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COMMUNICATION

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New locality records and call description of the Resplendent Shrub Frog *Raorchestes resplendens* (Amphibia: Anura: Rhacophoridae) from the Western Ghats, India

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Abstract: The Resplendent Shrub Frog, *Raorchestes resplendens* Biju, Shouche, Dubois, Dutta, & Bossuyt, 2010 is a Critically Endangered species endemic to the Western Ghats and was considered to be restricted to a three-square kilometer patch atop Anamudi summit. In this study, we report 36 new locations of the species from the Anamalai massif of the southern Western Ghats. Niche-based prediction modelling suggests that the species is restricted to Anamalai massif. The call description of this frog is also provided for the first time. The preferred microhabitat of the frog is *Chrysopogon* grass clumps in the marshy/swampy montane grassland ecosystem. Restricted to a small area with controlled burning management practiced in its habitat, *R. resplendens* needs immediate attention.

Keywords: Anamalai, Critically Endangered, ground-dwelling bush frog, new distribution record, vocalization.

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Competing interests: The authors declare no competing interests.

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Author contribution: PSE & SD conceived the study; SD, KPR carried out field work; all authors equally contributed to the data compilation, analysis and writing the manuscript

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INTRODUCTION

There are currently 8,134 described species of amphibians (Frost 2020) and an average of 144 species described every year starting from 2004–2015 (Tapley et al. 2018). At the same time, amphibians are the most threatened group of vertebrates with 41% of the total assessed species under threatened categories (IUCN 2016). Considering the total number of new species described between 2004 and 2016, India ranks second globally with 155 species (Tapley et al. 2018). Of these, 75% are from the Western Ghats and Sri Lanka Biodiversity Hotspot (Myers et al. 2000; Mittermeier et al. 2004). One of the most diverse groups of frogs in India with the greatest number of species described since 2004 is the genus *Raorchestes* known to be a genus of direct developing rhacophorid frogs (Biju et al. 2010).

Raorchestes resplendens Biju, Shouche, Dubois, Dutta, & Bossuyt, 2010 is a Western Ghats endemic, medium-sized, ground-dwelling bush frog. Its prominent orange colouration and large glands, bordered with black make it distinct from other species of *Raorchestes*. The species belongs to the *beddomii* clade (Vijayakumar et al. 2014) and is restricted to the Anamalai massif of Western Ghats. The species is known from only from its type locality, a three square kilometer patch of habitat on the Anamudi summit, the highest peak (2,695m) in Western Ghats in Eravikulam National Park (ENP) and a site approximately 20km north-east of Anamudi summit (Joseph et al. 2012). Joseph et al. (2012) suggested the possibility of a wider distribution of the species within ENP. *Raorchestes resplendens* is assessed as Critically Endangered (IUCN SSC Amphibian Species Specialist Group 2011).

In this study, we provide information on the distribution of the species inside and outside the protected area network based on surveys undertaken in 2015–2018. In addition, we also predict the probable distribution of the species using niche-based modelling. We also provide the first ever description of the vocalization of *R. resplendens*.

STUDY AREA

Eravikulam National Park (ENP, 10.083–10.333 °N & 77.00–77.166 °E) in Kerala, India. This 97km² national park is one of the few remaining undisturbed patches of the montane shola-grassland ecosystem in the Western Ghats. The high elevation protected area located in the Kannan Devan Hills of Idukki District has a base elevation

of approximately 2,000m. ENP experiences tropical montane climate with average annual rainfall of 5,000–6,500 mm. More than 60% of the park area is dominated by grasslands with shola patches in the valleys.

MATERIALS AND METHODS

A combination of survey methods including visual encounter surveys, call surveys, and scan searches (Heyer et al. 1994; Krishnamurthy 2003; Halliday 2006) were used between January 2015 and December 2018 to document the distribution of *R. resplendens*. During the breeding season (May–September), surveys were undertaken from 18.00–02.00 h, as bush frogs are known to be most active at night (Biju et al. 2010). Morning and evening surveys were conducted from 08.00–13.00 h and 14.00–17.00 h to record diurnal activity, if any. Surveys were done in shola-grassland ecosystems above 1,700m especially inside ENP from where the species was first described and reported. To avoid repeated count and getting maximum distribution range of the species the surveys were spatially replicated.

Calls of *R. resplendens* were recorded at approximately 0.5m distance using ZOOM H4nSP Handy Recorder from four locations in ENP, including Anamudi, Kolukan, Bheemanoda, and Sambamala area. Ten to 20 calls were recorded for each individual (n=10 males). Ambient temperature and snout vent length (SVL) was taken immediately after the recording using Kestrel 3500 hand-held weather station and a Mitutoyo digital vernier caliper. Analyses of the calls were done using Raven v1.4 software (Cornell Laboratory of Ornithology, Ithaca, NY, USA) (Bee et al. 2013a,b; Thomas et al. 2014). Temporal and spectral parameters of calls were measured following definitions of Bee et al. (2013a,b). Six call properties: call duration (ms)—time between the beginning of first pulse and the end of last pulse in a call; call rise time (ms)—time between the beginning of first pulse and the peak of pulse of maximum amplitude; call fall time (ms)—time between the peak of pulse of maximum amplitude and end of last pulse; inter-call interval—time between end of a call to the beginning of the next call; call rate—number of calls delivered per minute; and overall dominant frequency were analyzed for the current study.

Prediction of distribution and calculation of extent of occurrence (EOO): Maximum entropy species distribution modelling software (Maxent) version 3.4.1 was used to predict the distribution of *R. resplendens* in Anamalai Hills. We used approximately 30 arc seconds

of data for altitude, precipitation, average temperature and 19 bioclimatic variables available at the WorldClim website (<http://www.worldclim.org/>); 30-m resolution raster dataset layers were georectified to WGS 1984 43 North Zonation. Geographical coordinates and elevation of each location were recorded using Garmin Montana 680 and a map with sight records and the potential distribution was plotted using ArcGIS. The EOO and area of occupancy (AOO) (IUCN 2012) were calculated using the geospatial conservation assessment tool, GeoCAT (Bachman et al. 2011). The EOO was also calculated from species distribution model by overlaying fishnet squares over the prediction map. Each square covered an area of 4km². Squares with medium, high, and very high prediction values were included to calculate the EOO since there were no records of the species from areas of medium to very low prediction even after intensive surveys.

RESULTS AND DISCUSSION

Prior to our study the Critically Endangered (CR) *R. resplendens* (Image 1) was known to occur only inside ENP from two locations, Anamudi summit and Poovar. The present study reports 36 new locations for the species including four from outside ENP (Table 1 and Image 2). The four new locations outside ENP are Njandalamala of Chinnar Wildlife Sanctuary, a location south-east of ENP in Munnar Forest Division, a location near the south-west boundary of ENP in Munnar Forest Division, and

one location in the adjacent Anamalai Tiger Reserve of Tamil Nadu lying close to the north-west boundary of ENP. The record from near Konalar, Anamalai Tiger Reserve is the lowest elevational record (1,896m) for the species whereas Anamudi Peak (2,695m) is the highest. The previously reported lowest elevational record was from Poovar (2,522m).

During the three-year study period from within ENP limits *R. resplendens* was encountered 637 times. This makes the species the second most encountered *Raorchestes* species in the grasslands of ENP after *Raorchestes dubois* (1,438 times). The unique ground-dwelling habit favored by *R. resplendens* could be the reason they evaded researchers for such a long time. They seem to be very sensitive to light and retreat into grass clumps whenever there is an artificial source of light. Contrary to the tiny bamboo thicket (*Arundinaria densifolia*) habitat preferred by the *R. resplendens* recorded on Anamudi summit, the majority of the individuals observed elsewhere were found actively calling and breeding in marshy/swampy grasslands (Image 3) alongside a water source in the valleys of the montane grasslands rather than on peaks.

At 21.20h on 28 May 2015, a single male was observed calling within a grass clump (*Chyrsopogon* sp.), 5cm above the ground at a marshy area on the base of Sambamala Hill (Image 1). Further investigation resulted in reporting 21 individuals (14 calling males and 7 females) on the same day from the same habitat patch. A single male specimen was collected and preserved in the wildlife museum of Kerala Forest Research Institute,

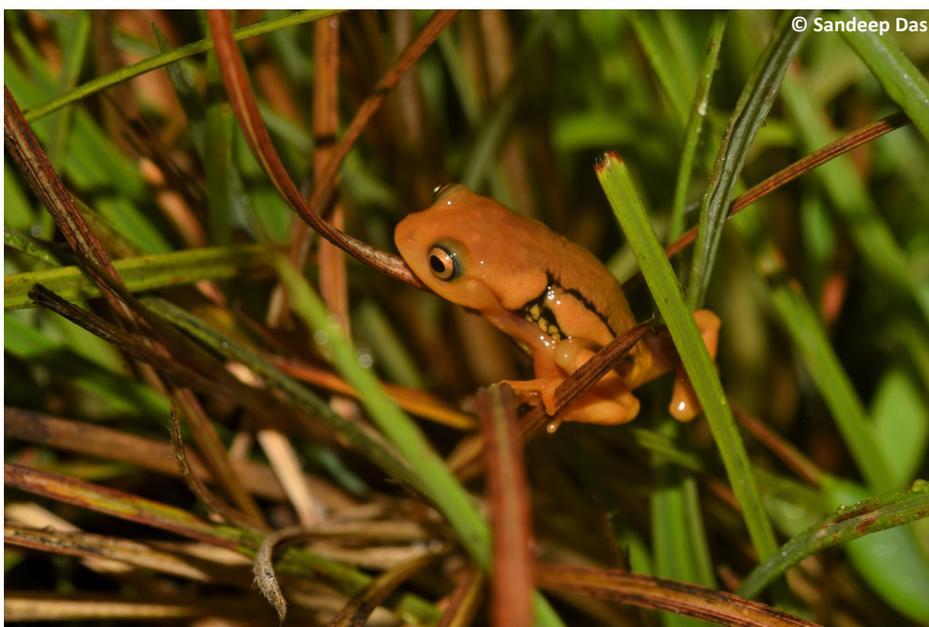


Image 1. *Raorchestes resplendens* in its habitat.

Table 1. Sighting locations of *Raorchestes resplendens* from southern Western Ghats.

	Location	Area	Lat.	Long.	Elevation
1	Njandalamala	Chinnar WS, KL	10.313642°	77.141561°	2346m
2	Munnar Division	Munnar Forest Division, KL	10.093747°	77.202883°	2587m
3	Rajamala Tourism Zone	Eravikulam, KL	10.143794°	77.037753°	1905m
4	Naaykollimala	Eravikulam, KL	10.142961°	77.036047°	1909m
5	Wireless Station Rajamala	Eravikulam, KL	10.149767°	77.044744°	2238m
6	Umayamala	Eravikulam, KL	10.163153°	77.072042°	2169m
7	Mesthirickettu	Eravikulam, KL	10.184550°	77.088272°	2174m
8	Range Point	Eravikulam, KL	10.187094°	77.085794°	2203m
9	Bheemanoda	Eravikulam, KL	10.195603°	77.084517°	2228m
10	Kallupaalam	Eravikulam, KL	10.194811°	77.077353°	2243m
11	Kallupaalam 2	Munnar Forest Division, KL	10.190761°	77.072839°	2173m
12	Bheemanoda 2	Eravikulam, KL	10.196908°	77.086600°	2204m
13	Bheemanoda 3	Eravikulam, KL	10.192550°	77.090950°	2200m
14	Varayattumala 1	Eravikulam, KL	10.204817°	77.085856°	2212m
15	Varayattumala 2	Eravikulam, KL	10.208128°	77.088392°	2237m
16	Kambipaalam Mala	Eravikulam, KL	10.217369°	77.081100°	2216m
17	Eravikulam	Eravikulam, KL	10.209414°	77.075336°	2199m
18	Eravikulam 2	Eravikulam, KL	10.218831°	77.078683°	2178m
19	Eravikulam 3	Eravikulam, KL	10.221906°	77.079378°	2156m
20	Sambamala Base	Eravikulam, KL	10.216506°	77.071711°	2200m
21	Sambamala	Eravikulam, KL	10.213450°	77.065103°	2266m
22	Anamudi View Near Kolukan	Eravikulam, KL	10.218089°	77.059017°	2229m
23	Kolukkan	Eravikulam, KL	10.227481°	77.047964°	2110m
24	Campamala	Eravikulam, KL	10.225033°	77.074289°	2329m
25	Erumapetti	Eravikulam, KL	10.231128°	77.089286°	2269m
26	Turners Valley	Eravikulam, KL	10.222319°	77.089286°	1901m
27	Chinna Mannumudi	Eravikulam, KL	10.228486°	77.094269°	2247m
28	Kudimala	Eravikulam, KL	10.215919°	77.109719°	2049m
29	Near Varattukulam	Eravikulam, KL	10.236183°	77.100469°	2182m
30	Kaatumala	Eravikulam, KL	10.254211°	77.097894°	2526m
31	Kaatumala 1	Eravikulam, KL	10.258489°	77.101667°	2271m
32	Kaatumala 2	Eravikulam, KL	10.267222°	77.090308°	2050m
33	Poovar 1	Eravikulam, KL	10.286419°	77.084633°	1984m
34	Konalar	Grass Hills, TN	10.321906°	77.070497°	1896m
35	Border Grass Hills	Eravikulam, KL	10.309903°	77.092350°	2096m
36	Border Chinnar	Eravikulam, KL	10.299444°	77.113611°	2092m
37	Poovar (Previous record)	Eravikulam, KL	10.273414°	77.086064°	2040m
38	Anamudi (Previous record)	Eravikulam, KL	10.168367°	77.059954°	2695m

KL—Kerala | TN—Tamil Nadu | WS—Wildlife Sanctuary.

Peechi, Kerala (KFRI/WLM/A0035). The size was small in comparison with the details given in published information and from those field-measured earlier during the study. The measurements of the preserved

specimens are as follows: snout vent length (SVL) 20.76mm small; head slightly wider than long (HW) 7.88mm, (HL) 7.44mm; snout length (SL) 2.63mm larger than horizontal diameter of the eye (EL) 2.43mm; snout

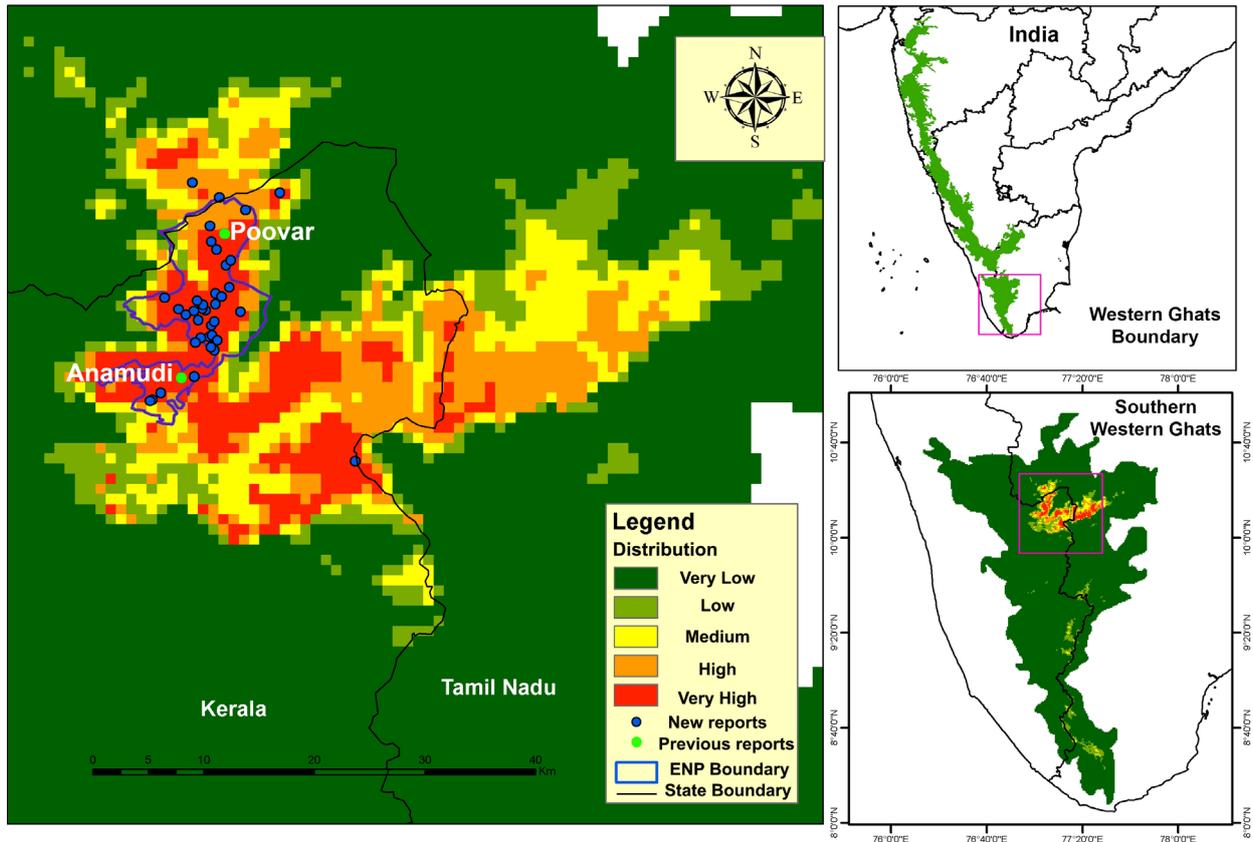


Image 2. Distribution of the *Raorchestes resplendens* and prediction based on niche-modelling.

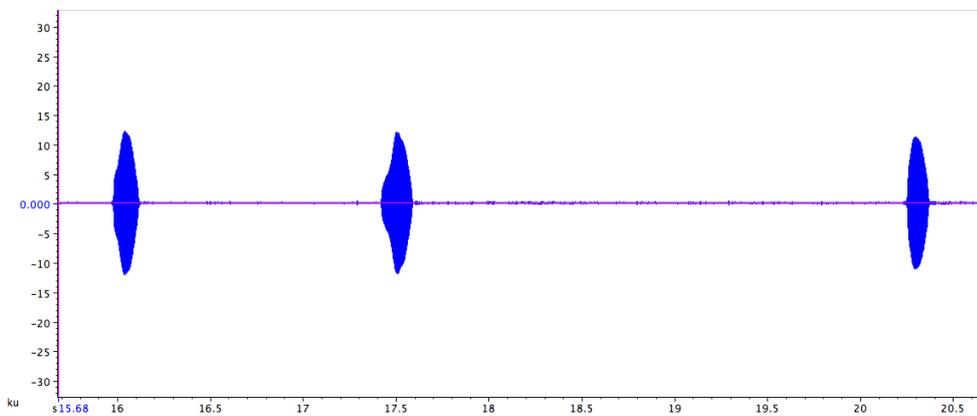


Figure 1. Wave form of *Raorchestes resplendens* call in 5s time frame.

rounded in dorsal view; minimum distance between upper eyelids (IUE) is 2.82mm and maximum width of upper eyelid (UEW) is 1.43mm. Distinct and rounded tympanum. Forelimb (FLL) 4.44mm shorter than hand length (HAL) 4.733mm; fingers with discs and distinct circum-marginal grooves; webbing absent on fingers and absence of nuptial pads. Unlike many of the species in the genus *Raorchestes*, the hind limbs are moderately short for this species; shank length (ShL) 5.37mm

shorter than thigh length (TL) 7.01mm; foot length (FOL) 7.06mm shorter than distance from the base of inner metatarsal tubercle to the tip of toe IV. Toes with discs and distinct circum-marginal grooves and reduced webbing. Dorsum with large orangish glands whereas the creamy white ventrum is granular.

Call Description

Raorchestes resplendens males were observed

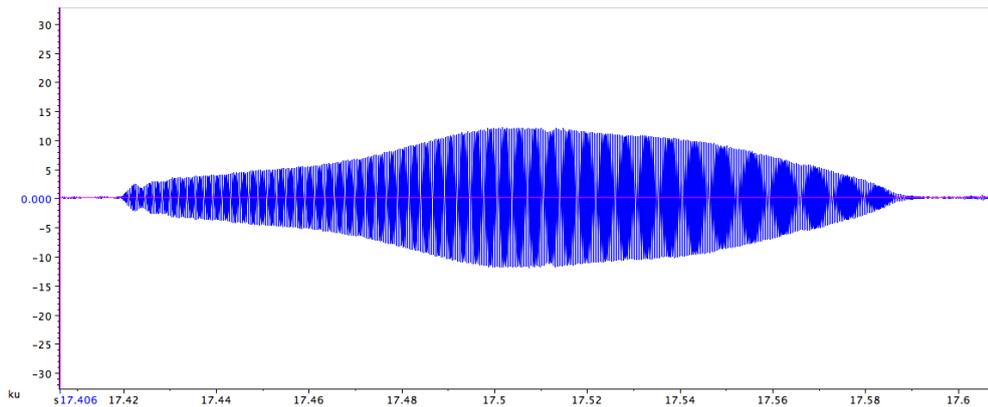


Figure 2. Wave form of *Raorchestes resplendens* call in 2s time frame

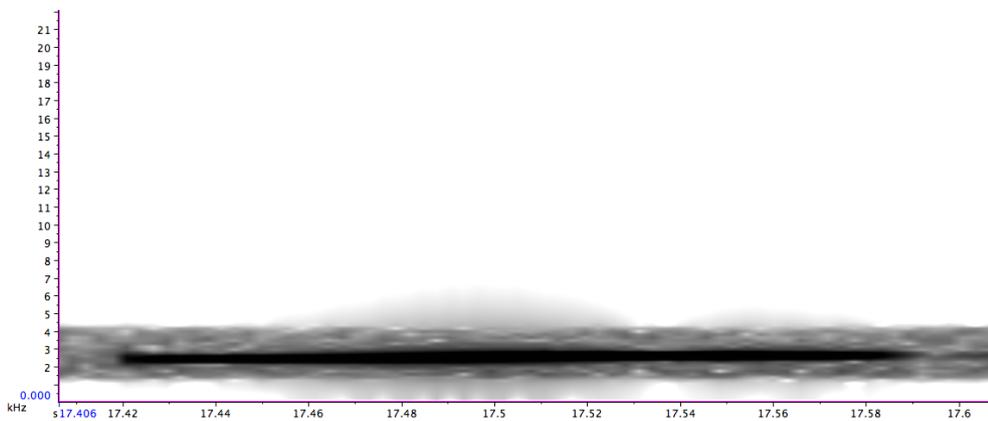


Figure 3. Spectrogram of *Raorchestes resplendens* call

actively calling from 18.00–02.00 h, during their peak breeding season in May–September. A total of 141 calls from 10 males were analyzed for the description of vocalization. Temperature ranged between 16–20 °C during all recordings. Calls were relatively simple (Figure 1 & 2). The advertisement call (<https://doi.org/10.6084/m9.figshare.12781229.v1>) had non-pulsatile temporal structure unlike published calls of other bush frogs including *Raorchestes graminirupes*, *R. flaviocularis*, *R. silentvalley*, *R. lechiya*, *R. travancoricus*, and *Pseudophilautus kani* (Bee et al. 2013a,b; Vijaykumar et al. 2014; Rajkumar et al. 2016; Zachariah et al. 2016). Advertisement calls typically ranged between 58.9–148.8 ms in duration (Table 2). On an average, the interval between two calls was 2.9 ± 3.6 s, and these intervals were uncorrelated with SVL or mass (Table 2). The call rise time ($\bar{x} = 46.3$ ms \pm 29.4 ms; Table 2) was slightly shorter than call fall time ($\bar{x} = 56.7$ ms \pm 16.8 ms; Table 2). The calls were typically delivered at rate of 21.5 calls/minute (Table 2).

The spectrum was characterized by single broad

peak with mean dominant frequency of 2.5 KHz (Figure 3, Table 2).

Distribution

The niche-based prediction model of distribution in the southern Western Ghats suggests that the species is restricted to montane grasslands of Munnar-Valparai area of Anamalai massif. The EOO and AOO calculated using GeoCAT are 289km² and 84km², respectively. The approximate EOO calculated based on the prediction using minimum convex polygon was ~272km² with the majority of the area being within ENP and the calculated EOO does not include areas where our model suggested a low, very low likelihood of occurrence as there were no actual observations of the species in these areas (Image 2). The species habitat is well-protected as its distribution largely occurs within protected areas. The areas outside the protected area network owned by the Kerala Forest Department where the species occurs could be further designated as eco-sensitive zones to prevent management-based habitat modifications

Table 2. Call characteristics of 141 calls of *Raorchestes resplendens* from 10 males.

Call character	Mean	SD	Minimum	Maximum
Call duration (ms)	103	37.3	58.9	148.8
Call rise time (ms)	46.3	29.4	11.9	80.5
Call fall time (ms)	56.7	16.8	39.9	69.8
Intercall interval (s)	2.9	3.6	1.4	4.9
Overall dominant frequency (KHz)	2.5	0.1	2.4	2.8
Call rate (calls/min)	21.5	7.9	16.1	41.4



Image 3. Marshy grassland habitat of *Raorchestes resplendens*.

(Kanagavel et al. 2018). The absence of the species at Anamudi National Park and adjacent areas could be due to the absence of grassland habitats.

The report of the species from areas other than Eravikulam National Park including Chinnar Wildlife Sanctuary, grass hills of Anamalai Tiger Reserve, and areas of Munnar Forest Division ensures better conservation possibilities as these areas are under protection by the Kerala and Tamil Nadu forest departments. Controlled cold burning of grasslands in November–February months before the grass gets dry (Image 4), practiced as a part of habitat management programme in Eravikulam National Park (Kerala Forests & Wildlife Department 2013), is observed to be detrimental to slow-moving reptiles and amphibians due to mortality during the fire and exposed habitat without thick grasses (Image 5) after fires. It was also observed that the mortality is



Image 4. Control burning in montane grasslands.

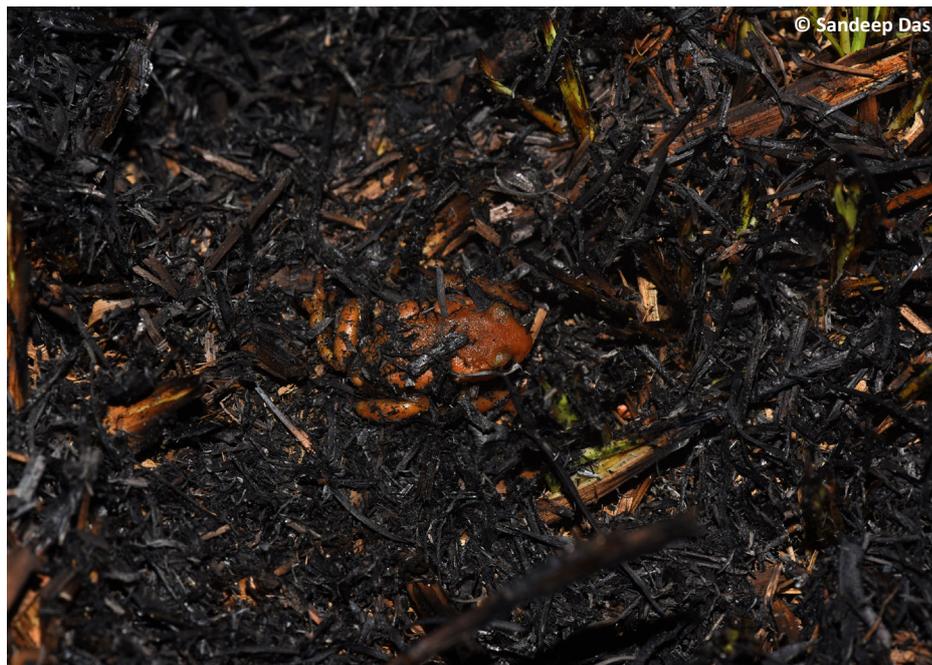


Image 5. *Raorchestes resplendens* moving through burnt grassland.



comparatively less and recolonization in smaller animals is faster in areas where mosaic pattern is followed while burning (Bhaskar et al. 2019). A further reduction in the size of the burnt areas in mosaic pattern would ensure better protection to the herpetofauna. More sampling efforts and systematic approach is required to understand more about the specific threats faced by the *Raorchestes resplendens*. The management practice of controlled burning, however, might be a threat that needs immediate attention which is specific to ENP, one of its major habitat.

Information on the call of the species will be helpful in further studies as the species is very hard to detect which might be the possible reason for detecting the species from only two locations after the initial description of species in 2010 and the knowledge of the distribution extent can lead to proper conservation action plans for the Critically Endangered species.

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Article

Use of an embedded fruit by Nicobar Long-tailed Macaque *Macaca fascicularis umbrosus*: II. Demographic influences on choices of coconuts *Cocos nucifera* and pattern of forays to palm plantations

– Sayantan Das, Rebekah C. David, Ashvita Anand, Saurav Harikumar, Rubina Rajan & Mewa Singh, Pp. 16407–16423

Communications

Habitat preference and current distribution of Chinese Pangolin (*Manis pentadactyla* L. 1758) in Dorokha Dungkhag, Samtse, southern Bhutan

– Dago Dorji, Jambay, Ju Lian Chong & Tshering Dorji, Pp. 16424–16433

A checklist of mammals with historical records from Darjeeling-Sikkim Himalaya landscape, India

– Thangsuanlian Naulak & Sunita Pradhan, Pp. 16434–16459

Golden Jackal *Canis aureus* Linnaeus, 1758 (Mammalia: Carnivora: Canidae) distribution pattern and feeding at Point Calimere Wildlife Sanctuary, India

– Nagarajan Baskaran, Ganesan Karthikeyan & Kamaraj Ramkumaran, Pp. 16460–16468

Suppression of ovarian activity in a captive African Lion *Panthera leo* after deslorelin treatment

– Daniela Paes de Almeida Ferreira Braga, Cristiane Schilbach Pizzutto, Derek Andrew Rosenfield, Priscila Viau Furtado, Cláudio A. Oliveira, Sandra Helena Ramiro Corrêa, Pedro Nacib Jorge-Neto & Marcelo Alcindo de Barros Vaz Guimarães, Pp. 16469–16477

Spatial aggregation and specificity of incidents with wildlife make tea plantations in southern India potential buffers with protected areas

– Tamanna Kalam, Tejesvini A. Puttaveeraswamy, Rajeev K. Srivastava, Jean-Philippe Puyravaud & Priya Davidar, Pp. 16478–16493

Innovative way of human-elephant competition mitigation

– Sanjit Kumar Saha, Pp. 16494–16501

New locality records and call description of the Resplendent Shrub Frog *Raorchestes resplendens* (Amphibia: Anura: Rhacophoridae) from the Western Ghats, India

– Sandeep Das, K.P. Rajkumar, K.A. Sreejith, M. Royaltata & P.S. Easa, Pp. 16502–16509

First record of a morphologically abnormal and highly metal-contaminated Spotback Skate *Atlantoraja castelnaui* (Rajiformes: Arhynchobatidae) from southeastern Rio de Janeiro, Brazil

– Rachel Ann Hauser-Davis, Márcio L.V. Barbosa-Filho, Lucia Helena S. de S. Pereira, Catarina A. Lopes, Sérgio C. Moreira, Rafael C.C. Rocha, Tatiana D. Saint’Pierre, Paula Baldassin & Salvatore Siciliano, Pp. 16510–16520

Butterfly diversity in an organic tea estate of Darjeeling Hills, eastern Himalaya, India

– Aditya Pradhan & Sarala Khaling, Pp. 16521–16530

Freshwater decapods (Crustacea: Decapoda) of Palair Reservoir, Telangana, India

– Sudipta Mandal, Deepa Jaiswal, A. Narahari & C. Shiva Shankar, Pp. 16531–16547

Diversity and distribution of figs in Tripura with four new additional records

– Smita Debbarma, Biplab Banik, Biswajit Baishnab, B.K. Datta & Koushik Majumdar, Pp. 16548–16570

Member



Short Communications

Open garbage dumps near protected areas in Uttarakhand: an emerging threat to Asian Elephants in the Shivalik Elephant Reserve

– Kanchan Puri, Ritesh Joshi & Vaibhav Singh, Pp. 16571–16575

A preliminary checklist of spiders (Araneae: Arachnida) in Jambughoda Wildlife Sanctuary, Panchmahal District, Gujarat, India

– Reshma Solanki, Manju Siliwal & Dolly Kumar, Pp. 16576–16596

Preliminary checklist of spider fauna (Araneae: Arachnida) of Chandranath Hill, Goa, India

– Rupali Pandit & Mangirish Dharwadkar, Pp. 16597–16606

Butterfly (Lepidoptera: Rhopalocera) fauna of Jabalpur City, Madhya Pradesh, India

– Jagat S. Flora, Ashish D. Tiple, Ashok Sengupta & Sonali V. Padwad, Pp. 16607–16613

Evaluating threats and conservation status of South African *Aloe*

– Samuel O. Bamigboye, Pp. 16614–16619

Notes

The first record of Montagu’s Harrier *Circus pygargus* (Aves: Accipitridae) in West Bengal, India

– Suman Pratihari & Niloy Mandal, Pp. 16620–16621

An account of snake specimens in St. Joseph’s College Museum Kozhikode, India, with data on species diversity

– V.J. Zacharias & Boby Jose, Pp. 16622–16627

Notes on the occurrence of a rare pufferfish, *Chelonodontops leopardus* (Day, 1878) (Tetraodontiformes: Tetraodontidae), in the freshwaters of Payaswini River, Karnataka, India

– Priyanka Chakraborty, Subhrendu Sekhar Mishra & Kranti Yardi, Pp. 16628–16631

New records of hoverflies of the genus *Volucella* Geoffroy (Diptera: Syrphidae) from Pakistan along with a checklist of known species

– Muhammad Asghar Hassan, Imran Bodlah, Anjum Shehzad & Noor Fatima, Pp. 16632–16635

A new species of *Dillenia* (Angiosperms: Dilleniaceae) from the Eastern Ghats of Andhra Pradesh, India

– J. Swamy, L. Rasingam, S. Nagaraju & Pooja R. Mane, Pp. 16636–16640

Reinstatement of *Pimpinella katrajensis* R.S.Rao & Hemadri (Apiaceae), an endemic species to Maharashtra with notes on its taxonomy and distribution

– S.M. Deshpande, S.D. Kulkarni, R.B. More & K.V.C. Gosavi, Pp. 16641–16643

***Puccinia duthiei* Ellis & Tracy: a new host record on *Chrysopogon velutinus* from India**

– Suhas Kundlik Kamble, Pp. 16644–16646

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