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A reappraisal of the rhacophorid bush frog *Raorchestes flaviventris* (Boulenger, 1882), with an evaluation of the taxonomic status of *R. emeraldi* Vijayakumar, Dinesh, Prabhu and Shankar, 2014

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Abstract

Raorchestes flaviventris, a species of rhacophorid bush frog described from the Western Ghats by George Albert Boulenger in 1882, has never been reported from the region since its description. However, we herewith report a record of the species after almost 132 years and redescribe the species and also clarify confusions that prevailed over the taxonomic status of the species and its closely-related congeners, along with shedding light on literature regarding its distribution. Also, the recently described *R. emeraldi* Vijayakumar et al., 2014, which we suggest to be the same species, becomes a junior subjective synonym of *R. flaviventris*.

Key words: *Raorchestes flaviventris*, rediscovery, Western Ghats, India

Introduction

The bush frog genus *Raorchestes* (Anura: Rhacophoridae) is a species-rich radiation of direct-developing frogs that ranges from Southern India to Indochina and continental Southeast Asia. Recent studies have been successful in discerning many novel species in this genus, and the Western Ghats can be credited as being the centre of diversity for this genus with 51 valid species (Biju & Bossuyt, 2009; Biju et al., 2010; Zachariah et al., 2011; Vijayakumar et al., 2014). However, in the comprehensive lists prepared for the bush frogs of the region, one particular species, i.e., *Raorchestes flaviventris* (Boulenger, 1882), has been repeatedly reported as not being sighted or located (Biju & Bossuyt, 2009; Vijayakumar et al., 2014) since its description. Vijayakumar et al. (2014) recently described several new species from the Western Ghats, of which their description of *Raorchestes emeraldi* very closely matches with the descriptions of *R. flaviventris* provided by Boulenger (1882) and Bossuyt and Dubois (2001). Although Vijayakumar et al. (2014) provided many relevant diagnostic characters, they have not accommodated some key characters in their description of *R. emeraldi*, nor have they compared their specimens with either the descriptions or lectotype of *R. flaviventris*. Herein, we update the taxonomic status of *Raorchestes flaviventris* and also provide additional data on the holotype of *R. emeraldi* and present evidence for the consideration of *R. emeraldi* as a junior subjective synonym of *R. flaviventris*.

Methods

Collection of field data of *Raorchestes* were carried out in the Western Ghats of India as part of a larger documentation exercise, during the period 2008–2014, and specimen collections were made from 2012 to 2014.

Our fieldwork yielded data for *Raorchestes flaviventris* in 2012, of which two specimens (two males) were euthanized, fixed in 10% neutral-buffered formalin (NBF) and then transferred to 70% ethanol. Measurements (rounded to 0.1 mm) and terminologies follow that of Zachariah et al. (2011). Specimens were deposited in the Natural History Museum, Trivandrum, India (TNHM). Other specimens compared include the lectotype of *R. flaviventris* (based on high resolution photographs) at the Natural History Museum, London (BMNH) and the holotype of *R. emeraldi* at the Zoological Survey of India - Western Ghats Regional Center, Calicut (ZSIC), for which additional measurements for comparison were taken.

Results

Taxonomy

Raorchestes flaviventris (Boulenger, 1882)

Name bearing type: Lectotype, BMNH 1947.2.26.98 [ex BMNH 1874.4.29.1202], adult male (SVL 29.4 mm) (Fig. 3), figured in Boulenger (1882: pl. 11 fig. 1b) collected from “Malabar”. **Other materials:** TNHM (H) 12.6.18/47a; adult ♂ (Fig. 1B; Fig. 2; Table 1), collected by Anil Zachariah from Kadalar (10°8'7.65"N, 76°59'55.48"E), Idukki district, Kerala, India; 1515m ASL; 14/06/2012; TNHM (H) 12.6.18/47b (Table 1); adult ♂, collected by Robin Kurian Abraham from Kadalar along with the previous specimen; 14/06/2012.

TABLE 1. Morphometric measurements (in mm) of specimens studied.

Specimen	SVL	HW	HL	IUE	UEW	SL	ED	TD	FLL	HaL	TL	ShL	TaL	FoL
<i>R. flaviventris</i> TNHM (H) 12.6.18/47a (Male)	36.2	14.9	12.3	4.4	3.7	5.4	5.5	1.8	8.5	11.3	17.9	17.5	8.2	15.1
<i>R. flaviventris</i> TNHM (H) 12.6.18/47b (Male)	32.8	13.8	10.9	3.8	3.2	4.8	4.2	1.5	6.5	11.3	16.2	16.1	8.1	14.4
<i>R. emeraldi</i> CESF 1353 Holotype ZSI/ WGRC/V/A/ 873 (Male)	35.3	14.3	12.7	4.3	3.6	4.4	4.7	1.4	8.0	11.1	16.8	17.1	9.4	15.0
<i>R. emeraldi</i> CESF 1365 Paratype ZSI/ WGRC/V/A/ 874 (Female)	49.3	19.7	18.5	4.7	3.9	6.3	5.9	1.9	10.2	14.5	20.8	22.7	12.4	18.9

SVL=snout-vent length; HW=head width, at angle of jaw; HL=head length, from rear of mandible to tip of snout; IUE=inter upper eyelid width, the shortest distance between the upper eyelids; UEW=maximum upper eyelid width; SL=snout length, from tip of snout to anterior orbital border of eye; ED=eye diameter; TD= horizontal tympanum diameter; FLL=forelimb length, from elbow to base of outer palmar tubercle; HaL=hand length, from base of outer palmar tubercle to tip of third finger; TL=thigh length; ShL=shank length; TaL= tarsal length; FoL=foot length, from base of inner metatarsal tubercle to tip of fourth toe.

Description of fresh material (N = 2): Large sized bush frog (mean SVL 34.5) with moderately elongated body; head wider (mean HW 14.3) than long (mean HL 11.6), slightly convex above; snout semicircular in ventral view, rounded in profile; snout length (mean SL 5.1) slightly more than or almost equal to horizontal diameter of eye (mean EL 4.8); canthus rostralis round, loreal region concave; nostrils oval, closer to tip of snout; tympanum distinct (mean TD 1.7), rounded; supratympanic fold distinct, from back of eye to shoulder; pineal ocellus absent; vomerine ridge present, vomerine teeth absent, posterior to choanae; tongue moderately large, emarginate, more

cordiform than lanceolate; lingual papilla present, conical; a small tooth-like projection present on the lower jaw; forearm (mean FLL 7.5) shorter than hand (mean HaL 11.3), fingers moderately long, tips with large well-developed disks, and with distinct circum-marginal grooves; fingers without dermal fringe; webbing on fingers basal, not well developed; subarticular tubercles distinct, rounded, single, present on all fingers; thenar tubercle oval, distinct; palmar tubercles small, rounded, not well developed, accessory palmar tubercles present; supernumerary tubercles absent; hindlimb moderately long, thigh length (mean TL 17.0) slightly longer than shank length (mean ShL 16.8), toe tips with moderate disks; distinct circum-marginal grooves present; toes basally webbed; webbing reaching only up to the penultimate subarticular tubercle on both sides of Toe IV; dermal fringe present on all toes; subarticular tubercles prominent, rounded, simple and present on all toes; inner metatarsal tubercle oval, not well developed; outer metatarsal tubercle, supernumerary tubercles and tarsal tubercle absent.



FIGURE 1. *Raorchestes flaviventris* (in life); A. male from Valparai; B. male from Kadalar.

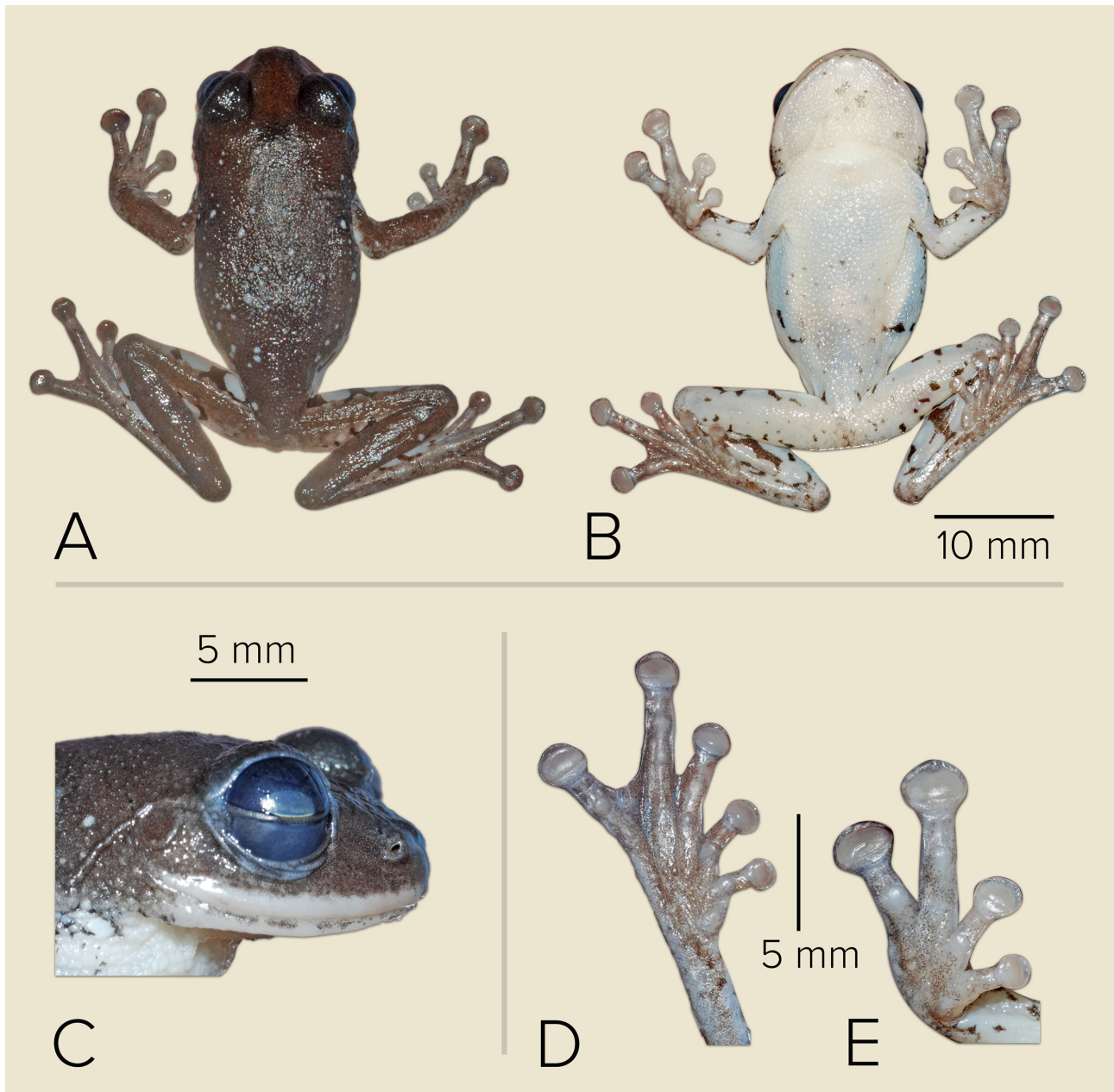


FIGURE 2. Fresh specimen of *Raorchestes flaviventris* (TNHM (H) 12.6.18/47a); A. dorsal view; B. ventral view; C. lateral view of head; D. ventral view of foot; E. ventral view of hand.

Snout, interorbital region and sides of head smooth; anterior and posterior part of back shagreen with sparse spicules; flanks shagreen; dorsal surface of forelimbs and hindlimbs smooth to slightly shagreen; throat, chest and belly granular; ventral part of thighs slightly granular; ventral sides of shanks and tarsus smooth.

Colour in preservation: One week after preservation (Fig. 2): Head and dorsum greyish brown with several white spots; upper lip creamy white; ventrum white with irregular greyish black patches at belly and tibia; dorsal parts of limbs brown with fewer number of white spots; hand greyish brown, foot greyish brown with white blotches on the anterior region; flanks white; groin, anterior and posterior parts of the thigh and anterior region of tarsals greyish white with dark black patches giving a blotched appearance.

Colour in life (Fig. 1): Dorsum bright green, with numerous pale yellow spots towards the posterior region; axilla, groin, anterior and posterior of thighs and anterior region of tarsals bright orange-yellow interspersed with brownish-black patches sometimes appearing as yellow blotches; flank creamy white, edge of upper and lower lip creamy white; iris pale grey bordered outwards with a bluish-black ring.

Distribution: Endemic to the evergreen forests of the western slopes of the Anamalai Hills and High Ranges of Tamil Nadu and Kerala (Fig. 5). Elevation ranges from 1300 to 1900m ASL.

Natural history: Vocalizing males were found on the trunks of forest trees from 2m to 4m above the forest floor. In adjacent cardamom plantations, they could be found on the leaves of the cardamom plants. Calls were akin to that of *R. ponmudi*.

Discussion

Taxonomic history

Raorchestes flaviventris was originally described as *Ixalus flaviventris* by Boulenger in 1882 based on several specimens collected by Col. Richard Henry Beddome from the Malabar region. Subsequently, the generic and sub-generic allocation of this species (and other congeners) has been debated, and several authors have placed them under the genus *Rhacophorus* or *Philautus* (Ahl, 1931; Gorham, 1974; Frost, 1985; Bossuyt and Dubois, 2001; Biju and Bossuyt, 2009). Bossuyt and Dubois (2001), in their review of the genus *Philautus*, mentioned that the type material of *Ixalus flaviventris* was heterotypic. To stabilise the species, they designated a lectotype for *Ixalus flaviventris* which matched the description and figure provided by Boulenger in his original description. Bossuyt and Dubois (2001) also noticed that the description of *Philautus montanus*, a species described by Rao in 1937, very closely resembled the description of *P. flaviventris* and thus designated the lectotype of *P. flaviventris* as a neotype for *P. montanus* Rao, 1937. However, since the name *Philautus montanus* was preoccupied by *Ixalus montanus* Gunther, 1876 and *Philautus montanus* Taylor, 1920, Dutta (1985) proposed a new name for the species as *Philautus hassanensis*. Thus, Bossuyt and Dubois (2001) considered the names *P. montanus* Rao, 1937 and *P. hassanensis* Dutta, 1985 to be junior synonyms of *Philautus flaviventris*. Later, Biju and Bossuyt (2005) described *Philautus ponmudi* (now *Raorchestes ponmudi*) from Kerala and in their comparison, mentioned that the species could be confused with *P. flaviventris* and *P. signatus*, both large sized bush frogs comparable with *P. ponmudi*. They also provided several characters to distinguish the two species based on examining the lectotype designated by Bossuyt and Dubois (2001). However, more recently, Vijayakumar et al. (2014) have considered *R. hassanensis* to be a valid species (not as a junior synonym of *R. flaviventris*) and have mentioned that the taxonomic validity of *R. ponmudi* and *R. hassanensis* should be reassessed. Vijayakumar et al. (2014) also described *R. emeraldi* as a new species from the Anamalai hills, which they mentioned as a green counterpart of *R. ponmudi* and *R. hassanensis* due to its overall morphometric similarity. However, they failed to compare *R. emeraldi* with the description of *R. flaviventris* as they were unable to identify the latter species in their surveys. The overall taxonomic history indicates that the descriptions of the four species *vis.* *R. flaviventris*, *R. emeraldi*, *R. hassanensis* and *R. ponmudi* show a high degree of similarity, and hence the reason for the confusion that prevailed.

Taxonomic assessment of the *Raorchestes hassanensis* clade:

Raorchestes flaviventris has not been recorded live since its original description for over 130 years, and can be diagnosed by attributes pertaining to its size, morphology and distribution, which distinguish it from all other congeners. As mentioned earlier, Bossuyt & Dubois (2001), in order to stabilize the nomenclatural status of this name, designated as lectotype, a specimen from the subseries, which had been described and figured (Plate XI, fig. 1b) in the type description by Boulenger (1882). They also provided a detailed description and a single photograph (page 71, fig. 12) of the lectotype in their account. We provide here detailed photographs (Fig. 3) of the same lectotype that make it easier for comparison. Our specimen identified here as *R. flaviventris* accurately matches the description of the lectotype designated by Bossuyt and Dubois (2001) (Table 2). Also, based on the overwhelming similarity in the type description of *R. montanus* (= *R. hassanensis*) provided by Rao (1937), they considered *R. hassanensis* to be a junior synonym of *R. flaviventris*. However, Bossuyt and Dubois (2001) overlooked a key character provided by Rao (1937) that suggested the two species could be distinct. Rao (1937), in his description of *R. montanus* mentioned that the toes were two-thirds webbed and that the fingers were devoid of webbing. Biju and Bossuyt (2005) in their description of *R. ponmudi* mentioned that *R. flaviventris* can be distinguished from *R. ponmudi* by the toe webbing, which reaches only up to the penultimate subarticular tubercle on both sides of Toe IV (vs. toe webbing reaching up to the distal subarticular tubercle on both sides of Toe IV in *R. ponmudi*).

suggesting that *R. hassanensis* (= *R. montanus* Rao, 1937) more closely resembles *R. ponmudi* and is distinct from *R. flaviventris* in possessing 2/3 webbed toes (see Fig. 4 and Table 2 for detailed comparison). Moreover, our observations of the large sized *Raorchestes* from Chikkamagaluru district of Karnataka (close to the type locality of *R. hassanensis*) have revealed frogs that very closely match the description of *R. hassanensis* and *R. ponmudi*, thus requiring further taxonomic validation. Vijayakumar et al. (2014) have also suggested the same and mentioned that the sister species pair (*R. hassanensis* + *R. ponmudi*) exhibit shallow genetic divergence. A detailed comparison of the type descriptions of *R. hassanensis* and *R. ponmudi* is provided in Table 2, which ascertains that the two species are distinct from *R. flaviventris*.

TABLE 2. Comparison of morphometric characters of *Raorchestes flaviventris* (Boulenger, 1885), *R. emeraldi* Vijayakumar et al., 2014, *R. hassanensis* (Dutta, 1985) and *R. ponmudi* (Biju and Bossuyt, 2005).

<i>R. flaviventris</i> (lectotype; BMNH 1947.2.26.98) (Bossuyt and Dubois, 2001; Biju and Bossuyt, 2009)	<i>R. flaviventris</i> (Present study)	<i>R. emeraldi</i> Vijayakumar et al., 2014	<i>R. hassanensis</i> (Dutta, 1985) (= <i>R. montanus</i> Rao, 1937)	<i>R. ponmudi</i> (Biju and Bossuyt, 2005 and present study)
SVL 29.4 mm	SVL 32.8 – 36.2 mm	SVL 36.5 – 50.5 mm	SVL 37 mm	SVL 35.9 – 38.9 mm
Snout rounded	Snout rounded	Snout rounded	Snout rounded	Snout rounded
Canthus rostralis rounded	Canthus rostralis rounded	Canthus rostralis angular rounded	Canthus rostralis vertical	Canthus rostralis sharp
Tympanum rather distinct, rounded, 36% of eye diameter	Tympanum distinct, rounded, mean tympanum diameter 35.12 % (N = 2) of eye diameter	Tympanum moderate, rounded	Tympanum not prominent; half the diameter of the eye	Tympanum rather distinct; one by third the diameter of the eye
Supra-tympanic fold present	Supra-tympanic fold present	Supra-tympanic fold present	Supra-tympanic fold present	Supra-tympanic fold present
Tongue moderately large, emarginated, with a lingual papilla	Tongue moderately large, emarginate, more cordiform than lanceolate, with a lingual papilla	Tongue moderately large, bifid with a lingual papilla	Tongue with a lingual papilla	Tongue large, cordate, emarginated, with a lingual papilla
Vomerine ridge present, vomerine teeth absent	Vomerine ridge present, vomerine teeth absent	Vomerine ridge present, vomerine teeth absent*	Vomerine teeth absent	Vomerine teeth absent
Webbing at base of fingers rudimentary	Webbing on fingers basal, not well developed	Webbing on fingers basal, not well developed*	No webbing on fingers	No webbing on fingers
Subarticular tubercles distinct, rounded, single, all present.	Subarticular tubercles distinct, rounded, single, present on all fingers	Subarticular tubercles moderate, rounded;	Subarticular tubercle moderately developed	Subarticular tubercles prominent, rounded, single (except IV1, bifid), IV2 absent
Palmar tubercles not evident; supernumerary tubercles present on some fingers, nuptial spine absent in males	Palmar tubercles small, rounded, not well developed; supernumerary tubercle absent; nuptial spine absent in males	Palmar tubercles small, rounded, not well developed; supernumerary tubercle absent; nuptial spine absent in the male*	-	Palmar tubercle, oval, rather distinct; supernumerary tubercles present on finger III. Nuptial spine present
Tips of toes with moderate discs; toe webbing reaching only up to the penultimate subarticular tubercle on both sides of toe IV	Toe tips with moderate discs; toes basally webbed; webbing reaching only up to the penultimate subarticular tubercle on both sides of toe IV	Toes webbing medium; webbing reaching only up to the penultimate subarticular tubercle on both sides of toe*	Discs of toes smaller than that of fingers; toes two-thirds webbed	Discs of toes rather wide; toe webbing reaching up to the distal subarticular tubercle on both sides of Toe IV

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TABLE 2. (Continued)

<i>R. flaviventris</i> (lectotype; BMNH 1947.2.26.98) (Bossuyt and Dubois, 2001; Biju and Bossuyt, 2009)	<i>R. flaviventris</i> (Present study)	<i>R. emeraldi</i> Vijayakumar et al., 2014	<i>R. hassanensis</i> (Dutta, 1985) (= <i>R. montanus</i> Rao, 1937)	<i>R. ponmudi</i> (Biju and Bossuyt, 2005 and present study)
Inner metatarsal tubercle distinct; outer metatarsal tubercle absent	Inner metatarsal tubercle oval, not well developed; outer metatarsal tubercle absent	Inner metatarsal tubercle oval, not well developed*; outer metatarsal tubercle absent	Inner metatarsal tubercle small, oval; outer metatarsal tubercle absent	Inner metatarsal tubercle rather distinct
Dermal fringe on toe V absent	Dermal fringe present on all toes	Dermal fringe present on all toes	-	Small dermal fringe along toe V
Snout, between eyes, side of head, and back smooth; upper part and lower part of flanks shagreen.	Snout, interorbital region and sides of head smooth; anterior and posterior part of back shagreen with sparse spicules.	Snout, interorbital region and sides of head smooth; anterior and posterior part of back shagreen with sparse spicules in the male.*	Skin smooth above; throat, chest, abdomen and underside of arms and hands finely granular	Snout and between eyes, side of head shagreen; anterior, and posterior part of back shagreen with a few scattered horny spicules; Ventral parts of throat, chest, belly and thighs granular
Colour in preservation: Head and dorsum light bronze-brown with several creamish-white spots; upper lip faded- yellow; ventrum brownish-yellow with darker markings; dorsal parts of limbs dark bronze-brown with several large yellowish spots; hand and foot orangish brown; flanks white; groin, anterior and posterior parts of the thigh and anterior region of tarsals light golden brown with several yellowish blotches and spots; webbing dark brown.	Colour in preservation: Head and dorsum greyish brown with numerous white spots; upper lip creamy white; ventrum white with irregular greyish black patches at belly and tibia; hand and foot greyish brown; groin, anterior and posterior parts of the thigh and anterior region of tarsals dark brown with greyish white blotches.	Colour in preservation: Head and dorsum greyish brown with several white spots; upper lip yellowish- white; ventrum yellowish-white with irregular greyish black patches at belly and tibia; hand and foot greyish brown; groin, anterior and posterior parts of the thigh and anterior region of tarsals dark brown with greyish off-white blotches.	Colour in preservation: Brownish red in spirit, with or without white spots on the body; throat and upper part of chest brownish, speckled with white; thighs barred, a single broad band on the shank	Colour in preservation: Dorsum light grey with a dark grey ‘‘X’’ and minute black spots; ventral side of abdomen grey with dark spots; hindlimbs light brown with dark brown cross bands; posterior surface of thighs light brown, vermiculated with variable sizes of light and dark grey patches.

* Indicates characters not-listed in original description but listed based on examination of the Holotype in the present study.

From the taxonomic history and description, it is clear that *R. flaviventris* closely resembles *R. hassanensis* and *R. ponmudi* in overall morphology. Vijayakumar et al. (2014) described *R. emeraldi* from the Valparai plateau of the Anamalai hills as belonging to the ‘Hassanensis’ clade, which was erected for the clade originating in the ancestor of *R. hassanensis*, *R. ponmudi* and *R. emeraldi*. *R. emeraldi* was shown to have moderate levels of divergence from its sister lineages (*R. ponmudi* + *R. hassanensis*) and morphologically different in its dorsum colouration. Although the description of *R. emeraldi* closely matches with that of *R. flaviventris*, Vijayakumar et al. (2014) failed to compare the species with *R. flaviventris* and did not provide any character to distinguish between the two species. Our examination of the holotype of *R. emeraldi* deposited at the ZSI-WGRC (Vijayakumar et al., 2014; fig. 8), with a few additional measurements not included in the type description, indicates that the types of *R. emeraldi* represent the same species ascribed here as *R. flaviventris* (Table 2). With the inclusion of *R. flaviventris* in the ‘Hassanensis’ clade as postulated by Vijayakumar et al. (2014), we update the name of the clade as the ‘Flaviventris’ clade by virtue of seniority.

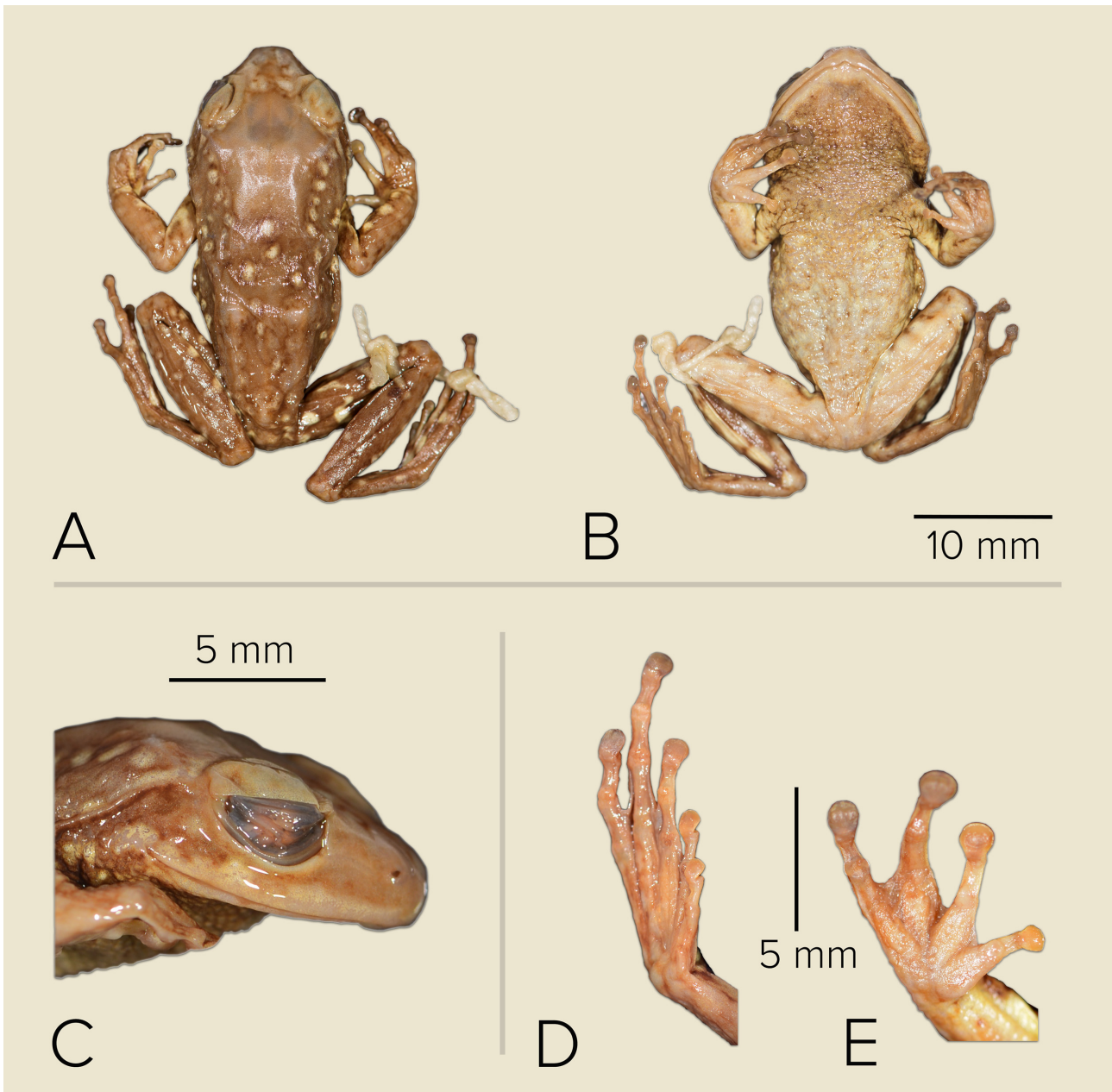


FIGURE 3. Lectotype of *Raorchestes flaviventris* BMNH 1947.2.26.98 [ex BMNH 1874.4.29.1202]; A. dorsal view; B. ventral view; C. lateral view of head; D. ventral view of foot; E. ventral view of hand. This specimen that has been in preservative for more than 130 years shows shrinkage, and alteration of colour; but the overall morphological characters are maintained.

The type description of *R. flaviventris* cites “Malabar” as the type locality for the species. Even though modern day designation of Malabar implies the region of Kerala north of the Palghat Gap, the usage of “Malabar” by colonial explorers during the time of this species’ description referred to the botanical/floristic province as described by Hooker and Thomson (1855) (Biju, 2001). The Malabar botanical province, according to Hooker and Thomson (1855), is the mountain range of the Western Ghats, extending from the River Tapti to Cape Kumarin (= Kanyakumari) (fide Biju, 2001). So, as per the historical usage, “Malabar” included hills of the Western Ghats south of the Palghat Gap.

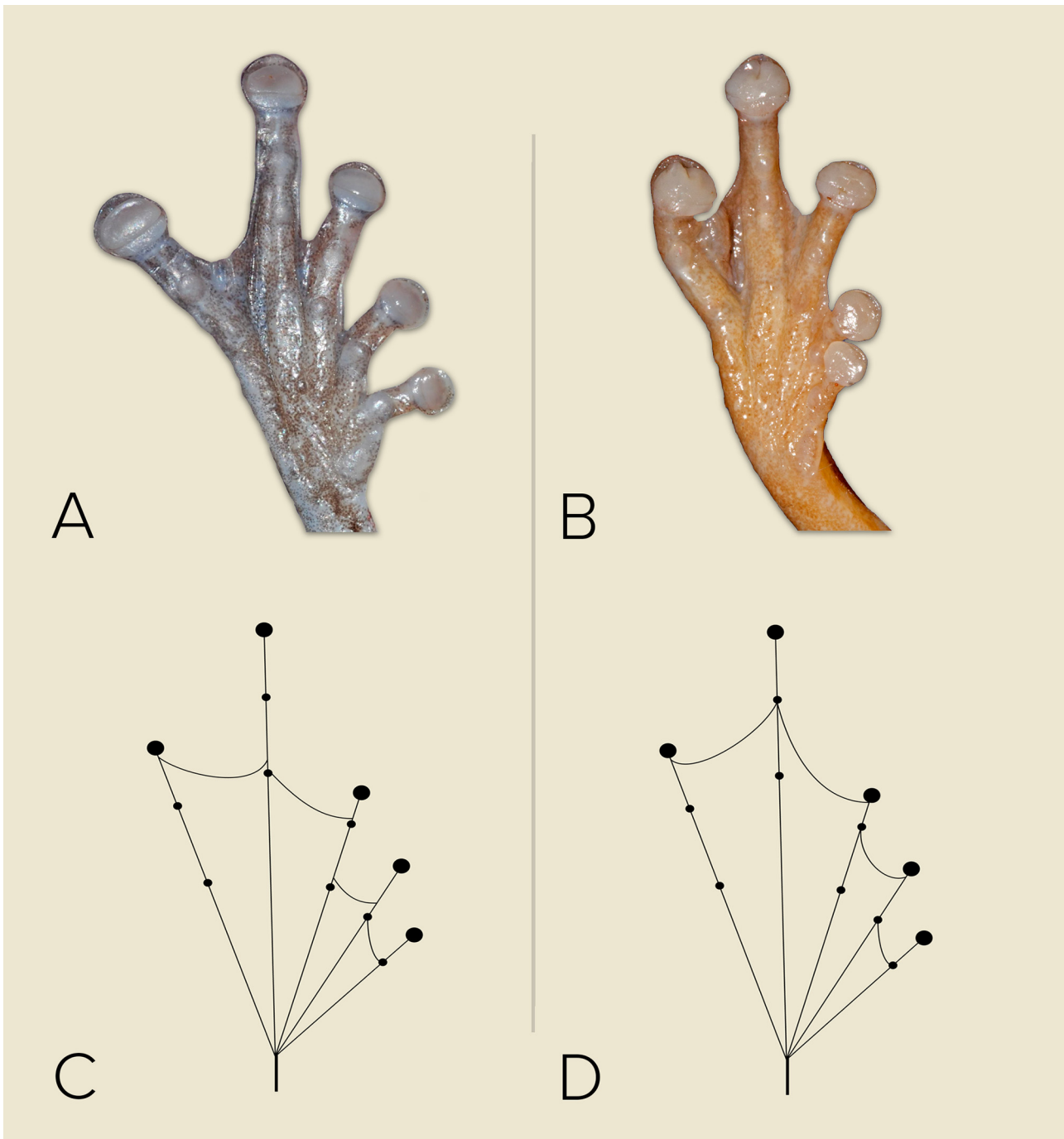


FIGURE 4. Comparison of webbing on the feet between specimens of *Raorchestes flaviventris*, TNHM (H) 12.6.18/47a (A. & C.) and *R. ponmudi* (B. & D.).

Moreover, the yellow blotches on the groin of live *R. flaviventris* extend all across the venter, and also on the ventral surfaces of the arms and thighs in some individuals, and matches with the specific name of the species (flavi = yellow; ventris = abdomen). Hence, we conclude that our specimens (TNHM (H) 12.6.18/47 a & b), by their complementarity with the original description by Boulenger (1882) and the lectotype specimen (BMNH 1947.2.26.98), are indeed that of *Raorchestes flaviventris*. The recently described *R. emeraldi* (Vijayakumar et al., 2014), which is of the exact same species from an adjacent locality, thus becomes a junior synonym of *R. flaviventris*. However, given the ambiguity in the type locality of *R. flaviventris*, we do not exclude the fact that future surveys may find species that more closely resembles the type of *R. flaviventris*, in that case, requiring further taxonomic revision. Until then, given that our specimens and the holotype of *R. emeraldi* are most

congruent with the lectotype of *R. flaviventris*, we retain the earlier name as *R. flaviventris*, which is the most parsimonious solution.

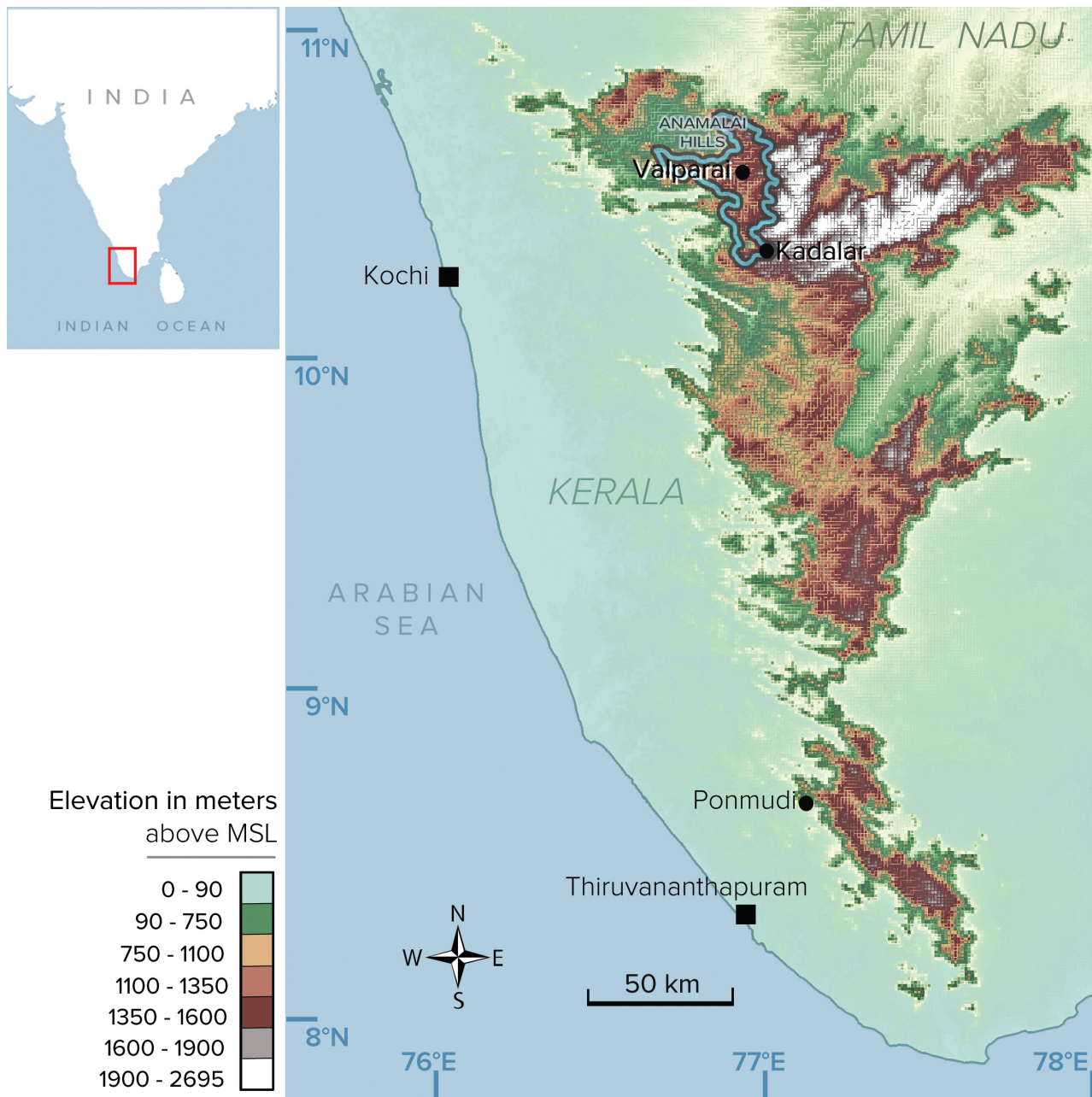


FIGURE 5. Map showing distribution range (marked by blue outline) of *Raorchestes flaviventris* in the Western Ghats.

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