonomy and distribution.

* Author for correspondence

During our explorations in the Western Ghats, we encountered several individuals which are assignable to the genus *Fejervarya* based on the diagnosable generic morphological characters assigned by Bolkay, 1915 for the genus (Dinesh *et al.*, 2015). Phylogenetic analysis confirmed our generic allocation and comparisons with available extant taxa reveals that it shares a sister relationship with *F. kudremukhensis*. It is diagnosable, along multiple axes, as a new species, which we describe here as *Fejervarya goemchi* sp. nov.

Material and Methods

As a part of our anuran explorations in the Western Ghats, field sampling was carried out in the foothills and hill ranges of the Western Ghats of Goa and adjoining states of Karnataka and Maharashtra since the year 2010 to 2016. Adult male individuals were collected and photographed in controlled conditions, following which they were euthanized in MS222.

Genetic analysis including DNA extraction, PCR amplification and sequencing followed as methods described in Dinesh *et al.*, 2015. Mitochondrial 16S rRNA was used for the genetic studies, for phylogenetic reconstruction we used the sequences from Dinesh *et al.*, 2015, Dahanukar *et al.*, 2017 and Garg and Biju, 2017 with our sequences for the undescribed species of *Fejervarya* (See Appendix I). *Occidozyga* species were used as out groups with the species of fejervaryan frogs from South and South east Asia (Dinesh *et al.*, 2015). RaxML (Silvestro and Michalak, 2012) was used to generate a Maximum Likelihood (ML) tree with data partitioned by gene under GTR+GAMMA+I model by running 1000 thorough bootstraps.

For morphological measurements, SVL was measured using Mitutoyo vernier caliper (to the nearest 0.1 mm). Natural history and habitat details were collected from multiple field visits.

For multivariate Principal Components Analysis (PCA), a total of 14 morphometric characters (marked with an asterisk in Table 1) were transformed to their ratio to SVL and taken into consideration for the new species; measurements for *F. gomantaki* were taken from Dinesh *et al.*, 2015; *F. cepfi* from Garg and Biju, 2017; *F. syhadrensis* and *F. kudremukhensis* from our field collections. PAST version 3.16c was used for PCA analysis (Hammer *et al.*, 2001).

For lineage diagnosis we used multiple criteria including phylogeny, genetic distance, geographical isolation and morphological separation following Vijayakumar *et al.*, (2014).

Abbreviations

AG- Axilla to Groin distance; EL- Eye Length, i.e. the horizontal distance between the bony orbital borders of the eye; FL1- First Finger Length (tip of finger to proximal palmar tubercle); FL2- Second Finger Length (tip of finger to proximal palmar tubercle); FLL- Forelimb Length, measured from the elbow to the base of the outer palmar tubercle; FOL- Foot Length, measured from the base of the inner metatarsal tubercle to the tip of the fourth toe; FTL- Fourth Toe Length, measured from base of proximal sub articular tubercle to toe tip; HAL- Hand Length, measured from the base of the outer palmar tubercle to the tip of the third finger; HL- Head Length, from the rear of the mandible to the tip of the snout; HW- Head Width, at the angle of the jaws; IBE- distance between posterior corner of eyes; IFE- distance between anterior corner of eyes; IMT- length of Inner Metatarsal Tubercle; IN- Internarial Distance; ITL- Inner Toe Length; IUE- Inter Upper Eyelid Width, i.e., the shortest distance between the upper eyelids; MBE- distance from the rear of the mandible to the posterior most orbital border; MFE- distance from the rear of the mandible to the anterior most orbital border; MN- distance from the rear of the mandible to the centre of the nostril; NE- Nostril to Eye distance; NS- Nostril to Snout tip distance; ShL/FL- Thigh Length; SL- Snout Length, measured from the tip of the snout to the anterior most orbital border; SVL- Snout to Vent Length; Tal- Tarsus Length; TE- Tympanum to posterior corner of Eye distance; TFL- Third Finger Length (tip of finger to proximal palmar tubercle); TiL- Tibia Length; TYD- tympanum diameter; UEW- maximum Upper Eyelid Width; WBS- body Width Behind Shoulders; WFG- body Width in Front of Groin. CESF- Centre for Ecological Sciences, Frogs; ZSI/WRC/A- Zoological Survey of India, Western Regional Centre, Pune.

Results

Generic allocation

The new species is assignable to the genus *Fejervarya* Bolkay, 1915 based on the morphological characters and phylogenetic position within the '*Fejervarya* clade' (Dinesh *et al.*, 2015).

Table 1. Morphometric data (in mm) for the type series of *Fejervarya goemchi* sp. nov. Prefix ZSI/WRC/A for holotype and paratypes and CESF for other referred specimens

Reg. No	ZSI/WRC/ A/2015 (CESF 2888) [#] Holotype	ZSI/WRC/ A/2016 (CESF 2890) [§] Paratype	ZSI/WRC/ A/2017 (CESF 2847) [§] Paratype	2887 ^{&}	2889 ^{&}	2891 ^{&}	2886 ^{&}	Average ± SD (Range)
Sex	Male	Male	Male	Male	Male	Male	Male	
SVL	46.8	45.7	41.4	45.3	43.8	42.5	42.0	43.9 ± 2.06 (41.4 - 46.8)
HW*	16.0	15.2	13.3	15.1	14.5	14.1	13.9	14.6 ± 0.91 (13.3 - 16.0)
HL*	15.5	14.9	13.0	14.5	14.2	13.8	13.2	14.2 ± 0.90 (13.0 - 15.5)
IN*	5.6	5.1	4.0	4.9	4.6	4.3	4.1	4.7 ± 0.58 (4.0 - 5.6)
NE*	4.0	3.8	3.2	3.6	3.6	3.4	3.2	3.5 ± 0.30 (3.2 - 4.0)
MN	11.9	11.1	10.2	11.0	10.8	10.6	10.5	10.9 ± 0.55 (10.2 - 11.9)
MFE	9.9	9.1	7.5	8.9	8.4	7.9	7.6	8.5 ± 0.88 (7.5 - 9.9)
MBE	5.9	5.2	4.4	5.1	4.9	4.8	4.7	5.0 ± 0.48 (4.4 - 5.9)
SL*	7.1	7.1	6.8	7.0	6.9	6.7	6.7	6.9 ± 0.17 (6.7 - 7.1)
EL*	6.2	6.0	5.2	5.9	5.6	5.4	5.3	5.7 ± 0.38 (5.2 - 6.2)
IUE*	3.9	3.6	2.4	3.2	3.1	2.9	2.8	3.1 ± 0.50 (2.4 - 3.9)
UEW	4.2	3.8	3.0	3.6	3.5	3.3	3.1	3.5 ± 0.42 (3.0 - 4.2)
IFE	7.5	7.3	6.1	7.1	6.7	6.5	6.6	6.8 ± 0.49 (6.1 - 7.5)
IBE	11.6	10.9	9.2	10.6	10.4	10.2	10.1	10.4 ± 0.74 (9.2 - 11.6)
TYD*	3.0	3.0	2.7	2.7	2.6	2.7	2.9	2.8 ± 0.16 (2.7 - 3.0)
TE	4.2	3.8	2.5	3.5	2.8	2.5	2.4	3.1 ± 0.73 (2.4 - 4.2)
FLL*	11.2	10.8	8.8	10.2	9.8	9.4	9.0	9.9 ± 0.90 (8.8 - 11.2)
HAL*	10.6	10.2	8.8	10.4	9.5	9.2	9.4	9.7 ± 0.68 (8.8 - 10.6)
FL1	5.9	5.2	4.2	5.1	5.0	4.8	4.9	5.0 ± 0.51 (4.2 - 5.9)
FL2	5.0	5.0	4.0	4.9	4.9	4.6	4.7	4.7 ± 0.35 (4.0 - 5.0)
TFL	6.6	6.2	4.8	5.0	5.2	5.0	5.0	5.4 ± 0.70 (4.8 - 6.6)
AGL*	19.9	19.4	16.4	18.0	17.8	17.0	15.9	17.8 ± 1.48 (16.4 - 19.9)
WBS	18.0	17.4	14.6	17.0	16.5	16.0	15.7	16.5 ± 1.14 (14.6 - 18.0)
WFG	9.4	9.0	7.6	8.8	8.0	8.5	8.0	8.5 ± 0.64 (7.6 - 9.4)
ShL/FL*	21.5	20.2	18.7	20.3	20.9	19.5	20.0	20.2 ± 0.91 (18.7 - 21.5)
TiL*	23.1	19.4	17.6	18.2	18.6	17.3	19.2	19.1 ± 1.94 (17.6 - 23.1)
Tal	12.3	11.7	11.0	11.4	10.9	11.0	11.2	11.4 ± 0.50 (10.9 - 12.3)
FOL*	24.2	23.2	21.8	24.1	21.4	22.9	23.0	22.9 ± 1.05 (21.4 - 24.2)
FTL	14.5	14.6	13.4	14.2	13.9	13.6	13.4	13.9 ± 0.50 (13.4 - 14.5)
ITL	3.5	3.2	3.0	3.6	3.2	3.0	2.9	3.2 ± 0.26 (2.9 - 3.5)
IMT	3.2	3.0	2.6	2.8	2.8	2.6	2.8	2.8 ± 0.21 (2.6 - 3.2)

*data used for PCA analysis; # holotype; § paratypes; & other referred specimens.

Species Description

Fejervarya goemchi sp. nov.

(Table 1,2,3; Figure 1,2,3,5,6)

Holotype: ZSI/WRC/A/2015 (CESF 2888), an adult male (SVL 46.8 mm) collected by K.P. Dinesh and Nirmal U. Kulkarni in August 2016 from Surla village (N 15.651; E 74.131, 700 amsl), Goa.

Paratypes: ZSI/WRC/A/2017 (CESF 2847) an adult male (SVL 41.4 mm) collected by K.P. Dinesh and Nirmal U. Kulkarni in July 2014 from Surla village (N 15.651; E 74.131, 700 amsl), Goa; ZSI/WRC/A/2016 (CESF 2890),

an adult male (SVL 45.7 mm) collected by K.P. Dinesh and Nirmal U. Kulkarni in August 2016 from Surla village (N 15.651; E 74.131, 700 amsl), Goa.

Lineage Diagnosis

Fejervarya goemchi sp. nov. can be diagnosed phylogenetically as a member of the fejervaryan clade (Figure 1), showing a sister relationship to *F. kudremukhensis* exhibiting high genetic divergence of 4.2 % for 16S rRNA. It is also very distinct from its sister species (*F. kudremukhensis*) in morphology (Figure 4). It can be distinguished from *F. kudremukhensis* in having larger adult male size of SVL 41.4 mm to 46.8 mm, n = 7 (vs. medium to large adult male size

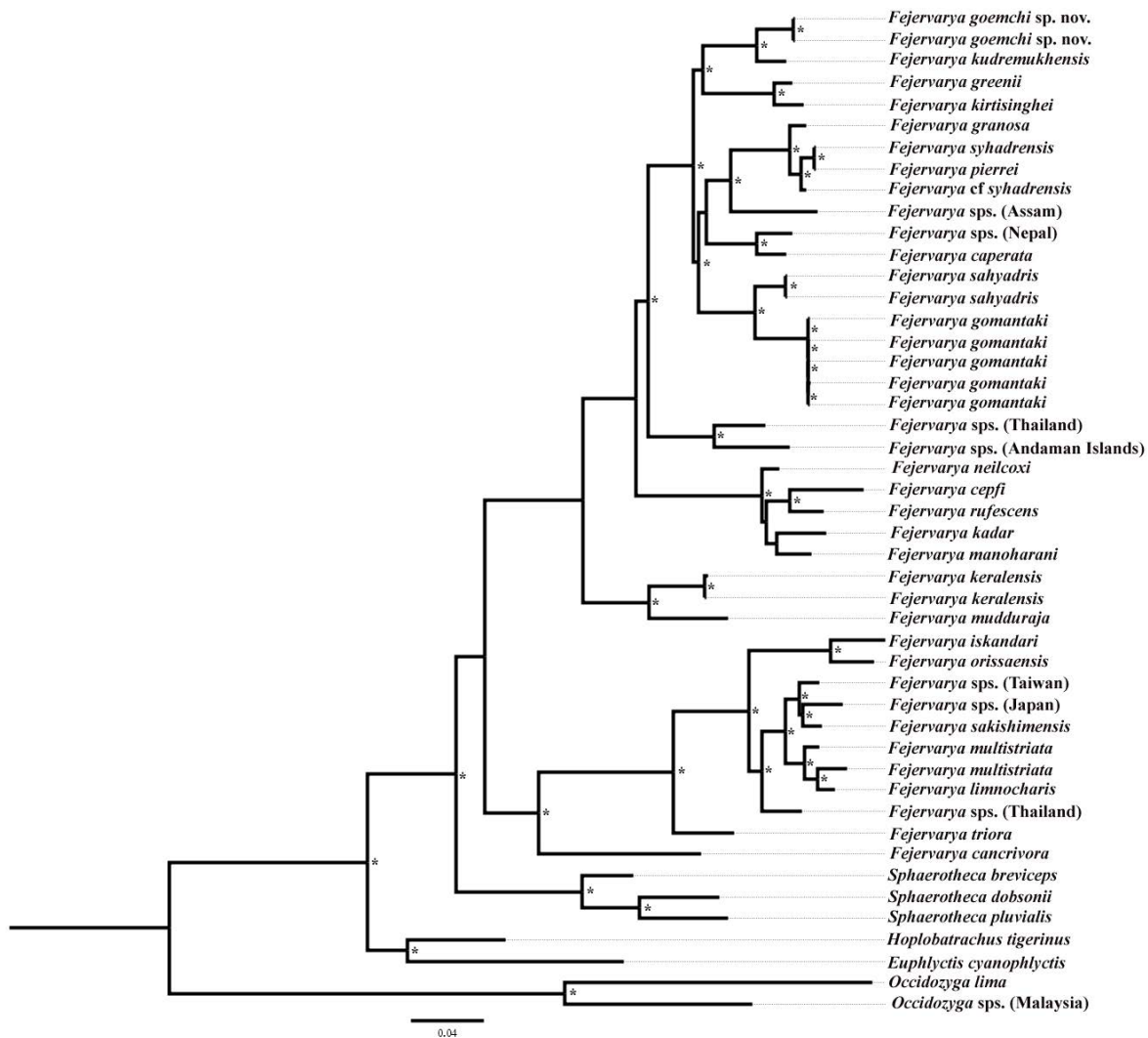


Figure 1. Maximum Likelihood tree for 40 dicoglossid taxa based on 5430 bp of mitochondrial (16S and 12S) and nuclear genes (BDNF, Rhod, Tyr, RAG-2, NCX1, and CXCR4) (*represents the bootstrap values above 50%).

34.8 mm to 41.1 mm, $n = 6$ in *F. kudremukhensis*); higher HAL/SVL ratio of 0.213 to 0.230, $n=7$ (vs. lower HAL/SVL ratio of 0.141 to 0.164, $n = 6$ in *F. kudremukhensis*); lower AGL/SVL ratio of 0.379 to 0.425, $n = 7$ (vs. higher AGL/SVL ratio of 0.440 to 0.483, $n = 6$ in *F. kudremukhensis*); lower TiL/SVL ratio of 0.402 to 0.494, $n = 7$ (vs. higher TiL/SVL ratio of 0.523 to 0.587, $n = 6$ in *F. kudremukhensis*); snout pointed (vs. snout moderately pointed in *F. kudremukhensis*); nostril near to snout tip (vs. nostril equidistant from eye and snout tip in *F. kudremukhensis*); webbing medium (I 1-2 II 2-3 III 2-2 IV 2-2 V) (vs. webbing short (I 2-2 II 2-3 III 2½-3½ IV 3½-2 V) in *F. kudremukhensis*). The species also shows geographical separation from its sister *F. kudremukhensis* (see field diagnosis).

Field diagnosis

Morphology: In the field, *Fejervarya goemchi* sp. nov. does not have any morphologically confusing congeneric sympatric species, and can be identified based on the combination of morphological characters including large adult size (SVL = 41.4 to 46.8 mm, $n = 7$); elongated robust body; head length equal to head width; pointed snout; inter orbital space equal to upper lid; fore arm length equal to hand length; first finger longer than the second; tibio-tarsal articulation reaching the front of eyes; femur length equal to tibia length; medium webbing (I 1-2 II 2-3 III 2-2 IV 2-2 V); large elongated shovel shaped inner metatarsal tubercle; glandular dorsum; throat and belly smooth and, upper and lower lip barred with the presence of rictal glands. For comparing the new species *Fejervarya goemchi* sp. nov. with its sympatric congener *F. cepfi* and other potential sympatric species *F. gomantaki* and *F. syhadrensis*, see comparisons presented below.

Geography: This species is restricted in distribution to medium elevated lateritic plateaus (700 m and above) with a small range around the Goa region in the northern Western Ghats. It is geographically disjunct (southern range limit 15.66 degrees North) from its phylogenetic sister species, *F. kudremukhensis*, whose known northern range limit is around 13.13 degrees North. Additional sampling is required to establish the range limits of both the sister lineages and to understand the geographical barrier for isolation of the sister species.

Description of Holotype ZSI/WRC/A/2015 (CESF 2888) (Figure 2, 3)

A large sized fejervaryan frog (SVL = 46.8 mm) with elongated robust body; head length sub equal to head width (HL = 15.5 mm; HW = 16.0 mm); snout pointed (SL = 7.1 mm) in both dorsal and ventral view and sub equal to eye diameter (EL = 6.2 mm); canthus rostralis blunt, loreal region concave, inter orbital space flat (IUE = 3.9 mm) sub equal to upper lid (UEW = 4.2 mm) and less than internarial distance (IN = 5.6 mm); distance between back of eyes 1.5 times more than front of eyes (IFE = 7.5 mm; IBE = 11.6 mm); nostrils oval, nearer to tip of snout; symphyial knob moderate, 'W' shaped; tympanum distinct visible below the supratympanic fold (TYD = 3.0 mm); vomerine ridges present with 6 to 8 spinose teeth; tongue bifid without a papilla.



Figure 2. *Fejervarya goemchi* sp. nov. in life.

Fore arm slender and short (FLL = 11.2 mm) sub equal to hand (HAL = 10.6 mm); fingers short and thin without any dermal fringes; first finger longer than the second (FL1=5.9 mm, FL2 = 5.0 mm, TFL = 6.6 mm), tips blunt, rounded without any enlarged discs, webbing between fingers absent; subarticular tubercles distinct (one each on finger 1 and 2, and two each on finger 3 and 4), rounded and pre-pollex tubercle distinct (two on either side), supernumerary tubercles absent.

Hind limbs long, overlap when folded at right angles to the body and tibio-tarsal articulation reaches front of eyes; femur length sub equal to tibia length (FL = 21.5 mm; TiL = 23.1 mm); foot length is 1.9 times tarsus length (FOL = 24.2 mm, TAL = 12.3 mm), relative toe length I<II<V<III<IV (FTL = 14.5 mm); webbing medium (I 1-2 II 2-3 III 2-2 IV 2-2 V); inner metatarsal tubercle (IMTL = 3.2 mm) large elongated and shovel shaped; outer



Figure 3. Holotype of *Fejervarya goemchi* sp. nov. (a) dorsal view. (b) ventral view.

metatarsal tubercle minute, bulbous; supernumerary tubercles absent and tarsal tubercle minute.

Overall skin on the dorsum glandular with small ridges, more glandular in front of the shoulders, flanks and belly smooth; ventrally smooth on throat and belly. Rictal gland present at the mouth commissural region below the tympanum. Irregular raised short glandular ridges on the back of the dorsum above the shoulders, no specific pattern.

In life, colour on the dorsum reddish brown, mottled blackish patch from the back of the tympanum till the groin covering the sides of belly, bright cream orange stripe between the dorsal reddish brown and lateral mottled blackish patch. Region between the eyes and tympanum, half of the tympanum and the region of rectal gland with bright cream orange patch. Light orange dorsolateral stripe from tip of snout to back of vent on the dorsal surface. Upper lip, lower lip, fore arm and hind limbs barred. Back of thighs reticulated with brown and creamish orange. Ventral region creamish white fejevryan lines on either side of the body, region of throat with blackish vocal sacks in males.

In preservative, colour on the dorsum blackish brown, mottled pattern from the back of the tympanum till the groin covering the sides of belly. Region between the eyes and tympanum, half of the tympanum and the region of rectal gland with cream white patch. Cream white dorsolateral stripe from tip of snout to back of

vent on the dorsal surface. Upper lip, lower lip, fore arm and hind limbs barred. Back of thighs reticulated with brown and creamish white. Ventral region creamish white, region of throat with blackish vocal sacks in males (Figure 3, 6).

Secondary Sexual Characters

Adult males have a bilobate external vocal sac at the region of throat which is blackish in colour, faint nuptial pad is present on the first finger.

Additional Information from Paratypes and Variations

Morphological data are given in Table 1. Paratypes SVL range from 41.4 mm to 45.7 mm; in all the external morphological characters they are similar to holotype and reference collections (Figure 6). All the 16S rRNA sequences generated for ZSI/WRC/A/2017 (CESF 2847) (paratype) and CESF 2843 (reference collection) are homogenous.

Etymology

The specific epithet is derived from the Konkani (an Indo-Aryan language) term ‘Goemchi ‘ meaning the state Goa’s Land. Suggested common name: ‘Goan large fejervarya’.

Distribution and Natural History

Fejervarya goemchi sp. nov. is known from the lateritic plateau and the surrounding grassland paddy field complex of the Surla village, Goa in the Western Ghats. We found this species to be locally abundant (during June, July and August) and to occur in sympatry with *F. cepfi*. Breeding calls were observed in male individuals surrounding the stagnant mud pools on the lateritic plateaus during the month of June and July (peak south west monsoon period).

Comparisons

In this section, we provide morphological comparisons with its sympatric species *F. cepfi*, other potential sympatric species including *F. gomantaki* and *F. syhadrensis* (Figure 4).

PCA analysis comparing this species with its phylogenetic sister and above sympatric species suggest a substantial morphological separation between *Fejervarya goemchi* sp. nov. and others (*F. gomantaki*, *F. cepfi*, *F. syhadrensis* and *F. kudremukhensis*) (Figure 5). PC1 accounted for 34.59% variance and PC2 accounted for 22.74% variance (Table 2).

Fejervarya goemchi sp. nov. can be distinguished from its sympatric species *F. cepfi* in having larger adult male size of SVL 41.4 mm to 46.8 mm, $n = 7$ (vs. relatively medium adult male size of SVL 29.9 mm to 33.1 mm, $n = 2$ in *F. cepfi*); lower HW/SVL ratio of 0.321 to 0.342, $n = 7$ (vs. higher HW/SVL ratio of 0.369 to 0.375, $n = 2$ in *F. cepfi*); lower HL/SVL ratio of 0.314 to 0.331, $n = 7$ (vs. higher HL/SVL ratio of 0.371 to 0.375, $n = 2$ in *F. cepfi*); lower

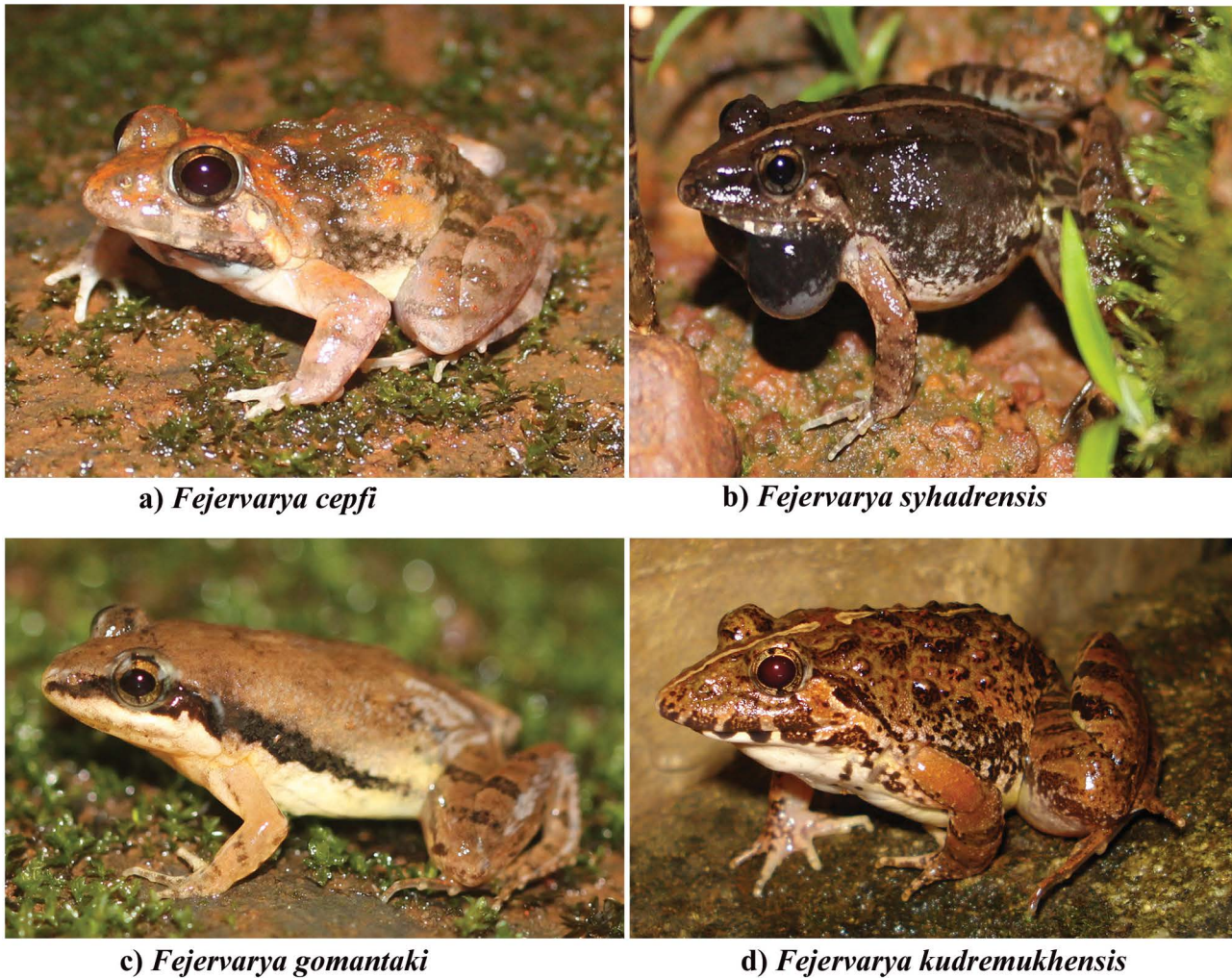


Figure 4. (a) Sympatric; (b) & (c) probable sympatric species and (d) phylogenetic sister species of *Fejervarya goemchi* sp. nov.

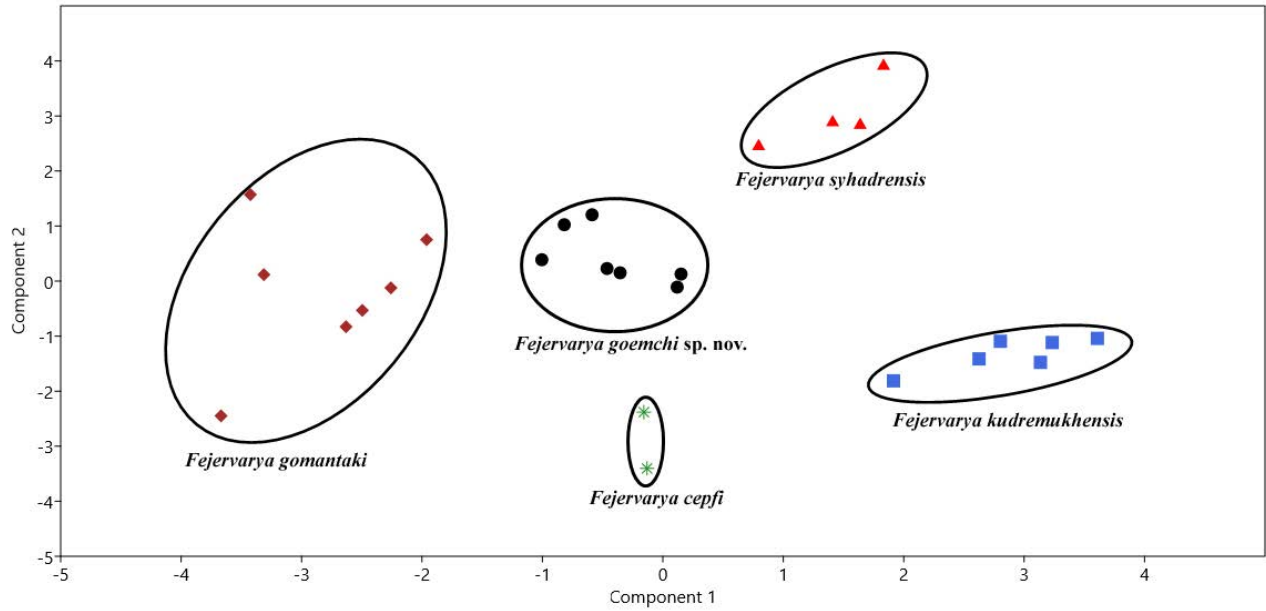


Figure 5. Multivariate Principal Component Analysis for male individuals of 14 morphometric characters marked as * in Table 1 transformed to their ratio to SVL for *Fejervarya goemchi* sp. nov., *F. kudremukhensis*, *F. cepfi*, *F. gomantaki* and *F. syhadrensis*.

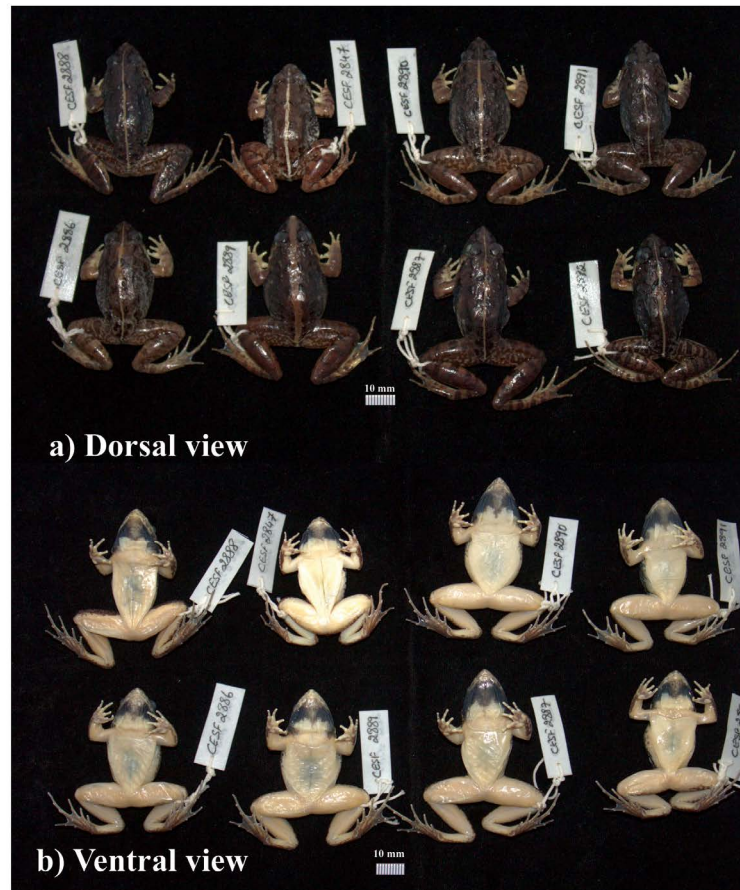


Figure 6. (a) Dorsal and (b) Ventral view of type series and reference collections.

Table 2. Factor loadings of Principal Component Analysis for male individuals for a total of 14 morphometric characters marked as * in Table 1 transformed to their ratio to SVL

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
HW	-0.3147	0.0597	0.4727	0.1236	0.0307	-0.1090	0.1657	-0.1116	-0.0855	0.2146	-0.1030	-0.3296	0.1663	0.6370
HL	-0.1504	-0.0748	0.5988	-0.2481	0.2423	-0.0183	-0.0131	0.2468	0.2324	0.0053	-0.4338	0.2725	-0.1883	-0.2822
IN	-0.1934	0.3072	-0.1403	-0.2376	-0.2360	0.6522	0.3298	-0.0060	0.3040	0.2770	-0.0978	-0.0830	0.1038	-0.0764
NE	0.1130	0.5105	-0.0052	-0.0693	-0.0914	-0.0575	0.1873	0.2781	0.1096	-0.5491	0.0421	0.2772	-0.1792	0.4165
SL	0.2492	0.2089	-0.0688	-0.4240	0.6108	-0.1905	0.0297	-0.0072	0.2782	0.0431	0.2093	-0.2958	0.2981	-0.0084
EL	0.1364	0.3786	0.1325	-0.3794	-0.3675	-0.3485	-0.1950	-0.2034	-0.1502	0.4776	0.1323	0.2303	-0.1372	-0.0244
IUE	-0.3284	0.1364	0.4040	0.0009	-0.1082	0.1397	-0.1578	0.0915	-0.0673	-0.2535	0.6670	-0.1842	0.0419	-0.3108
TYD	0.1538	0.3793	0.0211	0.1790	0.2551	0.3869	-0.5553	0.2690	-0.3694	0.1408	-0.1934	-0.0475	0.0662	0.0654
FLL	0.1755	0.4244	0.1038	0.3381	-0.1444	-0.2612	0.2429	-0.1261	-0.0463	-0.1395	-0.3387	-0.3946	0.0594	-0.4523
HAL	-0.2339	0.2800	-0.0550	0.5089	0.4064	-0.0430	0.1242	-0.2686	0.1857	0.2401	0.2059	0.4523	-0.0746	-0.0752
AGL	0.3665	-0.1025	0.1144	0.3408	-0.1710	-0.0653	0.0180	0.5334	0.4176	0.3687	0.2280	-0.1428	-0.1468	0.0585
ShL/FL	0.3825	-0.0523	0.2272	-0.0106	0.1265	0.3303	-0.0095	-0.4894	0.0646	-0.0869	0.0801	-0.2007	-0.6051	0.0995
TiL	0.3635	-0.0695	0.3015	0.1238	-0.2082	0.1553	-0.1974	-0.3063	0.2805	-0.1632	-0.0246	0.2938	0.6009	0.0564
FOL	0.3432	-0.0996	0.2073	-0.0365	0.1292	0.1569	0.5852	0.1457	-0.5472	0.1203	0.1738	0.2225	0.1494	-0.0838
Explained Variance (%)	34.6	22.7	14.0	7.8	5.7	4.7	4.4	2.0	1.3	0.9	0.7	0.6	0.5	0.1
Eigen value	4.8	3.2	2.0	1.1	0.8	0.7	0.6	0.3	0.2	0.1	0.1	0.1	0.1	0.0

AGL/SVL ratio of 0.379 to 0.425, $n = 7$ (vs. higher AGL/SVL ratio of 0.431 to 0.462, $n = 2$ in *F. cepfi*); lower TiL/SVL ratio of 0.402 to 0.494, $n = 7$ (vs. higher TiL/SVL ratio of 0.495 to 0.525, $n = 2$ in *F. cepfi*); lower FoL/SVL ratio of 0.489 to 0.548, $n = 7$ (vs. higher FoL/SVL ratio of 0.552 to 0.572, $n = 2$ in *F. cepfi*); higher FLL/SVL ratio of 0.213 to 0.239, $n = 7$ (vs. lower FLL/SVL ratio of 0.187 to 0.207, $n = 2$ in *F. cepfi*); higher EL/SVL ratio of 0.126 to 0.132, $n = 7$ (vs. lower EL/SVL ratio of 0.106 to 0.114, $n = 2$ in *F. cepfi*); higher NE/SVL ratio of 0.076 to 0.085, $n = 7$ (vs. lower NE/SVL ratio of 0.054 to 0.060, $n = 2$ in *F. cepfi*); higher IN/SVL ratio of 0.097 to 0.120, $n = 7$ (vs. lower IN/SVL ratio of 0.076 to 0.084, $n = 2$ in *F. cepfi*); snout pointed (vs. snout sub ovoid in *F. cepfi*); webbing between toes medium (vs. webbing between toes small in *F. cepfi*).

Fejervarya goemchi sp. nov. can be distinguished from its probable sympatric species *F. gomantaki* in having larger adult male size of SVL 41.4 mm to 46.8 mm, $n = 7$ (vs. smaller adult male size 18.4 mm to 20.2 mm, $n = 7$ in *F. gomantaki*); upper and lower lip barred (vs. upper and lower lip white in *F. gomantaki*); canthus rostralis blunt and loreal region concave (vs. canthus rostralis angled and loreal region concave in *F. gomantaki*); tympanum distinct half of the eye diameter (vs. indistinct and barely visible tympanum in *F. gomantaki*); vomerine ridges present (vs. vomerine ridges absent in *F. gomantaki*); tibiotarsal articulation reaches front of eyes (vs. tibiotarsal articulation reaches back of eyes in *F. gomantaki*); webbing medium (vs. rudimentary webbing in *F. gomantaki*).

Fejervarya goemchi sp. nov. can be distinguished from its probable sympatric species *F. syhadrensis* in having larger adult male size of SVL 41.4 mm to 46.8 mm, $n = 7$ (vs. medium adult male size 28.5 mm to 30.0 mm, $n = 4$ in *F. syhadrensis*); lower HW/SVL ratio of 0.321 to 0.342, $n = 7$ (vs. higher HW/SVL ratio of 0.351 to 0.358, $n = 4$ in *F. syhadrensis*); lower NE/SVL ratio of 0.076 to 0.085, $n = 7$ (vs. higher NE/SVL ratio of 0.093 to 0.098, $n = 4$ in *F. syhadrensis*); lower EL/SVL ratio of 0.126 to 0.132, $n = 7$ (vs. higher NE/SVL ratio of 0.140 to 0.157, $n = 4$ in *F. syhadrensis*); lower FLL/SVL ratio of 0.213 to 0.239, $n = 7$ (vs. higher FLL/SVL ratio of 0.422 to 0.435, $n = 4$ in *F. syhadrensis*); lower HAL/SVL ratio of 0.213 to 0.230, $n = 7$ (vs. higher HAL/SVL ratio of 0.232 to 0.250, $n = 4$ in *F. syhadrensis*); lower TiL/SVL ratio of 0.402 to 0.494, $n = 7$ (vs. higher TiL/SVL ratio of 0.500 to 0.537, $n = 4$ in *F. syhadrensis*).

Discussion

From the Goa landscape, five species of *Fejervarya* have been reported in the literature (Kulkarni *et al.*, 2013), which include *F. brevipalmata*, *F. caperata*, *F. granosa*, *F. rufescens* and *F. syhadrensis*. Of these, *F. caperata*, *F. granosa* and *F. syhadrensis* are small to medium sized species while the two large sized species were recorded as *F. brevipalmata* and *F. rufescens* (now *F. cepfi*). For *F. brevipalmata*, type locality data is erroneous (Frost, 2017) and the distribution of this species in the northern Western Ghats is unlikely; this taxonomic problem should be addressed before the species is considered *Incertae sedis* by revisiting the study sites of Boulenger (1920) and Pillai (1980) in the southern Western Ghats. Boulenger (1920) has reported 7 specimens from Niligiris, Malabar and, Devicolum and Piermud in Travancore, while Pillai (1980) has reported 19 specimens from Muthanga, Chedleth, Anamalai and Valparai.

Recently, based on the morphological studies Garg and Biju, (2017) have come up with four distinguishable morphological groups of *Fejervarya* in the Western Ghats. The morphological *Fejervarya nilagirica* group of Garg and Biju (2017) (hereafter Nilagirica group) contains nine species including, *F. brevipalmata*, *F. keralensis*, *F. kudremukhensis*, *F. mudduraja*, *F. murthii*, *F. mysorensis*, *F. nilagirica*, *F. parambikulamana* and *F. sauriceps*. Within this group type locality data is erroneous for *F. brevipalmata*. The species *F. murthii* and *F. mysorensis* are known only from the original descriptions from the type locality without any further reports. Type specimens are not available for the species *F. parambikulamana* and *F. sauriceps*, which needs taxonomic studies to establish the identity of the species. Of the other four species in the group, *F. keralensis* is found south of Palghat gap; *F. nilagirica* from the Waynaad and Nilgiri plateau; *F. mudduraja* from the Coorg plateau and *F. kudremukhensis* from the Kudremukh hill ranges with a wide distribution.

In the *Fejervarya rufescens* morphological group of Garg and Biju (2017) (hereafter Rufescens group), *F. cepfi*, *F. kadar*, *F. manoharani*, *F. neilcoxi* and *F. rufescens* are included with clear taxonomic identities, but the distribution range is not clear for the species *F. kadar* and *F. neilcoxi* which are known from single localities.

In the *Fejervarya sahyadris* morphological group of Garg and Biju (2017) (hereafter Sahyadris group), *F. gomantaki* and *F. sahyadris* are included which have clear taxonomic identities and defined distribution ranges.

In the *Fejervarya syhadrensis* morphological group of Garg and Biju (2017) (hereafter Syhadrensis group), *F. caperata*, *F. granosa*, *F. modesta* and *F. syhadrensis* are included which have clear taxonomic identities except for *F. modesta*, where type specimens are missing and the species needs validation. The species *F. syhadrensis* is known from the northern Western Ghats and reports outside the range (Frost, 2017) could be erroneous and needs further phylogenetic studies. The species *F. caperata* and *F. granosa* could have wide distribution ranges.

Morphological character crypticity is the major impediment in the identity of the *Fejervarya* frogs in the Western Ghats. Interestingly, the Goa mountain landscape is represented by *F. cepfi* from Rufescens group, *F. gomantaki* from Sahyadris group, *F. syhadrensis* from Syhadrensis group and the new species *Fejervarya goemchi*

sp. nov. represent the Nilagirica group following a pattern of a single species each from the four morphological groups of Garg and Biju (2017) from the Western Ghats. In the field, in most of the cases, *Fejervarya goemchi* sp. nov. and *F. cepfi* are sympatric or *F. gomantaki* and *F. syhadrensis* are sympatric and in a few locations, their distribution ranges overlap.

With the description of the new species *Fejervarya goemchi* sp. nov., *Fejervarya* frog diversity has increased to 21 species in the Western Ghats (Table 3). Systematic field sampling and phylogenetic studies are required to address the additional taxonomic problems discussed above. Since there is limited information on the range of distribution of *Fejervarya goemchi* sp. nov., it is proposed to treat the species as 'Data Deficient' for the IUCN Red List Conservation status.

Table 3. Extant valid species of *Fejervarya* in the Western Ghats

Species	Type locality
<i>Fejervarya goemchi</i> sp. nov.	Surla village, Goa
<i>Fejervarya brevipalmata</i> (Peters, 1871)	Pegu, Myanmar (doubtful)
<i>Fejervarya caperata</i> Kuramoto, Joshy, Kurabayashi and Sumida, 2007*	Karnoor, Dakshina Kannada
<i>Fejervarya cepfi</i> Garg and Biju, 2017*	Amboli, Sindhudurg
<i>Fejervarya gomantaki</i> Dinesh, Vijayakumar, Channakeshavamurthy, Toreskar, Kulkarni and Shankar, 2015*	Chigule, Belgaum
<i>Fejervarya granosa</i> Kuramoto, Joshy, Kurabayashi and Sumida, 2007*	Talapu, Dakshina Kannada
<i>Fejervarya kadar</i> Garg and Biju, 2017*	Thavalakuzhipara, Thrissur
<i>Fejervarya keralensis</i> (Dubois, 1981)*	Malabar (uncertain specific locality)
<i>Fejervarya kudremukhensis</i> Kuramoto, Joshy, Kurabayashi, and Sumida, 2007*	Kudremukh, Chickamagaluru
<i>Fejervarya manoharani</i> Garg and Biju, 2017*	Chathankod-Bonnacaud, Thiruvananthapuram
<i>Fejervarya modesta</i> (Rao, 1920)	Jog, Shimoga
<i>Fejervarya mudduraja</i> Kuramoto, Joshy, Kurabayashi, and Sumida, 2007*	Talapu, Coorg
<i>Fejervarya murthii</i> (Pillai, 1979)	Naduvattom, Nilgiris
<i>Fejervarya mysorensis</i> (Rao, 1922)	Jog, Shimoga
<i>Fejervarya neilcoxi</i> Garg and Biju, 2017*	Parambikulam, Palakkad
<i>Fejervarya nilagirica</i> (Jerdon, 1854)	Wayanad and Neelgherries
<i>Fejervarya parambikulamana</i> (Rao, 1937)	Parambikulam forests, Palakkad
<i>Fejervarya rufescens</i> (Jerdon, 1854)*	Malabar Coast (uncertain specific locality)
<i>Fejervarya sahyadris</i> (Dubois, Ohler, and Biju, 2001)*	Gundia, Hassan
<i>Fejervarya sauriceps</i> (Rao, 1937)	Wattekole, Coorg
<i>Fejervarya syhadrensis</i> (Annandale, 1919)*	Khandal, Poona

*species included in the phylogenetic analysis

Acknowledgments

We thank the Critical Ecosystem Partnership Fund (Western Ghats), and Ministry of Environment, Forests and Climate Change (MoEFCC), for funding. We are grateful to the forest officials of the state forest departments of Karnataka, Goa and Maharashtra for fieldwork and work permits. This publication is part of the Open Taxonomy Initiative, supported by Kartik Shanker and S. P. Vijayakumar at the Evolutionary Ecology Lab at Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), Bangalore. We thank Aditi Jayarajan for her support in the wet lab work. We acknowledge the help of Varun Torsekar, Saunak P. Pal, S. R. Chandramouli

and members of local communities for providing support during various field expeditions. KPD is thankful to DBT and SERB (SR/FR/LS-88/210/09.05.2012) for fellowship and financial assistance to conduct part of this work, and grateful to the Director, Zoological Survey of India (ZSI), Kolkata and the Officer-in-charge, ZSI, WRC, Pune for encouragement. NUK would like to thank Trustees of Mhadei Research Centre (MRC) for their continuous support. Authors are thankful to Kartik Shanker and S. P. Vijayakumar for the suggestions in improving the first version of the manuscript. We are also thankful to the anonymous referees for their valuable suggestions and critical comments on the earlier manuscript.

References

- Boulenger, G.A. 1920. A monograph of the South Asian, Papuan, Melanesian and Australian frogs of the genus *Rana*. *Records of the Indian Museum*, **20**: 1–226.
- Dahanukar, N., Sulakhe, S. and Padhye, A. 2017. Identity of *Sphaerotheca pluvialis* (Jerdon, 1853) and other available names among the burrowing frogs (Anura: Dicroglossidae) of South Asia. *Journal of Threatened Taxa*, **9**(6): 10269–10285.
- Dinesh, K.P., Vijayakumar, S.P., Channakeshavamurthy, B.H., Torsekar, V.R., Kulkarni, N.U. and Shanker, K. 2015. Systematic status of *Fejervarya* (Amphibia, Anura, Dicroglossidae) from South and SE Asia with the description of a new species from the Western Ghats of Peninsular India. *Zootaxa*, **3999**(1): 79–94.
- Dinesh, K.P., Radhakrishnan, C., Channakeshavamurthy, B.H., Deepak, P. and Kulkarni, N.U. 2017. A Checklist of Amphibians of India with IUCN conservation status (updated till September 2017) available at http://zsi.gov.in/WriteReadData/userfiles/file/Checklist/Amphibia_Checklist_2017.pdf (online only).
- Frost, D.R. 2017. Amphibian species of the World: an Online Reference. Version 6.0 (01/01/2018, Date of access). Electronic Database accessible at <http://research.amnh.org/herpetology/amphibia/index.html>. American Museum of Natural History, New York, USA.
- Garg, S. and Biju, S.D. 2017. Description of four new species of Burrowing Frogs in the *Fejervarya rufescens* complex (Dicroglossidae) with notes on morphological affinities of *Fejervarya* species in the Western Ghats. *Zootaxa*, **4277**(4): 451–490.
- Hammer, O., Harper, D.A.T. and Ryan, P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, **4**(1): 9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm
- Kulkarni, N., Dinesh, K.P., Prashanth, P., Bhatta, G. and Radhakrishnan, C. 2013. Checklist of Amphibians of Goa. *Frog leg*, **19**: 7–12.
- Pillai, R.S. 1980. Distinction, status and notes on habits of *Rana brevipalmata* Peters. *Bull. Zool. Surv. India*, **3**(1&2): 31–33.
- Silvestro, D. and Michalak, I. 2012. raxmlGUI: A graphical front-end for RAxML. *Organisms Diversity and Evolution*, **12**: 335–337.
- Vijayakumar, K., Dinesh, K.P., Prabhu, M.V. and Shanker, K. 2014. Lineage delimitation and description of nine new species of bush frogs (Anura: Raorchestes, Rhacophoridae) from the Western Ghats Escarpment. *Zootaxa*, **3893**(4): 451–488.

Appendix I GenBank accession numbers for the microglossid taxa used in the construction of Maximum-likelihood tree for 40 taxa based on 5430 bp of mitochondrial (16S and 12S) and nuclear genes (BDNF, Rhod, Tyr, RAG-2, NCX1, and CXCR4)

Species	16S	12S	BDNF	Rhod	Tyr	RAG-2	NCX1	CXCR4
<i>Fejervarya goemchi</i> sp. nov.	MG800343	----	----	----	----	----	----	----
<i>Fejervarya goemchi</i> sp. nov.	MG800344	----	----	----	----	----	----	----
<i>Fejervarya cepfi</i> (India)	KY447308.1	----	----	----	----	----	----	----
<i>Fejervarya kadar</i> (India)	KY447312.1	----	----	----	----	----	----	----
<i>Fejervarya manoharani</i> (India)	KY447315.1	----	----	----	----	----	----	----
<i>Fejervarya nelcoxi</i> (India)	KY447318.1	----	----	----	----	----	----	----
<i>Fejervarya rufescens</i> (India)	KY447322.1	----	----	----	----	----	----	----
<i>Fejervarya keralensis</i> (India)	JX573181.1	----	----	----	----	----	----	----
<i>Fejervarya keralensis</i> (India)	GQ478322.1	----	----	----	----	----	----	----
<i>Fejervarya gomantaki</i> (Goa, India)	KR781084.1	----	----	----	----	----	----	----
<i>Fejervarya gomantaki</i> (Goa, India)	KR781085.1	----	----	KT004439	----	----	----	----
<i>Fejervarya gomantaki</i> (Goa, India)	KR781086.1	----	----	KT004440	----	----	----	----
<i>Fejervarya gomantaki</i> (Goa, India)	KR781087.1	----	----	KT004441	----	----	----	----
<i>Fejervarya sahyadris</i> (Aralam, India)	AB530604.1	----	----	----	----	----	----	----
<i>Fejervarya sahyadris</i> (Aralam, India)	AB530605.1	----	----	----	----	----	----	----
<i>Fejervarya kudremukhensis</i> (Kudremukh, India)	AB488875.1	AB488875.1	AB489059.1	AB489035.1	AB489014.1	AB488994.1	AB488933.1	AB488916.1
<i>Fejervarya greenii</i> (Hakgala, Sri Lanka)	AB488891.1	AB488868.1	AB489053.1	AB489029.1	AB489008.1	AB488988.1	AB488927.1	AB488910.1
<i>Fejervarya kirtisinghei</i> (Hakgala, Sri Lanka)	AB488890.1	AB488867.1	AB489052.1	AB489028.1	AB489007.1	AB488987.1	AB488926.1	AB488909.1
<i>Fejervarya sp. hp4</i> (Chitwan, Nepal)	AB488889.1	AB488866.1	AB500239.1	AB500262.1	AB500268.1	----	AB500251.1	AB500245.1
<i>Fejervarya caperata</i> (Mudigere, India)	AB488894.1	AB488871.1	AB489055.1	AB489031.1	AB489010.1	AB488990.1	AB488929.1	AB488912.1
<i>Fejervarya sp. hp5</i> (Assam, India)	AB488900.1	AB488877.1	AB489061.1	AB489037.1	AB489016.1	AB488996.1	AB488935.1	AB488918.1
<i>Fejervarya syhadrensis</i> (India)	AY882955.1	----	----	----	----	----	----	----
<i>Fejervarya pierreii</i> (Chitwan, Nepal)	AB488888.1	AB488865.1	AB489051.1	AB489027.1	AB489006.1	AB490160.1	AB488925.1	AB488908.1
<i>Fejervarya cf. syhadrensis</i> (Matale, Sri Lanka)	AB488892.1	AB488869.1	AB500237.1	AB500260.1	AB500267.1	----	AB500250.1	AB500244.1
<i>Fejervarya granosa</i> (Mudigere, India)	AB488895.1	AB488872.1	AB489056.1	AB489032.1	AB489011.1	AB488991.1	AB488930.1	AB488913.1
<i>Fejervarya sp. hp3</i> (Pilok, Thailand)	AB277300.1	AB277284.1	----	----	----	----	----	AB277313.1

<i>Fejervarya</i> sp. <i>hp6</i> (Andaman Islands, India)	AB488899.1	AB488876.1	AB489060.1	AB489036.1	AB489015.1	AB488995.1	AB488934.1	AB488917.1
<i>Fejervarya mudduraja</i> (Madikeri, India)	AB488896.1	AB488873.1	----	AB489033.1	AB489012.1	AB488992.1	AB488931.1	AB488914.1
<i>Fejervarya multistriata</i> (Husa, China)	AB488884.1	AB488862.1	AB500234.1	AB500257.1	AB500265.1	AB500252.1	AB500248.1	AB500242.1
<i>Fejervarya limnocharis</i> (Java, Indonesia)	AB277302.1	AB277286.1	AB489044.1	AB489020.1	AB277354.1	AB488980.1	AB277327.1	AB277315.1
<i>Fejervarya multistriata</i> (Taipei, Taiwan)	----	AB488862.1	AB500235.1	AB500258.1	AB500266.1	AB500253.1	AB500249.1	AB500243.1
<i>Fejervarya iskandari</i> (Java, Indonesia)	AB277303.1	AB277287.1	AB489045.1	AB489021.1	AB277355.1	AB488981.1	AB277328.1	AB277316.1
<i>Fejervarya orissaensis</i> (Orissa, India)	AB277304.1	AB277289.1	AB500236.1	AB500259.1	AB277356.1	----	AB277329.1	AB277317.1
<i>Fejervarya</i> sp. <i>hp2</i> (Three Pagoda Pass, Thailand)	----	----	AB500238.1	AB500261.1	----	AB500254.1	AB277323.1	AB277308.1
<i>Fejervarya limnocharis</i> (Hiroshima, Japan)	AB488887.1	AB488864.1	AB489050.1	AB489026.1	AB489005.1	AB488986.1	AB488924.1	AB488907.1
<i>Fejervarya limnocharis</i> (Orchard Island, Taiwan)	----	----	AB500233.1	AB500256.1	AB500264.1	----	AB500247.1	AB500241.1
<i>Fejervarya sakishimensis</i> (Iriomote Island, Japan)	AB488886.1	AB488863.1	AB489049.1	AB489025.1	AB489004.1	AB488985.1	AB488923.1	AB488906.1
<i>Fejervarya triora</i> (Ubon Ratchatani, Thailand)	AB488883.1	AB488860.1	AB489046.1	AB489022.1	AB489003.1	AB488982.1	AB488922.1	AB488905.1
<i>Fejervarya cancrivora</i> (Salangor, Malaysia)	AB488882.1	AB488859.1	----	----	----	----	----	----
<i>Sphaerotheca breviceps</i> (India)	----	----	----	AF249110.1	DQ282927	----	----	----
<i>Sphaerotheca dobsoni</i> (India)	AB277305.1	AB277290	----	----	AB277357.1	----	AB277330.1	AB277318.1
<i>Sphaerotheca pluviialis</i> (India)	AF249042.1	AF161039	----	----	----	----	----	----
<i>Hoplobatrachus tigerinus</i> (India)	AB290412.1	----	AB489063.1	AB489039.1	AB277358.1	----	AB277331.1	AB277319.1
<i>Euphlyctis cyanophlyctis</i> (India)	AB272604.1	----	AB489062.1	AB489038.1	AB489017.1	----	AB488936.1	AB488919.1
<i>Occidozyga</i> sp. (Malaysia)	----	----	AB489067.1	AB489043.1	AB489019.1	----	AB488938.1	AB488921.1
<i>Occidozyga lima</i> (Malaysia)	----	----	AB489066.1	AB489042.1	AB489018.1	----	AB488937.1	----