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Annotated list of anurans from the lateritic plateau of western India with notes on malformations

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Abstract
Lateritic plateaus of India are geographically and ecologically complex plateaus that support endemic flora and fauna. However, despite their uniqueness they are termed as "wastelands". The plateaus' overall treeless structure makes them susceptible to developmental activities like infrastructure growth, waste dumping, and urbanization. This paper presents a list of anurans compiled from surveys carried out in the years between 2016 and 2018 in the town of Manipal, a predominant lateritic landscape on the west coast of India. The list comprises of 19 species belonging to five different families, includes notes on microhabitat structure and associated species. We also present descriptions of malformed frogs recorded during the surveys. The growing demands for urbanization, presence of malformed frogs, and habitat complexities that support species densities highlight the need to re-evaluate our understanding towards these plateaus. We express our concern towards the need for conservation of these lesser known amphibian habitats.

Keywords
Amphibians, frogs, conservation, Manipal, deformity.

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Introduction

Lateritic formations, rich in iron and aluminum, are typical of tropical regions and are a part of the Deccan Traps floodplains (Widdowson and Cox 1996). The lateritic plateaus of India's Western Ghats are known to have formed 25–40 million years ago during the mid-Tertiary and are the result of weathering of surficial rocks in tropical and subtropical climatic conditions (Ollier and Sheth 2008). The lateritic plateaus are important in regulating water and replenishing perennial streams in the peninsular India (Margherita 2014; Buono et al. 2015). The lateritic plateaus are largely treeless, but with abundant herbaceous vegetation during monsoon season (Lekhak and Yadav 2012).

Several endemic species of hydrogeomorphic plant, invertebrate, and vertebrate species thrive on these plateaus (Rao et al. 2012). Studies on the ecology, as well as floral and faunal diversity on lateritic outcrops are available for the northern Western Ghats, north of 16°N (e.g. Lekhak and Yadav 2012; Watve 2013). The rate of species discovery and endemicity on these plateaus is high

(Katwate et al. 2013; Watve 2013; Rahangdale and Rahangdale 2014; Thorpe and Watve 2016; Seshadri et al. 2016), possibly due to the presence of several microhabitats such as shallow perennial streams, rocky crevices, and soil-filled depressions (Sreejith et al. 2016; Thorpe et al. 2018). Recently described frog species, such as *Microhyla kodial* Vineeth, Radhakrishna, Godwin, Anwesha, Rajashekhar & Aravind, 2018, *Microhyla laterite* Seshadri, Singal, Priti, Ravikanth, Vidisha, Saurabh, Pratik & Gururaja, 2016 and *Euphlyctis karaavali* Priti, Naik, Seshadri, Singal, Vidisha, Ravikanth & Gururaja, 2016 have been discovered from the Karnataka Plateau in the last five years (Priti et al. 2016; Seshadri et al. 2016; Vineeth et al. 2018).

Despite the uniqueness of these plateaus for their geology and biodiversity, these areas are considered wasteland (Ministry of Rural Development and National Remote Sensing Agency 2010), and because these plateaus are flat, they are ideal areas for infrastructure growth or for garbage dumping (Hamer and McDonnell 2008). Watve (2013) and Thorpe and Watve (2016) highlighted the impacts of laterite mining for bricks used in building construction and of erecting wind farms and townships on laterite plateaus, which causes an irreplaceable loss of this unique ecosystem. The biodiversity of the region is neglected and yet to be explored (Watve 2013).

Evidence shows that extant amphibian species with smaller ranges or those living in tropical forested patches are suffering increased risk of extinction with up to 200 documented extinctions since 1970–80s (Pimm et al. 2014; Alroy 2015). With growing economic and infrastructure demands, natural habitats are under threat, especially in countries like India (Mckinney 2002; Butchart et al. 2010). Rapid landscape modifications have not only caused a decline in amphibian species and abundances but have also predisposed them to malformations (Caughley 1994; Wells 2007; Hamer and McDonnell 2008). There is a strong link between freshwater pollution and skeletal and soft tissue malformations in amphibians (Meteyer 2000; Lannoo 2008).

Although there have been several taxonomic studies on anurans of the Western Ghats, the unique plateau habitats within the Ghats that lie outside protected areas, remain understudied (Seshadri et al. 2016). A few new species have been described from the lateritic plateaus, but no effort has been made to understand ecology and conservation of anuran species in these habitats. In this paper, we document anurans from the lateritic plateaus of Manipal in western India, and we present notes on species presence according to the habitat complexity on the lateritic plateaus. The various types of malformations, seen during our surveys and surveys made along with citizen scientists on these plateaus, are described.

Methods

Study area. Our study was carried out on the lateritic plateaus of the town of Manipal (13.2868°–13.3757°N, 074.7795°–074.8731°E, WGS 84), in Udupi District, on the west coast of India in the state of Karnataka (Fig. 1).

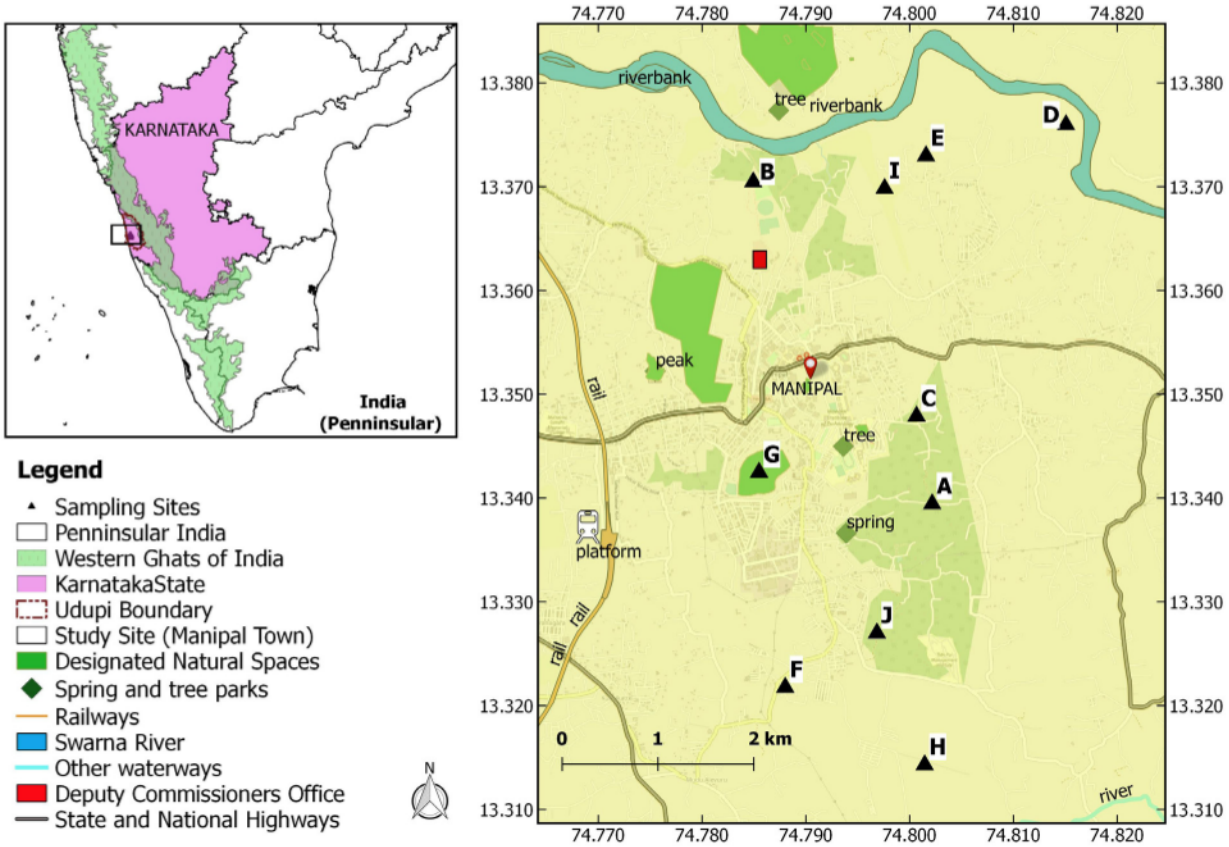

Figure 1. Map showing the study area and sampling sites (see Table 2) in the town of Manipal, Udupi District, Karnataka state, India.

The study site lies at an elevation of 50 m above mean sea level. The town of Manipal has the Western Ghats to the east and the Arabian Sea to the west. It is largely a plateau interspersed with patches of the tropical evergreen forest and moist deciduous forest dominated by *Dipterocarpus* species, grasses, herbs, and shrubs (Rao et al. 2012; Seshadri et al. 2016). Manipal also has agricultural fields, houses and other buildings, and garbage dumps. The climate is tropical, with around six months of precipitation (average rainfall 3700 mm) received during the south-west monsoon season (June to October). The month of May is the warmest, with temperatures reaching up to 35 °C, and January is the coldest with temperatures only reaching 18 °C (Seshadri et al. 2016).

Sampling. We conducted time-constrained, visual encounter surveys in pre-identified sites in and around Manipal (Crump and Scott 1994; Rodda et al. 2005). The sampling sites where transect walks were done are shown in Figure 1, and the habitats in the study site are shown in Figure 2. At each location, amphibians were sampled for 60 minutes from 1800 to 1900 hours twice a week during monsoons by two researchers (see Dodd 2010). Forty surveys were conducted between May 2016 and August 2018. At each sampling site an average of four surveys were carried out. The surveys included citizen scientists from the town to educate them about amphibians, and we ensured that they did not handle the animals. Once an animal was found, it was gently captured using powder- and latex-free medical gloves. For all captured animals, snout–vent length (SVL) was measured in the field to nearest 1 mm. Specimens were photographed in the field to assess the visual and morphological differences among the species. The species were identified using available keys (Das and Ravichandran 1998; Gururaja 2012; Biju et al. 2014; Modak et al. 2015; Peloso et al. 2015; Garg and Biju 2016; Priti et al. 2016; Seshadri et al. 2016; Sanchez et al. 2018; Garg et al. 2019; Dinesh et al. 2020). All photographs and audio recordings were made using an iPhone SEA1723. Some calls were recorded using the inbuilt voice recorder app in the same device and used for identification following Ramya et al. (2015).

Molecular barcoding. When tadpoles were encountered, tadpole tail tip of less than 5 mm was excised and preserved in ethanol for species identification (Clarke et al. 2019). The tail tips were processed for total genomic DNA extraction using QiagenDNeasy Blood and Tissue kit following the manufactures protocol in the molecular genetics lab at Ashoka Trust for Research in Ecology and the Environment (ATREE). The 16S rRNA gene was chosen as the gene for barcoding and species identification following Vences et al. (2005) and a touchdown PCR was performed following Biju et. al. (2014) and Gururaja et al. (2014). The amplified PCR products

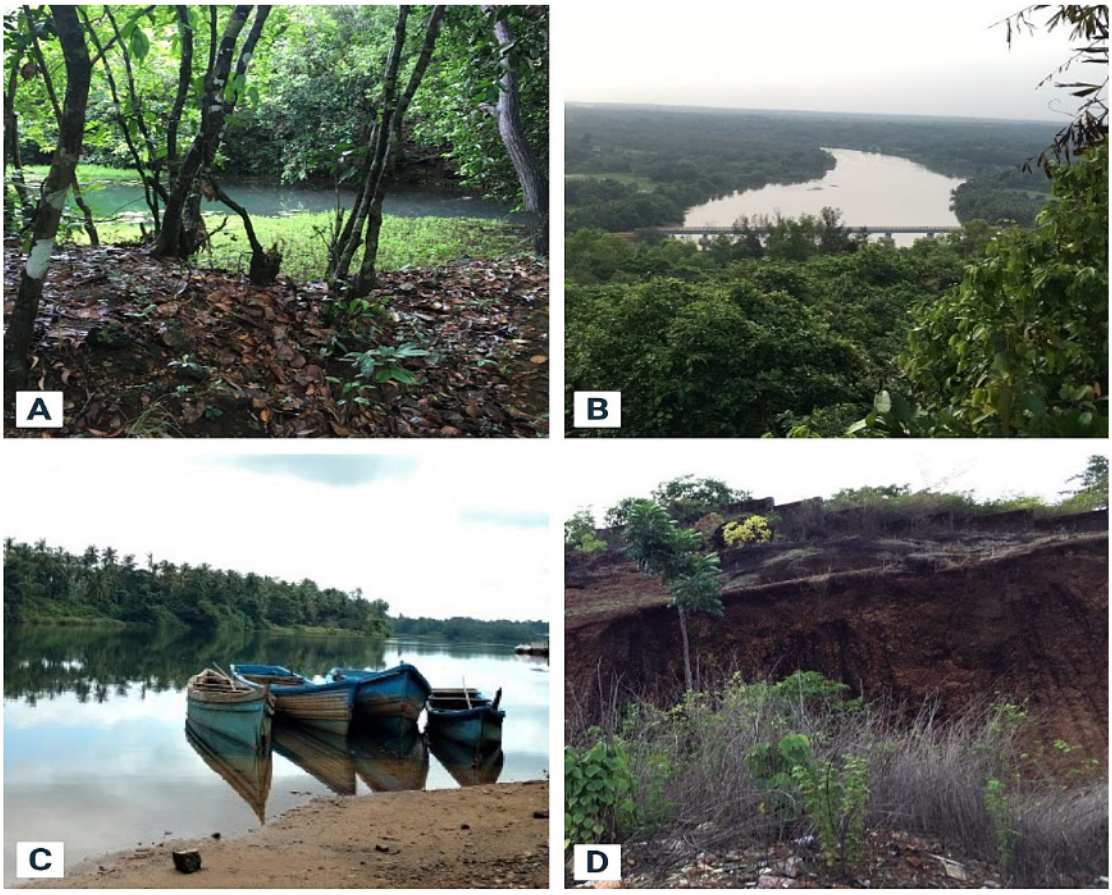

Figure 2. Habitats at sites in the study area in and around the town of Manipal, Udupi District, Karnataka state, India. **A.** Vegetation with pool. **B, C.** River. **D.** Exposed laterite, with garbage dumping and laterite mining.

were sequenced at Barcode Biosciences Pvt. Ltd., Bangalore, India, using an ABI 3730xl DNA sequencer. The sequences were edited using MEGA 10.1.6 and deposited in GenBank (Kumar et al. 2018). Accession numbers are provided in Result. All samples are currently stored at the ATREE repository and will be deposited at Bombay Natural History Society Museum, Mumbai, India, after the completion of our larger project by 2023.

Examination for malformations. All amphibians were visually examined for presence of any signs of malformations. The webbing (when present) was also checked for any signs of injury or deformity. All the descriptions of malformations follow Meteyer (2000) and Lannoo (2008).

Voucher specimens. We collected voucher specimens only for cryptic species. Accession numbers are provided for samples that were collected. We refrained from collecting samples for those species for which vouchers have been collected in the past and taxonomy has been resolved (Garg and Biju 2016; Priti et al. 2016; Seshadri et al. 2016).

Results

Nineteen species of anurans (Table 1; Fig. 3) were recorded from the lateritic plateaus of Manipal. These belong to six families and 13 genera. Among the six families, Dicroglossidae was the most species-rich family with eight species (42%), whereas Ranixalidae and Bufonidae had only one species each. Figure 4 shows the total number of individuals for each species recorded. *Euphlyctis mudigere*, *Minervarya caperata*, and *Hoplobatrachus tigerinus* had of the most sightings and *Sphaerotheca dobsonii*, *Uperodon mormoratus*, and *Polypedates pseudocruciger* were sighted the least.

Microhabitats at each of the sampling sites are according to Sreejith et al. (2016) and Thorpe et al. (2018), and species presence in the sites is shown in Table 2 and Figures 5 and 6. Along with the citizen scientists, we found 10 malformed individuals (Table 3; Fig. 7): three (30%) *Minervarya caperata* had dermal lesions, amelia, and micropthalmia; three (30%) *Euphlyctis mudigere* had nematode infection, dermal lesion, and a combination of ectrodactyly and micromely; two (20%) *Hoplobatrachus tigerinus* had dermal lesion and cloacal prolapse; and one (10%) each of *Uperodon mormoratus* and *Minervarya rufescens* had anophthalmia.

Family Bufonidae

***Duttaphrynus melanostictus* (Schneider, 1799)**

New records. INDIA • Karnataka: Udupi: Manipal, Dashrath Nagar, site code A (13.3394°N, 074.8021°E), obs. by MM and RS, 30 May 2017, 11 individuals; Fig. 3A.

Identification. The SVL is up to 150 mm. This species has a pair of elongated poison glands on the dorsum just

Table 1. Species present by sampling sites in the study area and their IUCN (2019) Red List categories. The total number of species at each site is given.

Family, species	Site code										Red List category
	A	B	C	D	E	F	G	H	I	J	
Bufonidae											
Duttaphrynus melanostictus	+	+	+		+			+			Least Concern
Dicroglossidae											
Euphlyctis aloysii				+			+		+		Not Evaluated
Euphlyctis karaavali					+				+		Not Evaluated
Euphlyctis mudigere	+	+	+	+	+	+	+		+		Not Evaluated
Minervarya caperata	+		+	+	+		+	+	+	+	Not Evaluated
Minervarya sahyadris		+	+		+	+	+	+	+	+	Endangered
Minervarya rufescens	+	+	+		+		+		+	+	Not Evaluated
Hoplobatrachus tigerinus	+	+	+	+	+	+	+		+	+	Least Concern
Sphaerotheca dobsonii		+				+	+				Least Concern
Microhylidae											
Microhyla laterite	+	+	+	+	+	+		+	+		Not Evaluated
Microhyla nilphamariensis	+	+	+	+	+	+		+			Not Evaluated
Uperodon mormoratus	+		+	+	+				+	+	Endangered
Ranidae											
Hydrophylax bahuvistara	+				+		+	+	+		Not Evaluated
Indosylvirana intermedia	+	+			+		+	+	+	+	Not Evaluated
Ranixalidae											
Indirana duboisi		+						+			Least Concern
Rhacophoridae											
Polypedates maculatus	+	+		+	+	+	+	+	+	+	Least Concern
Polypedates pseudocruciger	+	+	+		+			+	+	+	Least Concern
Pseudophilautus wynaadensis	+	+	+		+		+	+	+	+	Endangered
Rhacophorus malabaricus			+		+				+		Least Concern
Total species at each site	13	13	12	8	16	7	11	11	15	9	

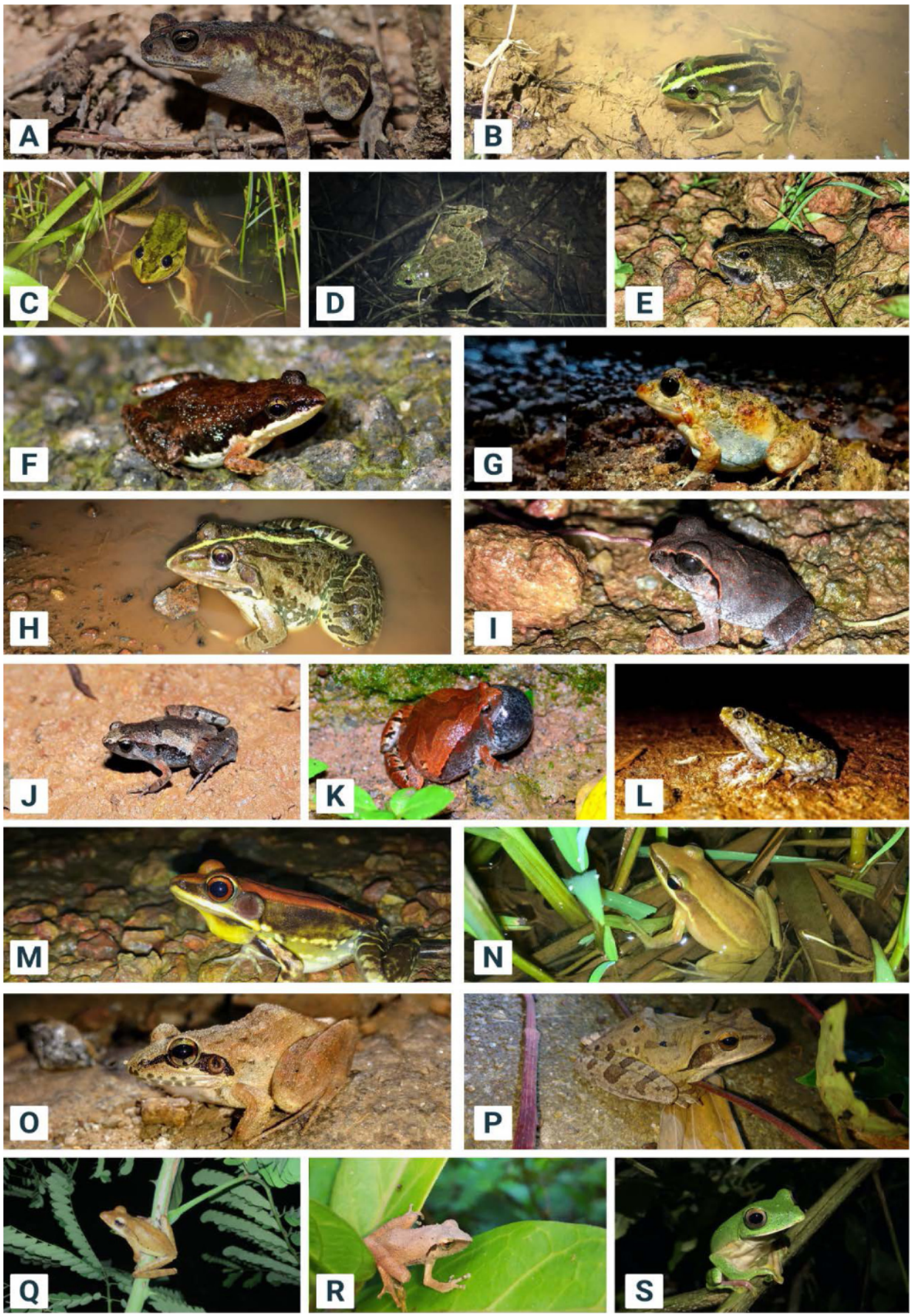

Figure 3. Reference images of all anurans from the laterite plateaus of Manipal. **A.** *Duttaphrynus melanostictus*. **B.** *Euphlyctis aloysii*. **C.** *Euphlyctis karaavali*. **D.** *Euphlyctis mudigere*. **E.** *Minervarya caperata*. **F.** *Minervarya sahyadris*. **G.** *Minervarya rufescens*. **H.** *Hoplobatrachus tigerinus*. **I.** *Sphaerotheca dobsoniii*. **J.** *Microhyla laterite*. **K.** *Microhyla nilphamariensis*. **L.** *Uperodon mormoratus*. **M.** *Hydrophylax bahuvistara*. **N.** *Indosylvirana intermedia*. **O.** *Indirana duboisi*. **P.** *Polypedates maculatus*. **Q.** *Polypedates pseudocruciger*. **R.** *Pseudophilautus wynaadensis*. **S.** *Rhacophorus malabaricus*.

Table 2. Habitats at sampling sites in the town of Manipal (Thorpe et al. 2018).

Sampling sites	Site code	Habitat	Latitude (°N)	Longitude (°E)
Dashrath Nagar	A	Dense, mixed vegetation of tree cover and associates, with small ephemeral pools interspersed with exposed laterite rocks	13.3394	074.8022
End Point	B	Public park; patches of dense, mixed vegetation; tree cover; on slope of laterite hill/rock; acacia and other (e.g. coconut and areca nut) plantations; grass patches and football fields	13.3704	074.7849
Eshwar Nagar	C	Dense mixed vegetation of tree cover and associates; on slope of laterite hill/rock, with small ephemeral pools	13.3478	074.8006
Golikatte	D	Mixed, *Acacia* and *Dipterocarpus* with vegetation patches of tree cover and associates; edge of a river with soil-filled shallow depressions; soil rich areas; paddy fields and plantations	13.3759	074.8150
Herga	E	Dense, mixed, *Acacia* and *Dipterocarpus* vegetation; edge of a river; soil rich areas; paddy fields and exposed laterite rock	13.3729	074.8015
Manchikere	F	Large, ephemeral pool and exposed laterite patch with rocky crevices, grass, and shrubs; ephemeral flush vegetation; no trees	13.3217	074.788
Manipal Lake	G	Lake with ephemeral, flush vegetation, boulders; soil rich areas interspersed with patches of natural and planted vegetation; tree cover	13.3424	074.7854
Pragathi Nagar	H	Small, ephemeral pools on laterite rocks surrounded by dense vegetation of *Dipterocarpus*; *Acacia* plantations	13.3142	074.8014
Saralebettu	I	Mixed vegetation on edge of river, exposed laterite patch, grasses, and shrubs; paddy fields and patches of *Dipterocarpus* vegetation; tree cover and associates	13.3698	074.7975
Shanthi Nagar	J	Dense *Dipterocarpus* vegetation interspersed with *Acacia* plantations on laterite slope; ephemeral flush vegetation	13.3269	074.7968
Baba Point*	—	Small restaurant surrounded with dense, mixed vegetation of *Dipterocarpus* and *Acacia* on edge of river	13.3729	074.7831
Egg Factory*	—	Restaurant with mixed vegetation on laterite plateau	13.3511	074.7878

*Sites not included in our sampling but having malformed frogs recorded by citizen scientists.

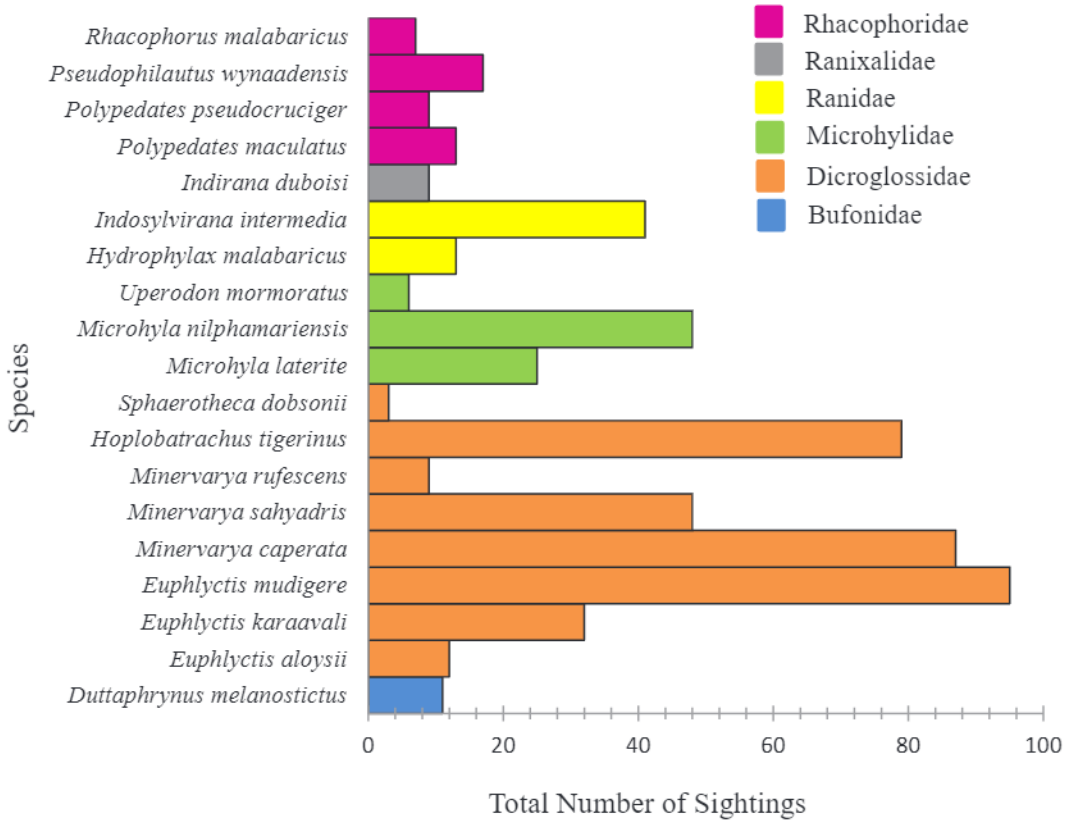

Figure 4. Number of sightings of each species in this study. The colors group the species into families.

above the eyes. There are prominent, black, V-shaped, bony ridges on the dorsal snout. The dorsal skin is marked with tiny, reddish warts. The coloration is usually dusty brown, but changes to yellowish brown during the breeding season, which coincides with monsoons. **Habitat.** This toad lives in relatively dry areas and is often found foraging in the leaf litter, under lampposts that fringe roads, and on terrain with few vehicles. **Distribution.** This frog is distributed across Asia, and is introduced in Sulawesi, East Timor, Madagascar, and Papua-New Guinea.

Family Dicroglossidae

Euphlyctis aloysii Joshy, Alam, Kurabayashi, Sumida & Kuramoto, 2009

New records. INDIA • Karnataka: Udupi: Manipal, Saralebettu, site code I (13.3698°N, 074.7975°E), obs. by MM, KVG and RS, 2 Jan. 2017, 12 individuals; Fig. 3B.

Identification. The SVL is 31.8–41.2 mm. This species has a deep greenish color with four elliptical marks (two are prominent) on the dorsum separated with a narrow, pale yellowish-white mid-dorsal line. There is full

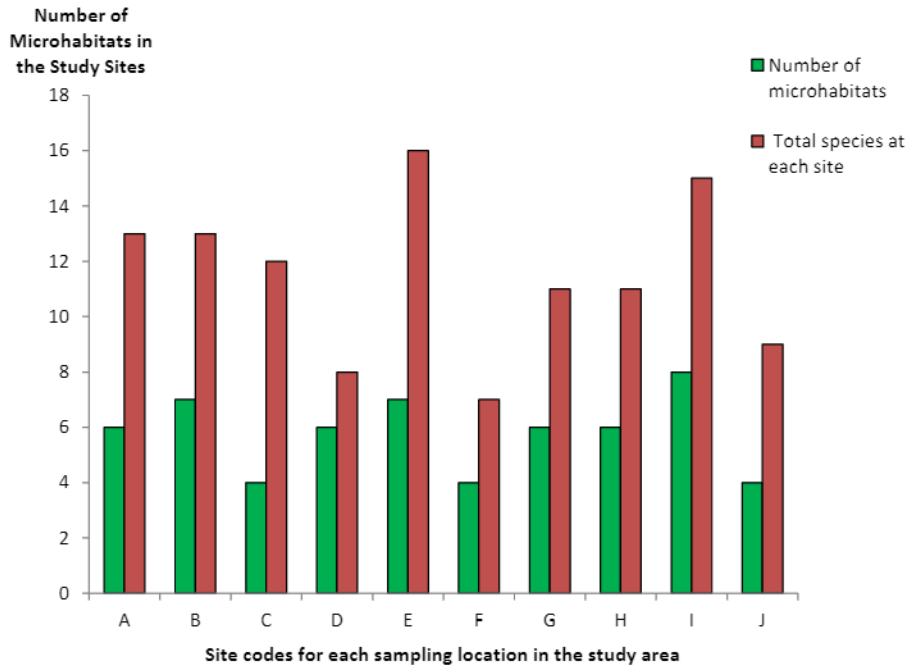

Figure 5. Microhabitat availability and the total number of species at each site in the study area. Site codes correspond to Table 2.

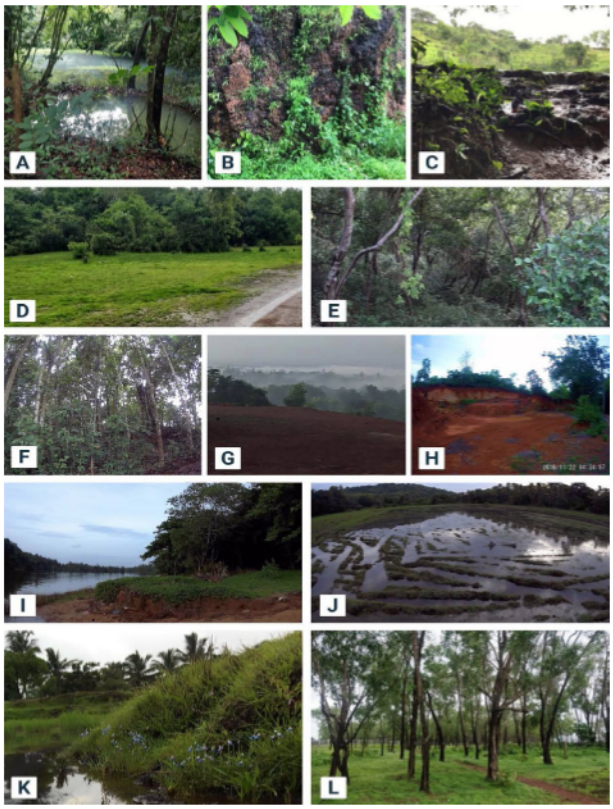

Figure 6. Microhabitats occupied by anurans in the laterite plateaus of Manipal. **A.** Ephemeral pool. **B.** Exposed laterite rocks. **C.** Rocky crevices. **D.** Grass patches and shrubs. **E, F.** Dense, mixed vegetation. **G.** Soil rich areas. **H.** Soil-filled shallow depressions. **I.** River and river banks. **J.** Paddy fields. **K.** Ephemeral, flush vegetation. **L.** *Acacia* plantations.

webbing on the hind feet. The call consists of a high pitched trill.

Habitat. It is an aquatic frog, found across the study area in waterlogged paddy fields and small ephemeral pools.

Distribution. This frog is endemic to south-western India.

Euphlyctis karaavali Priti, Naik, Seshadri, Singal, Vidisha, Ravikanth & Gururaja, 2016

New records. INDIA • Karnataka: Udupi: Manipal, Saralebettu, site code I (13.3698°N, 074.7975°E), obs. by MM, KVG and RS, 2 Jan. 2017, 32 individuals. Fig. 3C.

Identification. The SVL is 70.9–106 mm. This species was first described in 2016 from Herga, a part of the study area. It has a pointed snout, presence of granular tubercles on the dorsum and granular, short, spine-like tubercles from the eyes all the way to the groin. The body is unmistakable large and slimy. There is a pair of blackish-purple vocal sacs. A dark-green strip extends on the flanks from the supra-tympanic fold to the groin.

Habitat. It is an aquatic frog. It is often found calling from bunds in drier seasons and from waterlogged paddy fields in the breeding season/monsoon. The call is a distinctive, like the call of a White-throated Kingfisher.

Distribution. This frog is endemic to southwestern coast of India.

Euphlyctis mudigere Joshy, Alam, Kurabayashi, Sumida & Kuramoto, 2009

New records. INDIA • Karnataka: Udupi: Manipal, Saralebettu, site code I (13.3698°N, 074.7975°E), obs. by MM and RS, 2 Jan. 2017, 95 individuals. Fig. 3D.

Identification. The SVL is 28.1–34.8 mm. This species has sparse granules on its dorsum and an unmistakable, inverted, W-shaped mark. It has a pair of dark vocal sacks. The hind feet are fully webbed. This species is the smallest among species of *Euphlyctis* (Joshy et al. 2009). This species is one of the most abundant frogs

Table 3. Brief description of reported malformations in the study area followed by species names and number of individuals affected for each species.

Type of malformation	Description	Species and number of individuals affected
Nematode infection	Roundworm infection	*Euphlyctis mudigere* (1)
Anophthalmia	Missing eye	*Uperodon mormoratus* (1) *Minervarya rufescens* (1)
Dermal lesion	Infectious or non-infectious lesion of the skin	*Euphlyctis mudigere* (1) *Minervarya caperata* (1) *Hoplobatrachus tigerinus* (1)
Amelia	Missing limb	*Minervarya caperata* (1)
Micropthalmia	Small eye	*Minervarya caperata* (1)
Combination of ectrodactyly and micromely	Complete absence of digit including metatarsal bone and small limb	*Euphlyctis mudigere* (1)
Cloacal prolapse	Organs such as the bladder, intestines and uterus seen protruding from the cloaca	*Hoplobatrachus tigerinus* (1)

Figure 7. Malformations in anurans in the study area. **A.** Anophthalmia in *Uperodon mormoratus*. **B.** Amelia in *Minervarya caperata*. **C.** Combination of ectrodactyly and micromely in *Euphlyctis mudigere*. **D.** Micropthalmia in *Minervarya caperata*. **E.** Nematode infection in *Euphlyctis mudigere*. **F.** Dermal lesion in *Euphlyctis mudigere*. **G.** Cloacal prolapse in *Hoplobatrachus tigerinus*.

throughout the plateau. The call is distinctive, continuous, and repetitive, and only heard during monsoons.

Habitat. This species was often heard and seen calling from small to medium-sized ephemeral puddles along roadsides or in gardens.

Distribution. This frog is endemic to south-western India.

Minervarya caperata (Kuramoto, Joshy, Kurabayashi & Sumida, 2008)

New records. INDIA • Karnataka: Udupi: Manipal, Eshwarnagar, site code C (13.3478°N, 074.8006°E), obs. by MM and RS, 29 May 2017, 87 individuals. Fig. 3E.
Identification. The SVL is about 35 mm. This frog has distinctive lateral lines (Fejervaryan lines) beginning from the groin on the ventral side. It has four ridge-like skin folds on the dorsum which is overall patchy greenish brown.

Habitat. This frog is often found calling in semi-aquatic habitats, like the edges of drains, ephemeral pools, and other small water bodies. This was one of the frequently encountered frogs during the surveys. It lives close to roads and other human habitations (Sanchez et al. 2018). The continuous cricket-like call is only heard during monsoons.

Distribution. This frog is endemic to southern India.

Minervarya sahyadris (Annandale, 1919)

New records. INDIA • Karnataka: Udupi: Manipal, Pragathi nagar, area code H (13.3142°N, 074.8014°E), obs. by MM & RS, 9 Apr. 2017, 48 individuals, MN953003. Fig. 3F.

Identification. The SVL is about 22 mm. The dorsum is shiny, glandular, and brownish-red. In the breeding season, the colors are more prominent. A dark stripe is apparent on the flanks. The rictal gland is visible on close examination or in clear photographs. The ventral side is cream-colored (Sanchez et al. 2018). Single individuals are never found, but a group of about four or five individuals are seen calling. The call is cricket-like, a loud series of "chucks", and was heard only during monsoons.

Habitat. This species was found calling from edges of ephemeral pools, puddles, and drains. It was often found close to human habitations, like roads or old houses.

Distribution. This species is endemic to south-western India.

Minervarya rufescens (Jerdon, 1853)

New records. INDIA • Karnataka: Udupi: Manipal, Saralebettu, site code I (13.3698°N, 074.7975°E), obs. by MM and RS, 9 Jan. 2017, 9 individuals. Fig. 3G.

Identification. The SVL is about 45 mm. This species has granular dorsal skin, which more or less resembles that of a toad and distinguishes it from other similar species described above. There are no discs on the fingers and toes. The overall coloration is brownish to reddish. It has a pair of Fejervaryan lines. The call is similar to other species of *Minervarya* but is more nasal.

Habitat. This species occurs in semi-aquatic habitats, like laterite flats or plains and lake surfaces with flush vegetation.

Distribution. This frog is endemic to the southern Western Ghats and is known only from the states of Karnataka and Kerala.

Hoplobatrachus tigerinus (Daudin, 1803)

New records. INDIA • Karnataka: Udupi: Manipal, Manipal lake. site code G (13.3424°N, 074.7854°E), obs. by MM & RS, 15 Feb. 2017, 79 individuals, MN952994 and MN952995. Fig. 3H.

Identification. The SVL is up to 180 mm. The body is large, with the dorsum greenish overall, but turning yellow after the first monsoon shower. We did not see any bright-yellow individuals with neon blue vocal sacs and instead only say a few individuals with some yellowish coloration on the flanks and dorsum. We noted that some frogs retain their yellowness throughout the breeding season. The feet are fully webbed. This frog is similar to *H. crassus* (Jerdon, 1853); however, *H. crassus*, a species with a very limited range, and has oval spots on the lower limbs rather than the stripes of *H. tigerinus*. The call is wheezing, nasal, and growl-like.

Habitat. This species was seen in semi-aquatic habitats and on the edges of perennial lakes and other water bodies. It is also known from secondary forests lined with acacia plantations.

Distribution. This species occurs in India, Bangladesh, Pakistan, Nepal, Myanmar, Afghanistan, and Sri Lanka. It is introduced in Maldives and Madagascar.

Sphaerotheca dobsonii (Boulenger, 1882)

New records. INDIA • Karnataka: Udupi: Manipal, End Point, site code B (13.3704°N, 074.7849°E), obs. by MM and RS, 4 Jul. 2017, 3 individuals. Fig. 3I.

Identification. The SVL is up to 60 mm. This is a fossorial frog, and we recorded only three individuals, two males and one female from different sampling points. This species has a prominent metatarsal tubercle (a digging apparatus) on its hind limbs. The body is uniquely rotund, with relatively short limbs. The hind limbs appear to be much stronger than fore limbs. The dorsum is distinctive, light brownish. The ventral side is cream-colored with some brown-black pigmentation on the sides. Webbing is present on the toes of the hind feet. There is no webbing between the fingers (Gururaja 2012).

Habitat. This species was found on leaf litter of secondary forests or on the edges of pools with abundant to no canopy cover.

Distribution. This frog is endemic to the southern Western Ghats.

Family Microhylidae

***Microhyla laterite* Seshadri, Singal, Priti, Ravikanth, Vidisha, Saurabh, Pratik & Gururaja, 2016**

New records. INDIA • Karnataka: Udupi: Manipal, End Point, site code B (13.3704°N, 074.7849°E), obs. by MM, KVG and RS, 16 Jul. 2017, 25 individuals. Fig. 3J.

Identification. The SVL is up to 15.3–16.6 mm. This species has a distinctive horizontal line in-line with its forearm. The ventral side is cream-colored with dark purplish-brown-speckled vocal sacs. *Microhyla sholigari* Dutta and Ray, 2000 is similar to *M. laterite*, but *M. sholigari* has cream-colored vocal sacs with sparse brown pigmentation and the horizontal line is lacking on the dorsum (Seshadri et al. 2016). It has a continuous "zee-zee" insect-like call.

Habitat. This species was found in large numbers across most ephemeral pools in the study area. It breeds in the shallow puddles formed within laterite rocks.
Distribution. This frog is endemic to the southern Western Ghats in the state of Karnataka.

***Microhyla nilphamariensis* Howlader, Nair, Gopalan & Merilä, 2015**

New records. INDIA • Karnataka: Udupi: Manipal, Manchikere, site code F (13.3217°N, 074.788°E), obs. by MM, KVG and RS, 20 Jul. 2017, 48 individuals, MN952998, MN952999 and MN953000. Fig. 3K.

Identification. The SVL is up to 17.36–17.84 mm. This species is distinguished from *M. laterite* and *Microhyla* species by the presence of dark vocal sacs and dark speckles on the ventral side of the thighs. Unlike *M. laterite*, it lacks the horizontal line on its dorsum. There is an S-shaped ornamentation that is similar to *M. ornata* (Duméril & Bibron, 1841) but *M. ornata* is larger (SVL = 25 mm) and the ventral side of the thighs are cream-colored, not dark-speckled as in *M. nilphamariensis*. The call is a deep croak.

Habitat. This species was found at edges of ephemeral pools, waterlogged paddy fields and gardens.

Distribution. This species occurs in Bangladesh, Nepal, and India.

***Uperodon mormoratus* (Rao, 1937)**

New records. INDIA • Karnataka: Udupi: Manipal, Herga, site code E (13.3729°N, 074.8015°E), obs. by MM & RS, 1 June 2017, 6 individuals. Fig. 3L.

Identification. The SVL is up to 35 mm. The dorsum is rough and warty with black markings on a brownish-yellow skin. The ventral side is smooth and has tiny, light greyish speckles. The toes and fingers show dilations. The snout and head very small compared to the rotund body. This species can be confused with *U. montanus* (Jerdon, 1854); however, *U. montanus* is currently known from the southern tip of India and is more brightly colored compared to *U. mormoratus* (Gururaja 2012; Peloso et al. 2015).

Habitat. The species was often found on the edges of roads, in leaf litter, or on forest floors. In peak breeding season, it was encountered calling from waterlogged paddy fields as well.

Distribution. This species is endemic to the Western Ghats.

Family Ranidae

***Hydrophylax bahuvistara* Padhye, Jadhav, Modak, Nameer & Dahanukar, 2015**

New records. INDIA • Karnataka: Udupi: Manipal, Manipal lake, site code G (13.3424°N, 074.7854°E), obs. by MM and RS, 5 Aug. 2017, 13 individuals. Fig. 3M.

Identification. The SVL is up to 44–70 mm for males and 47–70 mm for females. This species has bright-orange flanks and a dark, blackish dorsum. In the absence of molecular data, we considered expert opinion, the unmistakable morphological features, and widespread distribution of this species to distinguish it from *H. malabaricus* (Tschudi, 1838) (Padhye et al. 2015). The call is a low-frequency, slow-paced 'ping-ping', which some liken to the sound of water droplets falling in puddles.

Habitat. This species was commonly heard calling from the rocks and crevices surrounding shallow puddles and large water bodies.

Distribution. This frog is endemic to the Western Ghats.

***Indosylvirana intermedia* (Rao, 1937)**

New records. INDIA • Karnataka: Udupi: Manipal, Herga, site code E (13.3729°N, 074.8015°E), obs. by MM & RS, 29 Apr. 2017, 41 individuals. Fig. 3N.

Identification. The SVL is 46–42 mm in males and 66–74 mm in females. This species has a bright, golden-yellowish dorsum. There are moderately developed dorso-lateral folds on the dorsum. This is the only *Indosylirana* species that has the thigh and tibia of equal length. We have not made measurements of these lengths, but our analysis of our photographs using ImageJ found the thigh and tibia length to be equal in our specimens. This species can be confused with *I. aurantiaca* (Boulenger, 1904); however, *I. aurantiaca* is much smaller, with the SVL from 27 to 32 mm, and there are weak dorso-lateral folds (Biju et al. 2014; Oliver et al. 2015). The call is a series of short, low-pitched, harsh "chuck" sounds.

Habitat. This species is often found in waterlogged paddy fields and ephemeral pools with some grass and small shrubs. This frog is known from near sea level to 1000 m above sea level.

Distribution. This species is endemic to the Western Ghats, from north of the Palghat Gap.

Family Ranixalidae

***Indirana duboisi* (Boulenger, 1882)**

New records. INDIA • Karnataka: Udupi: Manipal, Pragathi nagar, site code H (13.3142°N, 074.8014°E), obs. by MM and RS, 21 Mar. 2017, 9 individuals, MN952996 and MN952997. Fig. 3O.

Identification. The SVL is about 42 mm. The frogs have a unique, rotund, and stout structure. The eyes and dark-brown tympanum are almost of the same size. The dorsum has longitudinal folds and granules. The color is drab, pale muddy brown (Dahanukar et al. 2016; Gopalan et al. 2012; Dinesh et al. 2020). The frogs have a continuous, black canthal stripe that connects the nostril to the tympanum.

Habitat. Throughout our surveys we have seen this frog take refuge in the dry season, at one location, under an inch or two of leaf litter. It was mostly seen active in monsoons, and the males were heard calling on nights with heavy rain. The male frogs are seen sitting on wet rocks throughout the town, mostly around old houses and shops. These frogs were seen living in near human habitation. The call consists of a single note, a low pitched "quack" with an interval of 6–8 sec; it was often heard from areas well covered by the canopy and with a few exposed laterite rocks.

Distribution. This frog is endemic to the southern Western Ghats.

Family Rhacophoridae

***Polypedates maculatus* (Gray, 1830)**

New records. INDIA • Karnataka: Udupi: Manipal, Pragathi nagar, site code H (13.3142°N, 074.8014°E), obs. by MM and RS, 16 Apr. 2017, 13 individuals. Fig. 3P. Identification. The SVL is up to 85mm. This species is a remarkably large-bodied frog. It shows toe discs, strong hid limbs, large eyes, and a strong fold from eye to ear. The tympanum is large and almost of the size of the eye (Gururaja 2012). The body is brownish, with some dark spots on the dorsum. The call sounds like a series of knocks on a hard surface.

Habitat. This species is arboreal but can be seen at the edges of ephemeral pools where the females come to lay eggs and sometimes males call from exposed rock surfaces. It can also be heard calling from trees or shrubs to about 1 m from the ground.

Distribution. This frog is endemic to the southern Asia.

***Polypedates pseudocruciger* Das & Ravichandran, 1998**

New records. INDIA • Karnataka: Udupi: Manipal, Shanthinagar, site code J (13.3269°N, 074.7968°E), obs. by MM and RS, 1 Jun. 2017, 9 individuals, MN953001 and MN953002. Fig. 3Q.

Identification. The SVL is 47.5–55.1 mm. This species is a large-bodied, pale, tree frog with large eyes and tympanum. It can be confused with *P. occidentalis* Das & Dutta, 2006, a species known only from its type locality in the state of Kerala. Morphologically *P. pseudocruciger* differs from *P. occidentalis* by to the presence of a cutaneous spur on the heel. Also, *P. occidentalis* has nuptial pad on fingers 1 and 2, whereas *P. pseudocruciger* has a single nuptial pad on the first fingers of both forelimbs.

Habitat. This is an arboreal species but is often found on the edges of pools and waterlogged paddy fields where the males come on the ground and use bunds and muddy crevices to vocalize. During peak monsoon season, several frogs were seen calling from the ground instead of trees and shrubs in the study area.

Distribution. This frog is endemic to the southern Western Ghats in the states of Kerala, Karnataka, and Tamil Nadu.

***Pseudophilautus wynaadensis* (Jerdon, 1853)**

New records. INDIA • Karnataka: Udupi: Manipal, Golikatte, site code D (13.3759°N, 074.8150°E), obs. by MM and RS, 2 Feb. 2017, 17 individuals. Fig. 3R.

Identification. The SVL is 28.3–33.5 mm. This is a small bush frog with a large spherical vocal sac. It is overall greenish-brown with dark tympanum. The dorsum and the ventral skin have numerous small granules. Toes and feet have discs. It can be confused with other bush frogs, like *Pseudophilautus kani* (Biju & Bossuyt, 2009) and *Pseudophilautus amboli* (Biju & Bossuyt, 2009); however, these frogs occur at higher elevations than *P. wynaadensis*is, and their calls are distinct (Gururaja 2012; Ramya et al. 2015). The call of *P. wynaadensis*is is a series of croaky "krek" sounds often followed by a dry, low-frequency rattle.

Habitat. It is an arboreal species, often seen about 1–2 m above the ground in dense shrubs, roadside vegetation, household gardens, and secondary forests. It is rarely seen on ground or on roads.

Distribution. This frog is endemic to the Western Ghats.

***Rhacophorus malabaricus* Jerdon, 1870**

New records. INDIA • Karnataka: Udupi: Manipal, Eshwarnagar, site code C (13.3478°N, 074.8006°E), obs. by MM and RS, 12 Aug. 2017, 7 individuals. Fig. 3S.

Identification. The SVL is up to 110 mm. This is a bright-green tree frog with red webbing between the fingers and toes. The eyes and tympanum are of equal size. It builds large, foamy nests on leaves and branches of trees just above the surface of water bodies. The call is a series of four or five low-pitched notes of "phut" and is only heard during monsoons.

Habitat. This species was often heard calling during monsoons from vegetation that surrounds pools with significant canopy cover. It hides on the back of leaves during the day to prevent desiccation.

Distribution. This frog is endemic to the Western Ghats.

Discussion

In India, 451 species of amphibian have so far been identified (Frost 2020). In India, the Western Ghats and the North Eastern Region are biodiversity hotspots, where major anuran discoveries have been made (Thorpe et al. 2018). At least three new species of anurans were discovered in the last five years from lateritic plateaus, but despite taxonomic studies by Biju et al. (2014), Dahanukar et al. (2016), Garg and Biju (2016) and Garg et al. (2019) on anurans of the Western Ghats, the unique habitat of lateritic plateaus, which are not protected areas, remain under studied (Seshadri et al. 2016). In our study, we identified 19 species of anurans from lateritic plateaus of Manipal. We found three species, *Minervarya sahyadris*, *Pseudophilautus wynaadensis*, and *Uperodon mormoratus* that are categorized as Endangered by the International Union for Conservation of Nature (IUCN 2019). Seven species are Least Concern and the remaining nine species are Not Evaluated by the IUCN.

Nair and Kumar (2013), Seshadri et al. (2016), and Thorpe et al. (2018) have provided insights on the diversity of anurans on the lateritic plateaus. We add here new records of *Indirana duboisi*, *Microhyla nilphamariensis*, *Microhyla laterite*, *Uperodon mormoratus*, *Indosylvirana intermedia*, *Euphlyctis karaavali*, and *Sphaerotheca dobsonii* from lateritc plateaus of the Western Ghats. We found that habitats with more complexity, like mixed vegetation with ephemeral pools, laterite rocks, and paddy fields, support a greater number of species (Fig. 5), as already shown by previous studies (Van Buskirk 2005; Wanger et al. 2010; Skelly et al. 2014; Sreejith et al. 2016). A study by Thorpe et al. (2018) on the laterite plateaus of the northern Western Ghats showed that amphibians are particularly dependent on the availability of microhabitats (Fig. 6), which provide appropriate conditions for the survival of amphibians. We show that in Herga (site code E) and Saralebettu (site code I), the complex and varied habitats have higher species richness than sampling locations with less complex habitats (Fig. 5). The fewest species at a sampling location was in Manchikere (site code F), which consists of a lateritic slope with a couple of shallow ephemeral pools (Fig. 5). Studies are needed to understand influence of complex habitats on species diversity on lateritic plateaus and could help in formulating conservation action plans for rapidly changing landscapes like the lateritic plateaus.

Euphlyctis mudigere, Minervarya caperata, and *Hoplobatrachus tigerinus* are generalist species associated with semi-aquatic habitats (Thorpe et al. 2018). We found these species at the edges of most ephemeral pools and breeding there, but we also found these three species near human habitations, in roadside drains, in artificial water bodies, within *Acacia* plantations, and even on football fields that are unused during monsoons. We sighted *Sphaerotheca dobsonii* and *Uperodon mormoratus* only three and six times, respectively, during our surveys, perhaps due to the fossorial habit of the species (Wells 2007). Encountering fossorial species is difficult unless the species is foraging on the ground.

Ten malformed frogs were found during our surveys. Malformations are any soft-tissue or skeletal deformity that disrupts the symmetry of the body (Ouellet et al. 1997; Meteyer 2000; Lannoo 2008). We have included both soft-tissue and skeletal malformations, but we do not understand the reasons behind these malformations. Some of the malformations might be due to trauma, but we have seen malformed frogs in areas with limited human disturbance. Malformations among frogs have been linked to anthropogenic disturbance and pollution, such as pesticides (Ouellet et al. 1997; Ouellet 2000). Our study is the first that documents the occurrence of malformations among amphibians inhabiting the lateritic plateaus of India, but research is needed to fully understand the cause and effect of these malformations on populations of anuran in this region.

To enhance our study, we involved citizen scientists, mostly students and teachers, from the Manipal Academy of Higher Education in Manipal. These citizen scientists helped to collect data collection, but we noted that citizen scientists generally had difficulty spotting cryptic species, which led to disinterest in our project. Finding cryptic species may require training or spending long hours in the field to understand species' behavior and habitats. We suspect that the cryptic nature of frogs is one of the reasons for the lack of interest in amphibians and amphibian conservation among the public in Manipal. We organized leisurely frog walks with children and students to instill the idea of citizen science. With the help of citizen scientists, we were able to cover larger areas in our surveys and to better document malformations.

Lateritic plateaus are outside assigned Reserve Forest Areas and are not legally protected (Watve 2013). As we have shown, laterite plateaus host a variety of anuran species. Currently, waste dumping, laterite mining, infrastructure development, and landscape modification for aesthetic purposes are increasing throughout the plateaus (Seshadri et al. 2016). The plateaus not only support anuran biodiversity but harbour other animal and plant biodiversity (Watve 2013). We highly recommend a re-evaluation of laterite plateaus; the current status of wasteland does injustice to such a diverse and unique landscape. The preservation of areas of laterite plateaus for scientific studies is needed, and it is indeed valuable to conduct research on how anthropogenic activities are impacting anuran species in the highly vulnerable laterite plateaus. This will give us important insights for determining conservation policies for anurans and other priority species, and for these landscapes which need urgent action.

We conclude that the south-western laterite plateaus of India are home to several lesser studied anuran species. Our study is among the first to provide a comprehensive list of anurans from these plateaus, and it also

reports on the presence of malformations in anurans from this region.

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Authors' Contributions

AM saw the draft manuscript and helped with the design, overall content, and data analysis; KVG helped in the review process of draft manuscript, data analysis, and data collection; RS provided insights on the presence of species at particular habitats and descriptions of calls; MM conceptualized the paper and wrote the first draft of the manuscript along with collecting the data. All authors approved the final version of the manuscript.

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