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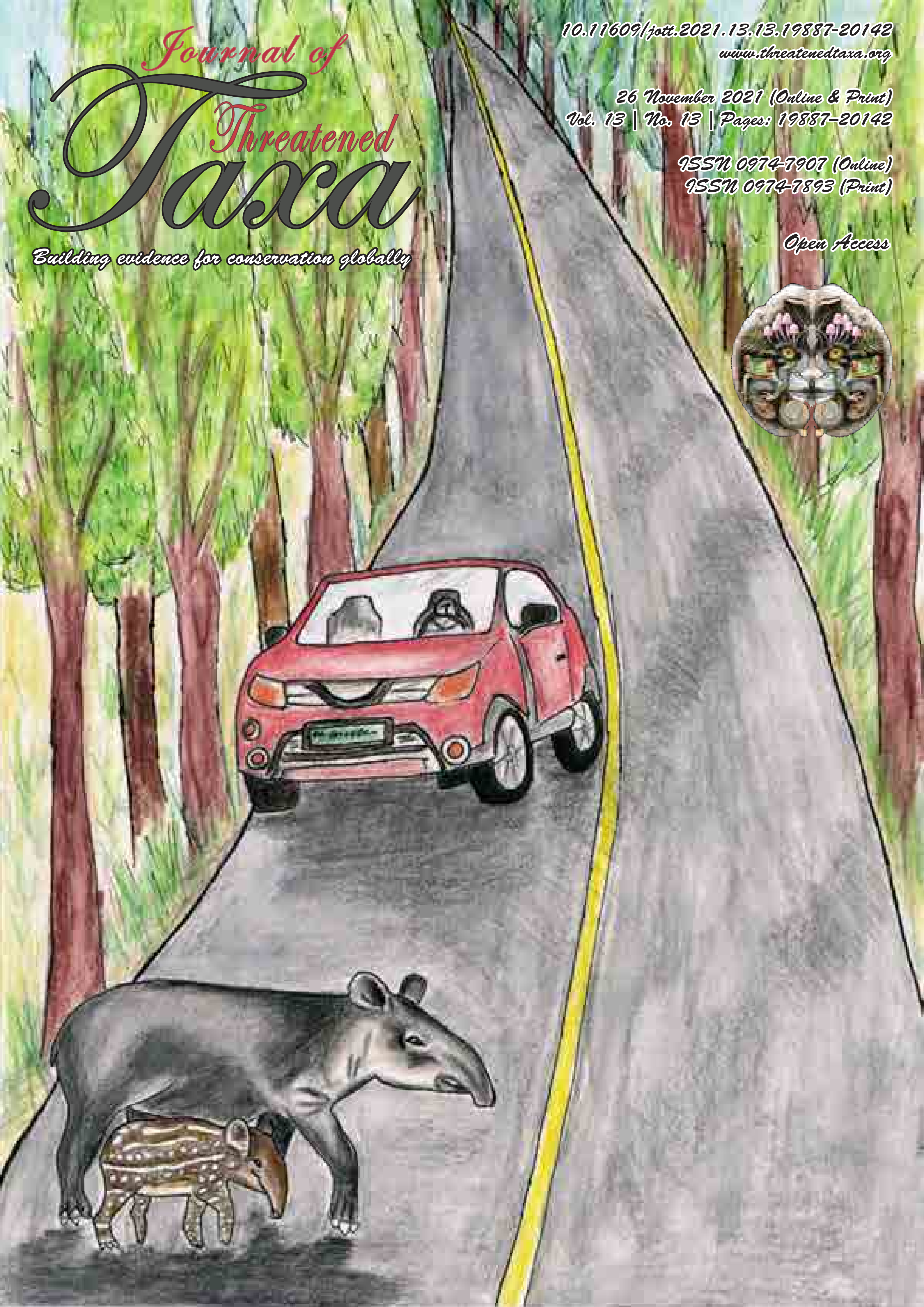

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No. 12, Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road, Saravanampatti,
Coimbatore, Tamil Nadu 641035, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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Caption: Lowland Tapir *Tapirus terrestris* (Medium—watercolours on watercolour paper) © Aakanksha Komanduri.

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ARTICLE

An inventory of geometrid moths (Lepidoptera: Geometroidea: Geometridae) of Kalakad-Mundanthurai Tiger Reserve, India

Geetha Iyer [1], Dieter Stüning [2] & Sanjay Sondhi [3]

[1] 11/49, Teppakulam street, Suchindrum-629704, Kanyakumari District, Tamil Nadu, India.
[2] Zoological Research Museum Alexander Koenig, Adenauerallee 160, 53113 Bonn, Germany.
[3] Titli Trust, 49, Rajpur Road Enclave, Dhoran Khas, near IT Park, PO Gujrada, Dehradun, Uttarakhand 248013, India.
[3] Indian Foundation for Butterflies. C-703, Alpine Pyramid, Rajiv Gandhi Nagar, Bengaluru, Karnataka 560097, India.
[1] scopsowl@gmail.com (corresponding author), [2] d.stuening@leibniz-zfmk.de, [3] sanjay.sondhi1@gmail.com

Abstract: The geometrid moths of Kalakad-Mundanthurai Tiger reserve were studied during the years 2012 to 2016. Since collection of specimens was not permitted, only field notes, accompanied by photo documentation was undertaken. Two-hundred-and-sixty geometrid moths identified to various hierarchical levels of taxa and one new genus for southern India, are reported.

Keywords: Agasthyamalai, biodiversity, Heterocera, KMTR, moth diversity, southern Western Ghats, Tamil Nadu.

Abbreviations: FW—Forewing | HW—Hindwing | KMTR—Kalakad-Mundanthurai Tiger Reserve, Tamil Nadu | KKWS—Kanyakumari Wildlife Sanctuary, Tamil Nadu | MoB—Moths of Borneo | UN—Underside | UP—Upperside | ZFMK—Zoological Research Museum Alexander Koenig, Bonn, Germany.

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Author details: Geetha Iyer is an independent educational consultant and author who writes for and trains teachers to help bring India's biodiversity into biology and environmental science classes. She is particularly interested in the moths of the Southern Western Ghats which she has studied for many years at KMTR and KKWS. She has authored two books, authored and edited school text books, published scientific papers, and writes popular articles on moths and other insects. Dieter Stüning is a German Geometridae specialist, who was Head of the Lepidoptera & Trichoptera Section of the Zoological Research Museum Alexander Koenig at Bonn for more than 30 years. Since retiring in 2014, he is working as a scientific associate, continuing to study Palearctic and Asian Geometridae, especially the taxonomy, systematics and phylogeny of subfamily Ennominae.He has described numerous new taxa of species and genera and also co-authored the description of a new moth-family. Sanjay Sondhi is a Dehradun-based naturalist. An engineering graduate from IIT-Kanpur, in 2009 he set up TITLI TRUST (www.titlitrust.org), a nature conservation not-for-profit organisation, which is devoted to studying and protecting India's lesser known flora and fauna. He has authored numerous books and technical papers on amphibians and reptiles, birds, butterflies and moths and other Indian wildlife.

Author contributions: GI—conceived and designed the study, surveyed and photographed the moths, prepared the species list, and wrote the manuscript. DS—supported species identifications with the help of literature and comparison with specimens of the ZFMK collection, and editing of the manuscript. SS—supported species identifications and editing of the manuscript during its various drafts.All three authors approve the final version.

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INTRODUCTION

Kalakad-Mundanthurai Tiger Reserve (KMTR) is located at the southern Western Ghats, in the Agasthyamalai range, approximately between 8.416N and 8.883N latitude and 77.166E and 77.583E longitude. It falls within Kanyakumari and Tirunelveli districts of the State of Tamil Nadu, India and is part of the Agasthyamalai Biosphere Reserve. With a core area of 895.39 km^2, KMTR was established as a tiger reserve in 1988 through the merger of Kalakad Wildlife Sanctuary, Mundanthurai Tiger Reserve, and parts of Veerapuli and Kilamalai reserve forests, from Kanyakumari district. The Nellai Wildlife Sanctuary, encompassing an area of 35.9 km^2, in the north and 201.36 km^2 of the Kanyakumari Wildlife Sanctuary towards the south form the buffer area of the reserve. The elevation ranges 100–1,880 m. Thus, a gradient of vegetation ranging from dry scrub to dense evergreen forest is found here. The reserve receives close to 3,000 mm of rainfall from both the south-west and north-east monsoons. It serves as a catchment area for no less than 14 rivers and streams. For this reason, it is sometimes referred to as a river sanctuary. The Agasthyamalai hills, which includes the core area of KMTR, are an important biogeographical 'hot spot' within the Western Ghats and a region of endemism in India (UNESCO 2016).

Being a tiger reserve, the biodiversity studies in this region have largely been focussed on mammals, herpetofauna, and plants for many years. Recent studies on invertebrates have been mostly on spiders or butterflies, and moths have not received any attention. This study is an attempt to enumerate the geometrid moths of this reserve. It is the first-of-its-kind study of moth diversity for this region, covering all habitats of the reserve, through seasons over multiple years.

Geometridae (Stephens, 1829) constitute the second largest family of moths in India, with at least 2,043 species listed so far (Kirti et al. 2019; Sondhi et al. 2020; Dey et al. 2021) from India. A large number of these slender moths, are mostly nocturnal, but day flying and crepuscular species are not uncommon. Some geometrids are strongly haired but most are examples of least-haired moths. In the forests of KMTR, we have observed them arrive in large numbers when the mist begins to set in. Protective colouration and camouflage were observed. Polymorphism was noticeable in many species. This paper outlines through photographic records, the diversity of geometrid moths arising out of a five-year survey in KMTR.

Geometrids have been reported from other parts of Western Ghats too: 77 species from Silent Valley National Park by Mathew & Rahamathulla (1995); six species by Bharmal (2015) from Amboli, Maharashtra and four species by Mishra et al. (2016) from Kodagu. From Kerala there are records of 47 species from Shendurney-Ponmudi by Sondhi et al. (2018). Elenchezhian et al. (2014) reported 28 species from Maruthamalai hills and Goyal (2010) described 19 species for his PhD. The last two are the only recently published records from Tamil Nadu and even these studies were restricted to Madurai and Nilgiri districts.

A literature survey of the older Indian records in Moore (1884–7,1889) or Hampson (1891, 1893) finds no mention of moths from Kalakad or Mundanthurai. A few scattered records of geometrids from 'Travancore State' are available. The State of Travancore was dissolved soon after India attained independence and the places under its jurisdiction were distributed between the present States of Kerala and Tamil Nadu. Kanyakumari, from the erstwhile southern part of Travancore State, thus became a part of Tamil Nadu. Published records of geometrid moths from the southern part of the erstwhile Travancore State are not available. Hence it is safe to assume that there are no historical records of moths from this region.

Some moth species have been recorded from KMTR in recent years by other researchers. Ron Brechlin described a sphingid, *Ambulyx sinjaevi* (Brechlin 1998), and a saturniid, *Loepa schintlmeisteri* (Brechlin 2000); *Stauropus thiaucourti,* a notodontid moth, was reported by Schintlmeister (2003); a cossid *Phragmacossia brahmana*, by Yakovlev (2009) and three geometrid species, *Racotis keralaria, Ophthalmitis kalakadaria*, and *Hypomecis tamilensis,* were described by Sato (2004, 2014, 2016). All these species were recorded from Manjolai (8.250N and 77.433E), a very small area of a few sq. km. All of them were new to science. There are no other published records of geometrids from KMTR. Thus, most of the moths presented are previously unrecorded, several unidentified and still to be described or species that are range extensions. One of them is a new record for southern India. Hence the moth inventory in this paper is the first attempt to generate a comprehensive list of geometrid moths found in this Tiger Reserve.

MATERIALS AND METHODS

Study sites

The moths listed in this paper were extensively surveyed from within the core area of KMTR during the years 2012 to 2015, covering most of the months except July and August, primarily due to lack of access during the monsoons. Moths were surveyed very briefly in the year 2016 and again, extensively, in the year 2019. The sites of study were Talayanai, Sengeltheri, Kuthiraivetti, Upper Kothayar, Mundanthurai, and Kannikatti. The list also includes geometrids from one of the buffer zones of KMTR, namely Kanyakumari Wildlife Sanctuary (KKWS), from sites located at Maramalai and Kalikesam (Table 1 & Figure 1–3. Locations and sites of study). Permission for collection was not available from the core or the buffer area of KMTR as the sites are within a legally protected area.

Some moths presented are not part of the planned survey, but were opportunistic observations during the years 2016, 2018, and early 2019. All sites being within the core regions of the Tiger Reserve, surveys were dependent on permissions from forest department, weather conditions, availability of accommodation, and finance. The entire study was self-funded by the first author.

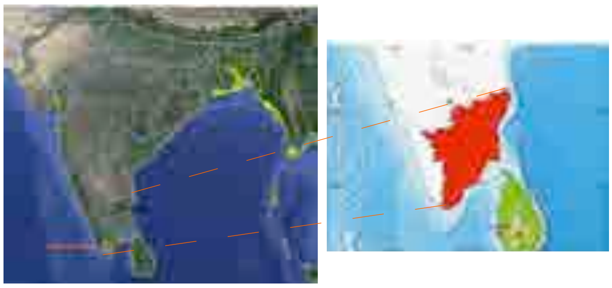

Figure 1. Map of India showing the state of Tamil Nadu.

Figure 2. Map of India showing the general study location in the state of Tamil Nadu

Figure 3. Sites of study in KMTR.

Survey methods

Moths were surveyed using a light trap consisting of a 160W mercury vapour bulb hung above a white cotton sheet measuring 3 x 5 feet (0.9144 x 1.524 meters), stretched between either two posts, trees, window bars, or sometimes, nails on a wall. Wherever electricity was not available (Sengeltheri and Kannikatti), a kerosene or petrol-powered Honda generator was used. The white cloth screen was illuminated starting at 1800 h or 1830 h, depending upon sunset, until 0130 h. Where mains electricity was available, the MV bulb was kept on till 0400 h. Diurnal activity of moths was noted at all locations.

Digital photographs were taken using a Panasonic FZ 200 and a Panasonic FZ 35 with a Lumix lens. Field notes were recorded for morphological details and of features that could not be captured through photography.

Methods for identification

The Tamil Nadu Forest Department discourages collection of specimens, even for research. This is one of the reasons for the poor records of moths and other insects from this region. Despite providing photographic evidence for new range and species records, permission to collect voucher specimens was not granted. Consequently, field notes and digital photography were the only methods available for assessing the diversity. The notes, photographs, comparisons (of photos) with museum specimens from ZFMK, Bonn, published papers, discussions with experts and researchers, and historical records have been the methods used for identification.

Walker (1860–62), Moore (1879, 1884–87), Swinhoe (1890), Hampson (1891, 1893, 1895), Rothschild (1894), Warren (1894, 1897), Prout (1912, 1917, 1920–41), Inoue (1953, 1972), Barlow (1982), Holloway (1983–2011), Butler (1886, 1889), and Scoble et al. (1999) were the

Table 1. Location of study sites along with elevation, habitat, and timeline.

	Place	Latitude	Longitude	Elevation in metres	Habitat type	Timeline in years
1	Talayanai	8.526°N	77.502°E	224	Riparian	2012, 2015
2	Sengeltheri	8.534°N	77.45°E	984	Semi-evergreen	2012, 2015
3	Kuthiraivetti	8.5931°N	77.352°E	1,146	Moist deciduous	2012–14, 2019
4	Upper Kothayar	8.527°N	77.359°E	1,286	Evergreen and montane	2012–14, 2018, 2019
5	Mundanthurai	8.6563°N	77.3332°E	250	Riverine and dry deciduous	2012, 2015
6	Kannikatti	8.732°N	77.226°E	762	Wet evergreen and riparian	2013
7	Maramalai	8.45°N	77.4°E	500	Mixed forest and estates	2012, 2015
8	Kalikesam	8.41°N	77.338°E	115	Riparian	2011–2014

prime sources of reference. Other than these sources, several research papers and books were also consulted. The second author referred extensively with the museum specimens at ZFMK, to arrive at identifications, and the third author used Moths of India website for the same. The classification in the paper, unless specified otherwise, follows that of Murillo-Ramos et al. (2019).

It is an established fact that without a specimen in hand, identification to the level of species is an extremely difficult task for many cryptic moth species. Hence, without specimens and therefore absence of genitalia information, it was not possible to identify all geometrids to the species level. Identifications, in such cases, have been limited to the level of subfamily, tribe or genus. For some individuals, where records or field data were insufficient, we have suggested provisional identifications. From our investigations, we believe that some of these could well be either new species to science or range extensions.

As this was the first comprehensive survey undertaken in this Tiger Reserve, most of the moths were first records for KMTR. They were also first records for the districts of Kanyakumari and Tirunelveli in the state of Tamil Nadu.

Box 1. Open Nomenclature qualifiers (ON)

Abbreviations used to indicate a taxon's provisional status of identification are termed as Open Nomenclature qualifiers. These qualifiers are used by researchers from different disciplines with some variations in interpretations. The qualifiers we have used for provisional identifications in this paper are 'cf.' and 'nr'. These terms have been used with the following interpretations:

cf. This is short for the Latin word confero/conferatur, meaning, 'to compare with'. We have used it to indicate that the species identification is provisional but is likely to be conclusive when we have more data, when it is further compared or crosschecked with reference materials, or discussed with a specialist of the taxon. The degree of uncertainty is less when compared with the term 'nr'.

nr This is short for 'near'. This qualifier has been used when the moth bears some similarities or resemblances to a known species. It appears closely related but is not identical to it.

Findings from the study

Three-hundred-and-ninety geometrids belonging to five subfamilies were investigated. Only 260 are presented in this paper with identities at different levels. Six taxa were identified to the level of subfamily and six to the level of tribe. While 98 taxa were identified to genus level, 160 taxa, which included males, females as well as morphs, were identified to the level of species. Thirty-four taxa are reported with provisional identifications using Open Nomenclature qualifiers (Box 1). They have been identified to the nearest recognisable species for comparison, or to a possible species close to them for further study.

Overall, 98 genera and 108 species have been identified. Polymorphism was quite marked in species from subfamilies Ennominae, Larentiinae, and Sterrhinae. Other than *Abraxas leucostola argyrosticta* Hampson, 1893, *Hypomecis tamilensis* Sato, 2016, *Luxiaria hypaphanes* Hampson, 1891, *Ophthalmitis kalakadaria* Sato, 2014, and *Racotis keralari*a Sato, 2004, all the moths presented in this paper (Table 2) are new records for KMTR and, Kanyakumari and Tirunelveli districts of Tamil Nadu, with *Acanthovalva* Krüger, 2001, a newly recorded genus for southern India.

Investigations have pointed to the possibility of some new species among the many tentatively identified or unidentified moth records. We hope this baseline survey report will assist in obtaining permission to collect and thus initiate a more detailed study of moths in this region.

Table 2. Summary of subfamilies, genera and species presented.

	Subfamily	Genera	Species with confirmed identity	Species with conditional identity	Species not identified
1	**Sterrhinae** Meyrick, 1892	12	13	5	3
2	**Larentiinae** Duponchel, 1845	13	9	2	3
3	**Geometrinae** Stephens, 1829	23	24	7	3
4	**Desmobathrinae** Meyrick, 1886	3	3	0	0
5	**Ennominae** Duponchel, 1845	47	59	20	11

Taxon notes

Details of select genera/species are shared below. The taxon order followed is as given in The Forum Herbulot World List of Family Group Names in Geometridae-Forum Herbulot (2003, updated 2007).

Subfamily Sterrhinae Meyrick, 1892

Plates 1–2 (5–36)

The classification of moths of this subfamily (Table 3) follows the most recent revision by Sihvonen et al. (2020). Of the 34 moths observed, 31 individuals from seven tribes were identified either to the genera or species level. Three individuals could not be identified further. Sihvonen et al. (2020) mention in their paper that a large number of species of this cosmopolitan family, comprising of nearly 3,000 moth-species worldwide, fall under the genera *Idaea* Treitschke, 1825 or *Scopula* Schrank, 1802. This abundance was reflected in our survey too.

Idaea Treitschke, 1825

Plate 2 (23–30)

Idaea Treitschke, 1825 is a genus with hundreds of small and very similar species which are difficult to identify even with voucher specimens in hand. In their absence, we have relied on published records and museum specimens. We report only three indivduals of *Idaea* (out of the 10 individuals), whose wing patterns were unique enough to be identified to species level. While researching to confirm *Idaea gemmaria* Hampson, 1896, (Plate 2(23)), we came across Holloway's statement in Moths of Borneo (Holloway 1997) about the taxon "*I. gemmataria*", Hampson (Sri Lanka). On contacting Dr Holloway (pers. comm., 21.ix.2020), he clarified that, "*it was indeed an error arising at some stage between his reading the handwritten name in the museum collection and the final appearance of his text in print! The correct name of the species described by Hampson was indeed I. gemmaria".* This has helped confirm the identity of the species.

The next most common species were from the genus *Scopula* Schrank, 1802 (Plates 1–2 (15–19)). Out of five individuals observed, two have been identified to the species level.

The key given by Xue et al. (2018) for the pattern of ocellus in the wings, descriptions and comparison with specimens in the ZFMK ollection, were used to identify *Problepsis apollinaria* Guenée, [1858] and *P. deliaria* Guenée, [1858] (Plate 1 (13–14)). All of the Sterrhinae listed are new records for KMTR.

Subfamily Larentiinae Duponchel, 1845

Plates 3–4 (37–60)

This is the second largest subfamily amongst Geometridae. Worldwide, 6,200 species (Õunap et al. 2016) have been described so far. We have recorded 24 moths from six tribes. Only nine of them could be identified to the species level. Fourteen larentiines reported belong to the tribe Eupitheciini Tutt, 1896. Of these, the genera *Collix* Guenée, [1858] and *Eois* Hübner, 1818 were the most represented. Three individuals from tribe Eupitheciini could not be identified even to the genus level. All the larentiine moths listed are new records for this region. We also believe that there are possibilities of new eupitheciine species from this region.

Subfamily Geometrinae Stephens, 1829

Plates 4–6 (61–101)

A large number of moths of this subfamily being green in colour, are often referred to as emerald moths. They were seen in large numbers at KMTR. However, the species diversity did not match individual abundance. According to Plotkin & Kawahara (2020), the current checklist of Geometrinae worldwide stands at 2,642 species. We recorded 41 different individuals from which 24 species from 23 genera were identified. Three moths remained unidentified while the remaining were identified to the level of genera or provisionally to the nearest species.

Tribe Comibaenini Inoue, 1961

Plate 4 (66–74)

Comibaena Hübner, [1823] 1816

Plate 4 (66–72)

We report four species and one individual referred for comparison to the nearest species. *Comibaena integranota* Hampson, 1893 and *Comibaena attenuata* Warren, 1896, are differentiated based on the patches seen in the tornal region of forewing and apex of the hind wing. In *attenuata*, the forewing patch has an irregular projection anteriorly that is separated from the margin. Warren (1896), while describing *attenuata* under the older synonym *Probolosceles attenuata* Warren, 1896, has pointed out that some features of *attenuata* have been mistakenly attributed to the female of *integranota* by Hampson (1893).

***Protuliocnemis* cf. *biplagiata* (Moore, 1887)**

Plate 4 (73)

Protuliocnemis biplagiata (Moore, [1887]) and *P. castalaria* (Oberthür, 1916), are similar in fasciae and genitalia. The number of spurs found in the hind tibia (Holloway 1996) is the only feature to distinguish the two species. Where as *P. biplagata* has four spurs in the hind tibia, *P. castalaria* has only two ((Prout 1933, *Gross-Schmett. Erde* 12: 88) in Holloway, 1996). *Protuliocnemis biplagiata* has been reported from Sri Lanka and, northern & northeastern of India and *P. castalaria* only from Khasi hills. This species of *Protuliocnemis* was frequently observed in both the core and the buffer zone of the reserve from the month of October to March. As the data of hind tibia spurs is not available and based on its presence in Sri Lanka, we report this individual provisionally as *P.* cf. *biplagiata*.

Tribe Hemitheini Bruand, 1846

Plate 5 (77–91)

We report 15 individuals belonging to 11 genera, of which six have been identified to the level of species; four are reported with provisional species identity and four are identified to the genus level. A few are detailed below.

***Pelagodes* Holloway, 1996**

Plate 5 (83)

Moths of this genus were quite abundant in higher altitudes and found at all study sites except Talayani. The genus *Pelagodes* Holloway, 1996, was identified and differentiated from the closely resembling *Thalassodes* Guenée, [1858] based on the hindwing architecture as given by Han & Xue (2011). They report that the outer margin of the hindwing is strongly angled in *Thalassodes* but not so in *Pelagodes*. Species level identification of *Pelagodes* was not attempted in the absence of genitalia details. The presence of *Thalassodes* cannot be ruled out as several individuals remained unidentified. Lack of specimens in hand was a constraint for further investigation.

***Jodis* Hübner, 1823**

Plate 5 (87–89)

Three species of *Jodis* were observed. One has been identified to species level. One is provisionally identified to species level while the third could not be identified beyond the level of genus.

***Jodis pallescens* (Hampson, 1891)**

Plate 5 (88)

Hampson (1893) has described this taxon from Nilgiris as *Thalera pallescens* and the description matches the species reported here. Prout (1934) reported it from Sri Lanka and described *J. pallescens* as a distinct species due to the sharp contrast seen between the green and the white areas. This was quite evident in the moths we observed and the details match the field notes.

***Jodis* nr. *undularia* (Hampson, 1891)**

Plate 5 (87)

Hampson (1893) described it from Nilgiris, and misidentified it as *Thalera caudularia.* It is, according to Prout (1934), widely distributed in India. A yellowish-green moth, it shows the features matching the description given by Hampson. The vertex of the head is white. The whitish antemedial and postmedial lines are dentate, excurved between veins 2 and 4, giving it, at first glance, a greyish-green appearance. The underside is white with shades of greyish-white. As Prout (1934) pointed, the tail of the hindwing is sharp. We, therefore, suggest the species identity tentatively, to facilitate further exploration.

Tribe Nemoriini Gumppenberg, 1887

***Eucylodes albisparsa* (Walker, 1861)**

Plate 5 (92)

Ban et al. (2018) placed *Eucylodes* in the tribe Nemoriini. However, its tribal position is reported as uncertain in the research paper by Murillo-Ramos et al. (2019). The paper also does not assign it to any tribe. We have retained the species in Tribe Nemoriini, after consulting Dr Hausmann (Hausmann, pers. comm. 01.vii.2020) who is one of the co-authors of the 2019 paper.

Eucyclodes albisparsa and *E. divapala* (Walker, 1861), are similar species, which fly in southern India. They are best separated by genitalic features. However, Barlow (1982) reports that the latter species found in southern India is more uniformly green and less contrasting than *divapala*. This matches the features in the individual observed by us. Hence, we report this moth as belonging to *Eucyclodes albisparsa* complex.

Subfamily Desmobathrinae Meyrick, 1886

Plate 6 (102–105)

Four individuals from three genera are presented here. *Derambila fragilis* (Butler, 1881), *Noreia ajaia* Walker, 1859, *Ozola microniaria* Walker, 1862 and the fourth moth belonging to the genus *Ozola* Walker, [1861] could not be identified to species level.

***Derambila* Walker, [1863] 1862**

Plate 6 (102)

Members of *Derambila* are small, slender, translucent white moths. *Derambila saponaria* (Guenée, [1858]) has been recorded from Travancore and Sri Lanka. Hampson (1895) records it as *Rambara saponaria* Guenée from Travancore. Rambara Moore, [1887] is currently treated as a junior synonym of *Derambila* (Scoble et al. 1999). *Derambila fragilis* (Butler, 1881), (Taiwan), described erroneously in the genus *Zanclopteryx* Herrich-Schäffer, [1855], is another similar species. *Zanclopteryx* is a genus with exclusively New World species. Prout (1921) notes that in *fragilis*, the antemedian lines are very few and mostly dissolved into spots. Holloway (1996), states that *D. fragilis* is also found in India and records that the wings are relatively slightly marked and lack the brown suffusion, seen in other species. In *D. saponaria*, the brown transverse markings are well expressed whereas in *D. fragilis*, they are present as dots. Based on the markings on the wings and the distribution given by Hampson & Moore, we report this species as *Derambila fragilis.*

Subfamily Ennominae Duponchel, 1845

Plates 6–13 (106–274)

With no anatomical details being available, members of the largest geometrid subfamily were the most challenging to identify from external morphological only. Along with historical records and published papers, the collections from ZFMK were most useful for identification. Polymorphism was quite vivid in several genera which added to the complexity. Explanations of our conclusions for select taxa are given below.

Tribe Abraxini Warren, 1893

***Abraxas* Leach, [1815]**

Plates 6–7 (106–123)

Specimens of the genus *Abraxas* were found in abundant numbers in Upper Kothayar, Kuthiraivetti, Sengeltheri, and Maramalai. Materials from Kalakad, Nilgiris, and Sri Lanka available in the collections at ZFMK were compared along with descriptions and figures published by Hampson (1891, 1893, 1907), Swinhoe (1890, 1891), Walker (1862), Warren (1894, 1898), and Prout (1925) for identification. Of the 15 individuals presented here, three are identified to the level of species (Plates 6–13 (106–109)). The rest of the unidentified individuals are in varying shades of grey and bluish-grey, with or without irregular yellow spots that ranged from many to none on the upperside. The underside of these specimens varied from being grey to grey with more or less irregular yellow spots and to one with a completely yellow underside with dark fasciae (Plate 7 (115)), the latter certainly a distinct species, the former probably variations of one species. All these species had yellow heads. The antennae were completely black or grey. The thorax showed varying degrees of greyness. Their legs were grey with yellow coxa. Large black spots on the upper side of the abdominal segment, and smaller ones on the sides and undersides were present. Based on these differences in patterns and colours on the upper and underside, the grey *Abraxas* moths and that with grey upper side and yellow underside have been categorised tentatively as different species. We cannot rule out the fact that some of them are probably just forms of two or more species. Hence collection is needed to investigate further and get greater clarity of this group of moths that were present during all seasons.

Another unidentified *Abraxas* was completely yellow on upper and underside, with grey postmedial fasciae and spots (Plate 7 (121–123)) which bore no resemblance to the two yellow *Abraxas* hitherto described from southern India, namely, *A. luteoaria* Swinhoe, 1890 and *A. germana* Swinhoe, 1891. Both have been described from Nilgiri Hills, but were not spotted at KMTR during our surveys. The second author who is familiar with the southern Indian *Abraxas* species found that the grey and the yellow series of *Abraxas* we have presented does not resemble any existing species. We therefore report them as unidentified species of *Abraxas* that need further investigation.

About 20 species of the genus *Abraxas* have been described from southern India and Sri Lanka at the end of the 19th century and the beginning of the 20th century. Most of them are endemic to the Western Ghats and do not look (Plates 6–13 (110–120)) like typical *Abraxas*, as known from examples seen in the Himalaya or Chinese mountainous regions. Only *A. leucostola* Hampson, 1893, described from Sri Lanka and later described from southern India by Hampson (1907) as *Abraxas argyrosticta* (which is at present treated as subspecies of *leucostola*), resembles the typical *Abraxas*. *A. fasciaria* (Guérin-Méneville, 1843), *A. poliostrota* Hampson, 1907,

Table 3. Checklist of geometrids of Kalakad-Mundanthurai Tiger Reserve.

	S. Family/ Genus	Tribe/ Species	Author & Year: S. Family/ Tribe/ Genus/ Species	Location	Month and Year of survey
	Sterrhinae Meyrick,1892	**Cosymbiini**	Prout, 1911		
1	*Chrysocraspeda*	sp.1	Swinhoe, 1893	Upper Kothayar	Mar 2014
2	*Chrysocraspeda*	sp.2	Swinhoe, 1893	Kannikatti, Kuthiraivetti	Feb 2013, Mar 2014
3	*Perixera*	*insitiva*	(Prout, 1920)	Kuthiraivetti	Dec 2012
		Cyllopodini	Kirby, 1892		
4	*Organopoda*	sp.	Hampson, 1893	Upper Kothayar	Oct 2018
		Lissoblemmini	Sihvonen & Staude, 2020		
5	*Lissoblemma*	*lunuliferata*	(Walker, [1863])	Upper Kothayar	Oct 2018
6	*Craspediopsis*	sp.	Warren, 1895	Talayanai	Feb 2015
		Rhodometrini	Agenjo, 1952		
7	*Traminda*	*aventiaria*	(Guenée, [1858])	Kuthiraivetti	Dec 2012
8	*Traminda*	*mundissima* - 3 forms	(Walker,1861)	Mundanthurai, Talayanai, Kuthiraivetti	Mar 2012, Oct 2012, Feb 2015, Dec 2012
		Scopulini	Duponchel, 1845		
9	*Problepsis*	*deliaria*	(Guenée, [1858])	Kuthiraivetti, Sengeltheri, Upper Kothayar, Maramalai	Dec 2011, 2012, 2019, Oct 2012, June 2013, Feb 2012
10	*Problepsis*	*appollinaria*	(Guenée, [1858])	Maramalai	Feb 2012
11	*Scopula*	*divisaria*	Walker, 1861	Upper Kothayar	Jun 2013
13	*Scopula*	*fibulata*	(Guenée, [1858])	Kannikatti	Feb 2013
14	*Scopula*	nr *relictata*	(Walker, 1866)	Kuthiraivetti	Mar 2014
15	*Scopula*	nr *actuaria*	(Walker, 1861)	Sengeltheri	Feb 2015
16	*Scopula*	sp.6	Schrank, 1802	Upper Kothayar	Mar 2014
17	*Somatina*	nr *plynusaria*	(Walker, [1863])	Sengeltheri	Oct 2012
18	*Somatina*	*rosacea*	Swinhoe, 1894	Kuthiraivetti	Mar 2014
19	*Somatina* or nr		Guenée, [1858]	Kannikatti, Upper Kothayar	Feb 2013, Mar 2014
		Sterrhini	Meyrick, 1892		
20	*Lophophleps*	*phoenicoptera*	(Hampson, 1896)	Kalikesam	Jul 2014
21	*Lophophleps*	*purpurea*	Hampson, 1891	Sengeltheri	Feb 2015
22	*Idaea*	*gemmaria*	Hampson, 1896	Maramalai	Feb 2012
23	*Idaea*	nr *gemmaria*	Hampson, 1896	Upper Kothayar	Mar 2014
24	*Idaea*	*violaceae*	Hampson, 1891	Maramalai	Feb 2012
25	*Idaea*	sp.4	Treitschke, 1825	Sengeltheri, Upper Kothayar	Oct 2012, Feb 2015, Mar 2014
26	*Idaea*	sp.5	Treitschke, 1825	Maramalai	Feb 2012
27	*Idaea*	sp.6	Treitschke, 1825	Maramalai	Feb 2012
28	*Idaea*	sp.7	Treitschke, 1825	Sengeltheri	Feb 2015
28	*Idaea*	sp.8	Treitschke, 1825	Kuthiraivetti	Mar 2014
		Timandrini	Stephens, 1850		
29	*Timandra*	sp.	Duponchel, 1829	Upper Kothayar	Jun 2013
30	**Unidentified Sterrhinae** -3		Meyrick, 1892	Sengeltheri, Maramalai	Feb 2015, Feb 2012
	Larentiinae Duponchel, 1845	**Asthenini**			
31	*Acolutha*	*pictaria*	(Moore, 1888)	Upper Kothayar	Mar 2014
32	*Polynesia*	*sunandava*	(Walker, 1861)	Kuthiraivetti	Dec 2012, Jan 2019

	S. Family/ Genus	Tribe/ Species	Author & Year: S. Family/ Tribe/ Genus/ Species	Location	Month and Year of survey
		Cidariini	Duponchel, 1845		
33	*Ecliptopera*	*dissecta*	(Moore, [1887])	Upper Kothayar, Kuthiraivetti,	Jun 2013, Jan 2019
34	*Ecliptopera*	*muscicolor*	(Moore, 1888)	Upper Kothayar	Jun 2018
35	*Chloroclystis*	sp.	Hübner, [1825]	Sengeltheri	Feb 2015
		Incertae sedis			
36	*Physetobasis*	*annulata*	(Hampson, 1891)	Kuthiraivetti	Dec 2012
		Eupitheciini	Tutt, 1896		
37	*Bosara*	*albitornalis*	(Prout, 1958)	Kuthiraivetti	Dec 2012
38	*Eupithecia*	sp.	Curtis, 1825	Sengeltheri	Feb 2015
39	*Collix*	sp.1	Guenée, [1858]	Sengeltheri	Feb 2015
40	*Collix*	sp.2	Guenée, [1858]	Marmalai	Feb 2012
41	*Collix*	sp.3	Guenée, [1858]	Marmalai	Feb 2012
42	*Eois*	sp.4	Hübner,1818	Marmalai	Feb 2012, 2015
43	*Eois*	sp.5	Hübner,1818	Upper Kothayar	Mar 2014
44	*Eois*	cf. *dissimilis*	(Moore,1887)	Kuthiraivetti	Dec 2012
45	*Eois*	*lunulosa* form ochraceae	(Moore, [1887])	Kuthiraivetti	Dec 2012
46	*Gymnoscelis*	cf. *admixtaria*	(Walker, 1862)	Kuthiraivetti	Dec 2012
47	*Ziridava*	*rubridisca*	(Hampson, 1891)	Upper Kothayar	Oct 2018
		Trichopterygini	Warren, 1894		
48	*Sauris*	sp.1	Guenée, [1858]	Kuthiraivetti	Dec 2012
49	*Sauris*	sp.2	Guenée, [1858]	Sengeltheri	Oct 2012
		Xanthorhoini	Pierce, 1914		
50	*Xanthorhoe*	*saturata*	Guenée, [1858]	Kuthiraivetti	Dec 2012
51	Unidentified Eupethiciini-3		Duponchel, 1845	Kuthiraivetti	Dec 2012, Mar 2014
	Geometrinae Stephens,1829	**Agathiini**	Ban & Han, 2018		
52	*Agathia*	*hemithearia*	Guenée, [1858]	Kuthiraivetti, Upper kothayar	Mar 2014, Jan 2019
53	*Agathia*	*lycaenaria*	(Kollar, 1844)	Upper Kothayar	Jul 2018
54	*Agathia*	*laetata*	(Fabricius, 1794)	Kuthiraivetti	Dec 2012
		Archaeobalbini	Viidalepp, 1981		
55	*Herochroma*	cf. *cristata*	Warren, 1894	Maramalai, Upper Kothayar	Feb 2012, Mar 2014
56	*Lophophelma*	*ruficosta*	Hampson, 1891	Kuthiraivetti, Sengeltheri	Dec 2012, Mar 2014, Jan 2019, Feb 2015
		Comibaenini	Inoue, 1961		
57	*Argyrocosma*	*inductaria*	(Guenée, [1858])	Kuthiraivetti, Upper Kothayar, Sengeltheri, Talayanai, Maramalai	Dec 2012, Feb 2015, Feb 2012
58	*Chlorochromodes*	sp.	Warren, 1896	Talayanai	Feb 2015
59	*Comibaena*	*attenuata*	(Warren, 1896)	Upper Kothayar	Mar 2014
60	*Comibaena*	*cassidara*	Guenée, [1858])	Mundanthurai, Upper Kothayar, Maramalai	Mar 2012, Oct 2016, Feb 2012
61	*Comibaena*	cf. *striataria*	Leech, 1897	Mundanthurai	Mar 2012
62	*Comibaena*	*integranota*	Hampson, 1893	Sengeltheri, Maramalai	Feb 2015, Feb 2012
63	*Comibaena*	*fuscidorsata*	Prout, 1912	Upper Kothayar, Kuthiraivetti	Mar 2016, Jan 2019
64	*Protuliocnemis*	cf. *biplagiata*	(Moore, [1887])	Kuthiraivetti, Upper Kothayar, Sengeltheri, Maramalai	Dec 2012, Mar 2014, Oct 2012, Feb 2012

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65	*Protuliocnemis*	*partita*	(Walker, 1861)	Upper Kothayar	Jan 2019
		Dysphaniini	Warren, 1895		
66	*Dysphania*	*percota*	(Swinhoe, 1891)	Kalikesam	Jul 2014
		Geometrini	Stephens, 1829		
67	*Cyclothea*	*disjuncta*	(Walker, 1861)	Sengeltheri	Feb 2015
		Hemitheini	Bruand, 1846		
68	*Comostola sp*	sp.	Meyrick, 1888	Sengeltheri, Kuthirai-vetti, Maramalai	Oct 2012, Jan 2019, Feb 2012
69	*Episothalma*	*robustaria*	(Guenée, [1858])	Upper Kothayar	Dec 2011
70	*Hemithea*	*tritonaria*	(Walker, [1863])	Upper Kothayar	Jul 2018
71	*Hemithea*	*wuka*	(Pagenstecher, 1886)	Kalikesam	Jul 2014
72	*Idiochlora*	nr *caudularia*	(Guenée, [1858])	Kuthiraivetti, Sengeltheri	Mar 2014, Feb 2015
73	*Orothalassodes*	*hypocrites*	(Prout, 1912)	Kuthiraivetti, Upper Kothayar	Jan 2019
74	*Pelagodes*	sp.	Holloway, 1996	All sites except Talayanai	Mar 2011, Dec 2012, Mar 2013, June 2014, Feb 2012,'15, Jan 2019
75	*Pentheochlora*	cf. *uniformis*	Hampson, 1891	Kuthiraivetti	Dec 2012
76	*Spaniocentra*	sp.	Prout, 1912	Maramalai	Mar 2012
77	*Berta*	cf. *chrysolineata*	Walker, 1863	Upper Kothayar	Oct 2018
78	*Jodis*	*nr undularia*	(Hampson, 1891)	Upper Kothayar	Mar 2014
79	*Jodis*	*pallescens*	(Hampson, 1891)	Upper Kothayar	Mar 2014
80	*Jodis*	sp.3	Hübner, [1823]	Kuthiraivetti	Jun 2013
81	*Microloxia*	*indecretata*	(Walker, [1863])	Talayanai	Feb 2015
82	*Microloxia*	sp.2	Warren, 1893	Mundanthurai	Mar 2012
		Nemoriini	Gumppenberg, 1887		
83	*Eucyclodes*	*gavissima*	(Walker, 1861)	Sengeltheri	Oct 2012
84	*Eucyclodes*	*albisparsa* complex	(Walker, 1861)	Sengeltheri	Oct 2012
		Ornithospilini	Ban & Han, 2018		
85	*Ornithospila*	*lineata*	(Moore, 1872)	Kuthiraivetti	Jan 2019
86	*Ornithospila*	*submonstrans*	(Walker, 1861)	Kuthiraivetti	Dec 2012, Jan 2019
		Pseudoterpnini	Warren, 1893		
88	*Pingasa*	*dispensata* M, F	(Walker, 1866)	Kuthiraivetti	Dec 2012
89	*Pingasa*	*ruginaria*	(Guenée, [1858])	Upper Kothayar, Sengeltheri, Kuthiraivetti, Maramalai	Mar 2014, Feb 2015, Dec 2012, Jan 2019, Feb 2012, Feb 2015
90	**Unidentified Geometrinae**-3		Leach, 1815	Maramalai, Mundanthurai	Feb 2012, Mar 2012
	Desmobathrinae Meyrick,1886	**Desmobathrini**	Meyrick, 1886		
91	*Noreia*	*ajaia* M	(Walker, 1859)	Upper Kothayar	Jun 2013
92	*Ozola*	*microniaria*	Walker, 1862	Kuthiraivetti, Sengeltheri	Mar 2014, Feb 2015
93	*Ozola*	sp.	Walker, 1861	Sengeltheri	Feb 2015
94	*Derambila*	*fragilis*	(Butler, 1881)	Sengeltheri	Feb 2015
	Ennominae Duponchel,1845	**Abraxini**	Warren, 1894		
95	*Abraxas*	*leucostola argyrosticta*	Hampson, 1893	Upper Kothayar, Kuthiraivetti, Maramalai	Jan 2019, Dec 2012, Feb 2012
96	*Abraxas*	*fasciaria*	Guerin-Meneville, 1843	Sengeltheri, Upper Kothayar, Kuthiraivetti,	Oct. 2012, Jan 2019
97	*Abraxas*	*Poliostrota* M, F	Hampson, 1907	Kuthiraivetti	Dec. 2012

	S. Family/ Genus	Tribe/ Species	Author & Year: S. Family/ Tribe/ Genus/ Species	Location	Month and Year of survey
98	*Abraxas*	(grey)sp.4	Leach, [1815] 1830	Upper Kothayar, Kuthiraivetti, Sengeltheri	Dec 2012, Oct 2013, Feb 2015, Jan 2019
99	*Abraxas*	(grey)sp.5	Leach, [1815]1830	Upper Kothayar	Mar 2014
100	*Abraxas*	(grey)sp.6	Leach, [1815]1830	Upper Kothayar,	Jan 2019, Feb 2012.
101	*Abraxas*	(grey)sp.7	Leach, [1815]1830	Upper Kothayar	Jan 2019
102	*Abraxas*	(grey)sp. 3 forms	Leach, [1815]1830	Upper Kothayar, Kuthiraivetti, Sengeltheri, Maramalai.	Jan 2019, June 2013, Mar 2014, Feb 2015, Feb 2012
103	Abraxas	(yellow)sp.8	Leach, [1815]1830	Upper Kothayar, Sengeltheri	Mar 2014, Mar 2019, Feb 2015
		Baptini	Forbes, 1948		
106	*Borbacha*	cf. *pardaria*	Guenée, [1858]	Kuthiraivetti, Maramalai	Dec 2012, Feb 2012
107	*Synegia*	*imitaria*	(Walker, 1861)	Upper Kothayar	Mar 2014
108	*Yashmakia*	*erythra* M	(Hampson, 1891)	Upper Kothayar	June 2018
109	*Yashmakia*	*conflagrata* F	(Hampson, 1912)	Upper Kothayar	June 2018
110	*Lomographa*	*inamata*	(Walker, [1861]1860)	Kuthiraivetti, Maramalai	Dec 2012, Jan 2019, Feb 2012
111	*Platycerota*	*vitticostata*	(Walker, [1863])	Upper Kothayar	June 2013
		Boarmiini	Duponchel, 1845		
112	*Alcis*	*nilgirica*	Hampson, 1891	Kuthiraivetti, Upper Kothayar, Sengeltheri	Dec 2012, June 2013 Mar 2014, Oct 2012, Feb 2015
113	*Amblychia*	cf. *angeronaria*	Guenée, 1858	Maramalai, Upper Kothayar	Feb 2012, June 2018
114	*Amraica*	*recursaria*	Walker, 1860	Sengeltheri,	Feb 2015
115	*Catoria*	cf. *sublavaria* F	Guenée, [1858]	Kuthiraivetti, Upper Kothayar, Sengeltheri,	Dec 2012, Feb 2015, Jan 2019
116	*Chorodna*	*strixaria*	(Guenée, [1858])	Upper Kothayar	Mar 2014
117	*Cleora*	*alienaria* M 5 forms	Walker, 1860	Kuthiraivetti, Upper Kothayar, Sengeltheri, Marmalai	Dec 2012, June 2013, Jan 2019, Feb 2012, 2015
118	*Cleora*	*alienaria* F	(Walker, 1860)	Kuthiraivetti	Jan 2019
119	*Cleora*	sp.3	Curtis, 1825	Kuthiraivetti	Jan 2019
120	*Cleora*	*injectaria* or nr.	(Walker,1860)	Kuthiraivetti	Dec 2012
121	*Ascotis*	cf. *imparata* F	(Walker, 1860)	Kuthiraivetti	Dec 2012, Jan 2019
122	*Cusiala*	*boarmoides*	Moore, [1887]	Talayanai, Sengeltheri	Oct 2012, Feb 2015
123	*Cusiala*	*raptaria*	Walker, 1860	Sengeltheri	Feb 2015
125	*Cusiala*	*raptaria* form *disterminata*	Walker, 1860	Mundanthurai	Mar 2012
126	*Cusiala*	*raptaria distermi-nata-* variant	Walker, 1860	Kuthiraivetti, Talayanai	Dec 2012, Feb 2015
127	*Cusiala*	*raptaria distermi-nata-* variant	Walker, 1860	Kuthiraivetti,	Dec 2012
128	*Cusiala*	*raptaria* form *rufifasciata*	Walker, 1860	Sengeltheri	Feb 2015
129	*Cusiala*	*raptaria* form *suiasasa* M	Walker, 1860	Mundanthurai, Kuthiraivetti	Feb 2015, Dec 2012
130	*Cusiala*	*raptaria*-6 forms	Walker, 1860	Mundanthurai, Kuthiraivetti, Talayani, Sengeltheri	Mar 2012, Oct 2012, Dec 2012, Feb 2015, Jan 2019
131	*Ectropis*	cf. *dentilineata*	(Moore, 1868)	Kuthiraivetti	Jan 2019
132	*Ectropis*	*bhurmitra*	(Walker, 1860)	Maramalai	Feb 2012
133	*Dasyboarmia*	cf. *inouei*	(Sato, 1987)	Sengeltheri, Kuthiraivetti	Feb 2015 March 2014
134	*Gasterocome*	*polyspathes*	Prout,1934	Upper Kothayar, Sengeltheri, Maramalai	Mar 2014, Oct 2012, Feb 2015, Feb 2012
135	*Hypomecis*	*pallida* 1M, 4F	(Hampson, 1891)	Upper Kothayar	Jun 2013

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136	*Hypomecis*	*trancissa*	(Walker, 1860)	Maramalai	Feb 2012
137	*Hypomecis*	*tamilensis*	Sato, 2016	Mundanthurai, Talayanai	Mar 2012, Feb 2015
138	*Hypomecis*	*separata*	(Walker, 1860)	Maramalai	Feb 2012
139	*Hyposidra*	*talaca*	(Walker, 1860)	Upper Kothayar, Kuthiraivetti, Maramalai	Feb 2012, Dec 2012. Mar 2014
140	*Hyposidra*	*violescens* M, F	Hampson, 1895	Kuthiraivetti, Maramalai	Dec 2012, Feb 2012
141	*Hyposidra*	sp. 3	Guenée, [1858]	Upper Kothayar	Jan 2019
142	*Ophthalmitis*	cf. *herbidaria*	(Guenée, [1858])	Sengeltheri	Oct 2012
143	*Ophthalmitis*	*kalakadaria*	Sato, 2014	Sengeltheri	Feb 2015
144	*Psilalcis*	cf. *subtochracea* M, F	(Hampson, 1902)	Kuthiraivetti, Sengeltheri, Talayanai, Maramalai	Dec 2012, Jan 2019, Oct 2012. Feb 2015, Feb 2012
145	*Psilalcis*	sp.2	Warren, 1893	Sengeltheri	Feb 2015
146	*Psilalcis*	sp.3	Warren, 1893	Sengeltheri	Feb 2015
147	*Psilalcis*	sp.4	Warren, 1893	Maramalai	Feb 2012
148	*Racotis*	*keralaria*	Sato, 2004	Kuthiraivetti, Upper Kothayar, Sengeltheri, Maramalai	Dec 2012, Jan 2019, Feb 2015, Feb 2012
149	*Ruttellerona*	cf. *cessaria*	(Walker, 1860)	Kuthiraivetti	Dec 2012
150	*Ruttellerona*	cf. *pseudocessaria*	Holloway, [1994]	Upper Kothayar	Jan 2019
151	*Biston*	*strigaria*	(Moore, 1879)	Kuthiraivetti, Sengeltheri, Maramalai	Dec 2012, Feb 2015, Feb 2012
		Unidentified Boarmiini	Duponchel, 1845	Kuthiraivetti	June 2013
		Caberini	Duponchel, 1845		
152	*Astygisa*	sp.	Walker, 1864	Upper Kothayar	Mar 2014
153	*Petelia*	*medardaria* M	Herrich-Schäffer, [1856]	Maramalai, Upper Kothayar, Kuthiraivetti	Feb 2012, Jun 2013, Jan 2019, Dec 2012, Mar 2014, Jan 2019
154	*Petelia*	*distracta* F	(Walker, 1860)	Kuthiraivetti, Sengeltheri, Upper Kothayar	Dec 2012, Oct 2012, Feb 2015, Jan 2019
155	*Petelia*	*immaculata* 2M, 2F	Hampson, 1893	Kuthiraivetti	Dec 2012, Mar 2014, Jan 2019
156	*Petelia*	*fasciata*	Moore, 1868		
157	*Petelia*	sp.3	Herrich-Schäffer, 1855	Kuthiraivetti	Dec 2012
158	*Hyperythra*	*lutea*	(Stoll, [1781])	Upper Kothayar	Mar 2014
		Cassymini	Holloway, 1994		
159	*Heterostegane*	*subtessellata* M, F	(Walker, [1863])	All sites	Feb 2012, 2015, Mar 2012, 2014, June 2014, Jan 2019
160	*Heterostegane*	cf. *tritocampsis* M, F	(Prout, 1934)	Sengeltheri, Talayanai	Feb 2015
161	*Heterostegane*	sp.3	Hampson, 1893	Maramalai	Feb 2015
162	*Zamarada*	cf. *excisa*	Hampson, 1891	Kuthiraivetti, Sengeltheri, Maramalai	Dec 2012, Oct 2012, Feb 2012
		Ennomini	Duponchel, 1845		
163	*Ourapteryx*	*marginata*	(Hampson, 1891)	Kuthiraivetti, Kannikatti, Upper Kothayar, Sengeltheri, Maramalai	Dec 2012, Feb 2013, Mar 2014, Oct 2015, Feb 2012, 2015
164	*Ourapteryx*	*peermaadiata*-yellow and white	Thierry-Mieg, 1903	Kuthiraivetti-yellow Upper Kothayar-both	Mar 2014
		Eutoeini	Holloway, 1994		
165	*Calletaera*	*postvittata*	(Walker, 1861)	Upper Kothayar	Jun 2018
166	*Luxiaria*	*emphatica*	Prout, 1925	Kuthiraivetti	Dec 2012
167	*Luxiaria*	*hypaphanes* M	Hampson, 1891	Sengeltheri, Kuthiraivetti, Upper Kothayar	Oct 2012, Dec 2012, Jan 2019, Mar 2014

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168	*Luxiaria*	*phyllosaria*	(Walker, 1860)	Upper kothayar	Jan 2019
169	*Luxiaria*	sp.4	Walker, 1860	Kuthiraivetti	Jan 2019
170	*Zeheba*	nr *aureata* 2M, 1F	Moore, [1887]	Sengeltheri,	Oct 2012, Feb 2015
171	*Zeheba*	cf. *aureatoides*	Holloway, [1994]	Sengeltheri, Kuthiraivetti	Feb 2015, Dec 2012
		Gonodontini	Forbes, 1948		
172	*Gonodontis*	*pallida*	(Butler, 1880)	Maramalai	Feb 2012
		Hypochrosini	Guenée, 1858		
173	*Fasceliina*	*plagiata*	(Walker, 1866)	Upper Kothayar, Maramalai,	Feb 2012
174	*Fasceliina*	*Chromataria*-M5 forms, 1F	Walker, 1860	Upper Kothayar	Oct 2018
175	*Achrosis*	*incitata* complex-2 forms	(Walker, 1862)	Kuthiraivetti, Upper Kothayar	Mar 2014, Jan 2018
176	*Achrosis*	intexta	(Swinhoe, 1891)	Kuthiraivetti	Mar 2014
177	*Achrosis*	sp.4 4M	Guenée, [1858]	All sites	All survey years.
178	*Achrosis*	sp.4 1F	Guenée, [1858]	Kuthiraivetti, Sengeltheri	Dec 2012, Feb 2015
179	*Achrosis*	sp. 4F	Guenée, [1858]	Kuthiraivetti	Dec 2012
180	*Celenna*	*festivaria*	(Fabricius, 1794)	Kannikatti, Upper Kothayar	Feb 2013, Mar 2014
181	*Celenna*	*festivaria* and form *formosensis*	(Fabricius, 1794)	Kuthiraivetti Upper Kothayar	Mar 2014, Feb 2013, Mar 2014
182	*Corymica*	*deducta*	(Walker, 1866)	Upper Kothayar	Jun 2018
183	*Corymica*	sp.	Walker, 1860	Kannikatti	Feb 2013
184	*Hypochrosis*	*hyadaria- chlorozonaria complex*-3 forms	(Guenée, [1858]) - (Walker, 1861)	Kuthiraivetti, Upper Kothayar, Sengeltheri, Maramalai	Dec 2012, Mar 2014, Feb 2015, Feb 2012, 2015
185	*Omiza*	miliaria F-3 forms	Swinhoe, 1890	Kuthiraivetti, Upper Kothayar, Sengeltheri, Maramalai	Dec 2012, Mar 2014, Oct 2012, Feb 2015, Feb 2012, Jan 2019
186	*Omiza*	miliaria M-2 forms	Swinhoe, 1890	Kuthiraivetti	Mar 2014
		Incertae sedis			
187	*Eumelea*	ludovicata M	Guenée, [1858]	Kuthiraivetti	Dec 2012
188	*Eumelea*	sp.2	Duncan [&Westwood], 1841	Kuthiraivetti, Sengeltheri	Dec 2012 Feb 2015
		Macariini	Guenée, 1858		
189	*Acanthovalva*	sp.	Krüger, 2001	Talayanai	Feb 2015
190	*Chiasmia*	*eleonora*	(Cramer, [1780])	Kuthiraivetti, Upper Kothayar, Sengeltheri	Dec 2012, Mar 2014, Feb 2015,
191	*Chiasmia*	*inchoata*	Walker, 1861	Maramalai, Kuthiraivetti	Feb 2012, Dec2012, Feb2015
192	*Chiasmia*	*myandaria*	(Walker, [1863])	Maramalai	Feb 2012
193	*Chiasmia*	*nora*	(Walker, [1861])	Kuthiraivetti, Upper Kothayar, Sengeltheri	Dec 2012, Mar 2014, Feb 2015
194	*Chiasmia*	*ornatataria*	(Leech, 1897)	Maramalai	Feb 2012
195	*Chiasmia*	*ozararia*	(Walker, [1860])	Upper Kothayar	Oct 2018
196	*Chiasmia*	*perfusaria*	(Walker, 1866)	Kuthiraivetti	Dec 2012
197	*Chiasmia*	*triangulata*	(Hampson, 1891)	Maramalai	Feb 2012
198	*Chiasmia*	cf. *normata*.	(Walker, 1861)	Talayanai	Feb 2015
199	*Chiasmia*	sp.11	Hübner, [1823]	Maramalai	Feb 2012
200	*Chiasmia*	sp.12	Hübner, [1823]	Kuthiraivetti	Dec 2012
201	*Chiasmia*	sp.13	Hübner, [1823]	Maramalai	Feb 2012
202	*Chiasmia*	sp.14	Hübner, [1823]	Kuthiraivetti, Sengeltheri	Dec 2012, Feb 2015
203	*Isturgia*	*disputaria* group	Krüger, 2001	Maramalai	Feb 2012

	S. Family/ Genus	Tribe/ Species	Author & Year: S. Family/ Tribe/ Genus/ Species	Location	Month and Year of survey
204	*Isturgia*	*disputaria*	Guenée, [1858]	Talayanai	Feb 2015
		Plutodini	Warren, 1894		
205	*Plutodes*	*nilgirica*	Hampson, 1891	Kuthiraivetti, Upper Kothayar	Dec 2012, June 2013, Jan 2019
206	*Plutodes*	*pseudocyclaria*	Kirty & Goyal, 2011	Kuthiraivetti, Upper Kothayar	Dec 2012, Jan 2019
		Scardamiini	Warren, 1894		
207	*Aplochlora*	sp. 2 forms	Warren, 1893	Sengeltheri, Upper, Kothayar, Kuthiraivetti	Oct 2012, Mar 2014
208	*Scardamia*	*metallaria*	Guenée, [1858]	Kuthiraivetti	Mar 2014

and *A. latizonata* Hampson, 1907, being white with grey or black pattern, are less similar. All the other *Abraxas* species from southern India show rather untypical coloration, grey or brown or yellow, sometimes with shining surface. Moths of the genus *Abraxas* are known to be toxic and their conspicuous appearance is a very significant and successful signal to predators which therefore avoid them, hence their abundance in many habitats, and presence of more than a hundred species across Europe to Australia. Why do species of southern Indian *Abraxas* not exhibit the typical kind of mimicry but prefer a rather mimetic appearance is a point for future research?

Tribe Boarmiini Duponchel, 1845
Plate 7–10 (130–190)

***Cleora* Curtis, 1825**
Plate 8 (138–146)

Individuals identified as *Cleora alienaria* (Walker, 1860), (Plates 8 (138–144)) were quite common in KMTR. They were especially abundant in higher altitudes where they were recorded during most months of the year, except during April and May. The species has conspicuous pattern elements and their identity was determined with the help of literature sources and comparison with specimens in the ZFMK collection. Males were seen to be polymorphic; we have recorded five different variants which made identification even more difficult. A further problem is the existence of a very similar species, *C. fraterna* (Moore, 1888), described from Sikkim. *Cleora alienaria* was described from Sri Lanka and has a generally more southern distribution, but *C. fraterna* may perhaps occur also in the south. Externally both are not distinguished with certainty without details of their genitalia, which are very different. As there is no existing record of *fraterna*'s presence in the south we report these as *Cleora alienaria*.

Cleora acaciaria (Boisduval, 1833), reported in Goyal's PhD thesis (Goyal 2010; Pl. 36) from the Western Ghats is a misidentification of *C. alienaria*, as is evident from the comparison of genitalia figures depicted in the thesis and in Holloway, [1994] (Moths of Borneo, Part 11). The name *C. acaciaria* is valid today only for the species flying on Réunion Islands, extending perhaps to Mauritius.

Cleora nr *injectaria* (Walker 1860), (Plate 8 (145)), recorded druing the surveys, could not be confirmed to be true *injectaria* from the available information including distribution ranges, though it looks very similar to the typical, dark grey form of *injectaria* that is known to fly in montane habitats, from where this particular specimen was photographed. It is tentatively identified to the nearest possible species as *C.* nr *injectaria* for further investigation. True *C. injectaria* is known to be a lowland species, occurring mostly at seashore-areas with mangrove and along riverines (Holloway 1994; Kendrick 2015).

Externally, *Cleora* sp. 3. (Plate 8 (146)) is a member of the *Carecomotis*-group (Fletcher, 1953), but it bears resemblance to several species of this group. Of these, *C. falculata* (Fletcher, 1953), and *C. onycha amplissima* (Fletcher 1953), were reported from erstwhile Travancore. The holotype and paratype of *C. falculata* and the paratype of *C. onycha amplissima* are from this region. The study site from which *Cleora* sp. 3 was observed and photographed was earlier part of Travancore. A very similar species of *Cleora,* also of the *Carecomotis*-group, was recorded as *C. propulsaria* by Goyal from southern India in his thesis (Goyal 2010, Plate 37). On comparison of the genitalia Plates of *C. falculata, C. onycha amplissima* (Fletcher, 1953), and *C. propulsaria* (Holloway, [1994]) with that presented in his thesis, it is seen that the species reported by him is *falculata* and not *propulsaria*. *Cleora* sp. 3, therefore, could belong to any one of these three species. Without genitalic information, this remains identified as another species of *Cleora*.

***Ascotis* Hübner, 1825**

Plate 8 (147)

Ascotis cf. *imparata* (Walker, 1860) (Plate 8 (147), female) was a species difficult to identify. Pattern and coloration are extremely similar to *C.* a*lienaria* (Walker, 1860), but this was ruled out since this individual had narrower wings and was larger in wingspan (>45 mm). In size, this wingspan compared well with that reported for *C. fraterna* (Moore, 1888). But without any discerning characters (males of *Ascotis* with simple antennae would be easy to distinguish from males of *Cleora* with strongly pectinated antennae) and with scarce evidence of the presence of *fraterna* in southern India we at first, provisionally identified it as a species near *alienaria*. After further comparative studies the 2nd author could identify it as a female of *A. imparata*, described from Nepal and "Hindostan", although not yet recorded from southern India. We believe that the presence of *imparata* cannot be excluded and it is unlikely, that the South Indian individuals may be members of any other closely related species.

Examination of genitalia is needed to identify this moth which was observed frequently in KMTR.

***Cusiala* Moore, 1887**

Plates 8–9 (148–160)

Thirteen individuals of *Cusiala* Moore are reported. There are two species of *Cusiala* that fly in India, *C. boarmoides* Moore, [1887] and *C.* raptaria Walker, 1860. Both are polymorphic but at KMTR the latter was observed to be more widely polymorphic. *Cusiala boarmoides*, the type species described from Sri Lanka, flies both in northern and southern India but *C. raptaria* is reported only from southern India (Hampson 1895). The only distinguishable external difference between the two species (Moore 1887; Hampson 1895) is the postmedial band of the hindwing. In *boarmoides,* it is angled beyond the cell instead of curved as in *raptaria*. In the absence of any other clearly identifiable characteristics based on external morphology, to differentiate *boarmoides* from the typical *raptaria* of southern India, we have presented one individual as *C. boarmoides* (Plate 8 (148)), and all others are designated *C. raptaria*.

Hampson (1895) determined the species *disterminata, rufifasciata* and *suiasasa* as forms of *C. raptaria*. Our elementary investigation suggests that these determinations, too, need investigation. In addition, the sexual polymorphism, that this genus displays, too, needs investigation. These three forms were not the only ones that we found in our study sites. There were variants in the form *disterminata*, a black variant form, and several other with variable wing markings were observed. Twelve *Cusiala rapataria* that includes the described and undescribed forms (Plates 8–9 (149–160)) are reported. The existence of a wide variety of previously undescribed forms among *C. raptaria* require a more thorough investigation of the genitalic features to understand this genus and its species, as well as its sexual variations. Several other variants seen have been omitted from this paper, for want of detailed descriptions. This further underscores the importance of permitting collection to correctly document the diversity and furthering the scientific knowledge.

***Hypomecis* Hübner, 1821**

Plate 9 (164–171)

Four species of Hypomecis – *H. transcissa* (Walker, 1860), *H. separata* (Walker, 1860), *H. tamilensis* Sato, 2016 and *Hypomecis pallida* (Hampson, 1891), are reported in this paper. Dark and light forms of *H. separata* are reported from the buffer area of the reserve. *Hypomecis tamilensis* is a species that was described from KMTR by Sato (2016). *H. pallida* was quite abundant in our study sites. The females of this species are polymorphic (Plate 9 (164–167)) and were found more abundantly and frequently than males. The postmedial fasciae on their wings varied from shades of light and dark grey with brownish or blackish tinge.

H. pallida had been earlier described as a member of the genus *Narapa* Moore, 1887, which later was placed as a junior synonym under *Hypomecis* (Scoble 1999; Hausmann, pers. comm. 29.vi.2019). Preliminary studies of the type-species of *Narapa*, *N. adamata* Felder & Rogenhofer, 1875, from Sri Lanka, by the second author (2nd author, unpublished data), which included analysis of male genitalia indicate that *Narapa* should be treated as a distinct genus in future again.

Several individuals that bore close resemblance to *pallida*, but differing in size, wing shape and markings were observed in the study sites, especially at Kuthiraivetti and Upper Kothayar. We believe that collection and further investigation is likely to reveal new data.

Tribe: Caberini Duponchel, 1845

Plate 10 (191–200)

Ten individuals, belonging to three genera, namely *Astygisa* Walker, 1864, *Petelia* Herrich-Schäffer, 1855, and *Hyperythra* Guenée, [1858], are reported.

***Petelia* Herrich-Schäffer, 1855**

Plate 10 (191–198)

Members of this genus were common in KMTR and were sighted during all surveys at all sites except Talayanai. Four species of *Petelia* – *Petelia medardaria* Herrich-Schäffer, [1856], *P. immaculata* Hampson, 1893, *P. distracta* (Walker,1860), and. *P. fasciata* Moore, 1868, are reported in this paper. One individual could not be identified to species level. All four species are differentiated by the pattern of lines and spots on the wings.

Three almost straight, and almost parallel transverse lines in the forewing are typical to *medardaria* (Plate 10 (191)). Black apical patches are sometimes present in the forewings.

A curved medial line in the forewing, curved toward apex near costa and towards base near hind-margin is typical to *immaculata*. Females of *Petelia* species show wide variation, which the second author has noticed from the collections at ZFMK. This was evident in the two individuals of *immaculata* we have presented. The elements of black pattern near forewing apex which is typical of the females in *immaculata* (Hampson, 1893) was present in one and absent in another female (Plate 10 (196–197)). This pattern is lacking in males.

Identification of *P. distracta* (Plate 10 (192)), was difficult as the facies of *distracta* bears resemblance with that of *medardaria* female and *P. delostigma* Prout, 1932. The fasciae, however, have some discernable differences. The medial line in *delostigma* is curved more towards the tornus unlike in *distracta* in which it runs straight towards the inner margin. *Petelia delostigma* is larger than *distracta* and has not been reported from India. The black spots in *distracta* lie very close to the medial line almost touching it, whereas in the female of *medardaria* the spots lie well below the medial line, closer to the outer margin of the HW. Given these differences we conclude that the individual is *P. distracta.*

In *P. fasciata* (Plate 10 (193)), the antemedial and medial line of the forewing are diffused and rufous-brown with the postmedian band also being rufous-brown, but ill-defined and waved. Diffused transverse greyish fascies between the rufous bands on both wings, a grey centred blackish discal spot in the HW and a marginal row of black spots form the markings of this species.

The markings on the *Petelia* sp. 5 (Plate 10 (198)) bear similarity to *immaculata*, but the presence of additional patterns on the hindwings require a more thorough investigation, hence it remains unidentified at the species level.

Tribe: Ennomini Duponchel, 1845

***Ourapteryx* Leach, 1814**

Plate 11 (207–209)

We report two species, the white *Ourapteryx marginata* (Hampson, 1891) (Plate 11 (207)), and the yellow *Ourapteryx peermaadiata* Thierry-Mieg, 1903 (Plate 11 (208)). The yellow *O. peermaadiata* was first described by Thierry-Mieg in 1903. Hampson (1907) described it again as *Urapteryx ebuleata palniensis* from Palani Hills, Tamil Nadu and Inoue (1993) redescribed *peermadiata* placing *O. ebuleata palniensis* as a junior synonym of *peermaadiata*. This is the only yellow coloured *Ourpateryx* that flies in southern India. The third author who is researching *Ourapteryx* species of India (3rd author, unpublished data) has recorded a white morph of *O. peermaadiata* from southern India which has also been recorded in KMTR (Plate 11 (209)). Wing-shape and all pattern elements are exactly the same in both forms, but genitalia have not been compared yet.

Comparisons of genitalia presented by Inoue (1993) with that reported by Goyal in his PhD thesis (Goyal 2010, Plate 57) show that *O. peermaadiata* has been incorrectly described as *O devikulamensis* sp. n.

Tribe Eutoeini Holloway, 1994

Plate 11 (210–219)

***Zeheba* Moore, [1887]**

Plate 11 (216–219)

Four individuals that we report are only tentatively identified. The second author has compared these individuals (Plate 11 (216–219)) to the material of an undescribed *Zeheba* from Sri Lanka in the ZFMK collection. Based on external morphology, these individuals from KMTR resemble the material at the museum.

Males and females of *Zeheb*a are easily distinguished. While both have simple, unpectinated antennae, the hindwing margin is dentate in males, but is smooth, broader and angled in the middle (at vein M3) in females (Plate 11 (216)). *Zeheba marginata* that Moore (1884) describes and figures in Lepidoptera of Ceylon (Moore, 1884–7) is a female of the yet-to-be described *Zeheba* species from Sri Lanka. True *Z. marginata* was described from Java by Walker in 1886 and is likely to be extralimital to India. The female we report is very similar to the female described by Moore, erroneously as *Z. marginata.*

The presence of this undescribed species in southern

India is further confirmed from another erroneous record of *Zeheba marginata* in Goyal's PhD thesis (Goyal 2011; pl. 1). The genitalia details of the male presented in the thesis are identical to the male genitalia of the undescribed Sri Lankan material in ZFMK collection, which the second author has dissected and studied (2nd author, unpublished data).

These individuals (Plate 11 (216–218)) also bear strong resemblance to *Z. aureata* Moore, [1887], a Himalayan species, but the genitalia of the *aureata* are quite distinctly different (2nd author, unpublished data). We report them tentatively as Z. nr *aureata* but they require a detailed investigation to confirm the species identity.

The individual in Plate 11 (219) is a male which is larger than the other three Individuals, half-white (or pale-yellow), including the broader wing borders, and with almost-hyaline basal part of hindwing. Without genitalic details its identity cannot be determined with certainty, but likely belongs to Z. *aureatoides* Holloway, [1994], described from Borneo, but with a wider distribution to Sulawesi and Peninsular Malaysia (Holloway, [1994]; coll. ZFMK), Thailand, Myanmar (coll. ZFMK, unrecorded) and perhaps, as a new record, to southern India. Examination of specimens would be necessary to investigate further to prove this.

Tribe Hypochrosini Guenée, 1858
Plates 11–12 (221–246)

***Achrosis* Guenée, [1858]**
Plates 11 (221–223); Plate 12 (226–230)

Several individuals of the genus *Achrosis* were observed, mostly in the wet evergreen or moist deciduous habitats. Of the seven individuals of this genus presented in this paper, *A. intexta* (Swinhoe, 1891) (Plate 11 (223)) is identified with certainty, because of its conspicuous pattern and coloration and as it is the only species of the *intexta*-group known from South India (type-locality: Kanara, southwestern India). Other species of the *intexta*-group are known from Peninsular Malaysia, Borneo and Sumatra (Holloway [1994], the Philippines (ZFMK, not yet recorded).

We report another two individuals (Plate 11 (221 & 222)) with pattern and coloration of *Achrosis incitata* (Walker, 1862) (type-locality: northern India, Darjeeling). Both of them differ considerably from each other and may be members of two different species. From southern India (Nilgiri Hills), Swinhoe (1891) described *Zomia miscella* as new to science which Hampson (1895) synonymized with *"Prionia" incitata*, indicating that *incitata* flies throughout India. Swinhoe later opines that *miscella* is a southern form of *incitata*. A further species of this group was described from Sri Lanka as *Timandra? serpentinaria* (Walker, 1866), which certainly may also occur in the extreme south of India. Identification of two Individuals we recorded of the *incitata*-group is only possible by dissection of genitalia; hence further investigation is required.

Holloway (1994) described a new species close to *A. incitata* from Borneo and Sumatra and in the process reviewed what he calls the *incitata* complex. According to him almost all species of this complex are allopatric (except his new Bornean species which overlaps with the Sumatran species) and all are distinguished by differences in the male genitalia.

The two individuals we report as *A. incitata* (Plate 11 (221 & 222)) may be one among the three species of *incitata* complex that fly in southern India or Sri Lanka or they could be a new species of the *incitata* complex. Further investigation is required.

We also report one unattributed species, *Achrosis* sp. 4 (Plate 12 (226–230)). The ZFMK, too, has specimens of this species that do not match any described so far in their collection. More than one form of the male was observed but only a single female was spotted during the survey. Neither *Achrosis* sp. 4 nor the *incitata* complex resemble *Achrosis euchroes* (Prout, 1917), described from Nilgiris, which also does not find mention in the *incitata*-complex described by Holloway [1994], as it did not occur in Borneo.

***Celenna festivaria* (Fabricius, 1794)**
Plates 11–12 (224–225)

Two forms of *Celenna festivaria* Fabricius were found flying from March to August. They were found only in two sites of the survey (Table 3). The typical form of *festivaria* where the green patches are separated in the forewing, was less frequently seen than the form where the green bands were fused completely (Plate 11 (224)) and formed a large green patch on the FW. Although this species is common in India, there has been no report of racial differences so far. This form with the large fused bands that is dominant in Taiwan was named f*ormosensis* by Inoue (1964) and treated as a subspecies of *festivaria*. Holloway [1994] reports that the genitalia of ssp. *formosensis* described by Inoue resemble those of the Indian nominal subspecies *C. festivaria festivaria* and he therefore confirms it as a subspecies.

Celenna centraria Snellen, 1880, described from Sumatra, but also occurring in Borneo, is reported by Kirti et al. (2019) as found in the Andaman Islands.

The fused pattern on the forewing of *centraria* is quite different from the species we are reporting here. Holloway [1994] states and figures that the genitalia of *centraria* differ strongly from those of *festivaria*. Until further investigation is undertaken, we report both forms as *C. festivaria*.

***Fascellina chromataria* Walker, 1860**

Plate 12 (234–238)

These moths were seen from the month of June onwards till November. Four males and one female recorded is presented here. Sexual dimorphism is well marked; the female was yellowish-brown with cream coloured antemedial and postmedial lines. The postmedial line had cream spots at regular intervals. The wing colour in males ranged from shades of greenish-brown, brown to black (Plate 12 (235–238)). The submarginal fascia was white in three forms, while in the fourth, the brown form, there was merely a white speck near the excavated tornal margin (Plate 12 (237)). Each of the differently coloured forms were seen in different months and did not fly together.

The hindwing of the underside of the males were chrome-yellow, as their name suggests. The basal parts of the forewing were yellow, red-brown around the postmedial line; the postmedial regions being a mix of brownish-red. A greyish angled line and a patch near the apex of FW was also observed. *Fascellina chromataria* was described from Sri Lanka, and it has been reported from the Shendurney Wildlife Sanctuary in Kerala (Sondhi et al. 2018). Forests of KMTR and Shendurney Wildlife Sanctuary are part of Agasthyamalai Biosphere Reserve. The female seen in KMTR (Plate 12 (234)) is similar to the female collected and identified from Shendurney and therefore is identified as *Fascellina chromataria.* As we also observed more than one form of *chromataria* males, we report this group of four males and one female as *Fascellina chromataria* complex. Examination of specimens are needed to determine whether the individuals of this complex are morphs, subspecies or different species.

***Hypochrosis hyadaria* (Guenée, [1858]) - *H. chlorozonaria* (Walker, 1861)**

Plate 12 (239–241)

Hypochrosis hyadaria is treated at present as a single species with a large number of described subspecies (Holloway [1994]; Scoble et al. 1999), distributed allopatrically from India, over large areas of southeastern Asia and the Malayan archipelago. *Hypochrosis chlorozonaria* Walker, 1861, described from Sri Lanka, is treated as a related, but distinct species. It was later described again as *Numaria galbulata* (Felder & Rogenhofer, 1875) and *Marcala sulphurescens* (Moore, [1887]), from Sri Lanka. *Hypochrosis galbulata* and *H. sulphurescens* are just different forms of the same variable species, *chlorozonaria*. Unlike the description of *hyadaria* given by Hampson (1895), the facies described by Moore for these two forms of *chlorozonaria* match well with the facies of the individuals (Plate 12 (239–241)) we have recorded. Holloway (1994) states, "India through S.E. Asia", as the geographical range for *hydaria.* Evidence of *hyadaria* flying in southern India comes from the surveys at Shendurney Wildlife Sanctuary by Yash Sondhi (Sondhi et al. 2018). It is possbile that both the species—*hyadaria* and *chlorozonaria*—could be found flying together in this region. Investigations through examination of the genitalia of collected specimens alone can provide their correct identity. Therefore, we report these three individuals as forms of *Hypochrosis hyadaria* or *chlorozonaria*.

Tribe Macariini Guenée, 1858

Plate 12–13 (250–269)

The identities of various moths in this tribe were investigated by referring to Krüger's (2001) extensive work on African species and a range of global macariine species, and the review of this tribe by Scoble & Krüger (2002). The details given in the works of Hampson (1891, 1895), Moore (1884–7), and Walker (1862) were also consulted. Some macariine genera can be identified based on wing colour, shape, and pattern (Scoble & Krüger 2002). However, genitalia structure is the most reliable feature for identification of moths from this tribe.

The macariine taxonomy is still in flux as several species from the Oriental region, including some from India, have not yet been described, as is evident from this paper. Nineteen macariine individuals have been observed and are classified here in three genera, namely, *Acanthovalva* Krüger, 2001, *Chiasmia* Hübner, [1823] 1816, and *Isturgia* Hübner, [1823] 1816.

***Acanthovalva* Krüger, 2001**

Plate 12 (250)

The general features of this moth match the description given for *Acanthovalva* by Krüger (2001). Further investigation about the species requires collection and examination of genitalia. Although he could not examine any specimens, Krüger suggests that *Tephrina fumosa* (Hampson, 1895) from Nilgiris may be closely related to *Acanthovalva bilineata* (Warren, 1895) from South Africa, extending, if verified, the range of this genus to the Oriental region. This is the first record of the genus *Acanthovalva* from southern India.

***Chiasmia* Hübner, [1823] 1816**

Plate 12–13 (251–266)

Fourteen macariine species belonging to the genus *Chiasmia* Hübner are reported. Four of them could be identified only to genus level. One is presented with a provisional identification and nine of them are identified to species level using the various published records listed throughout in this paper.

We report here that the ZFMK has a group of four specimens named *C. ablataria* Swinhoe, collected from the Nilgiri Hills. Externally, they bear close resemble to the unidentified *Chiasmia* sp. 13 (Plate 13 (265)). However, our research did not yield any more information, such as the year Swinhoe described this species, whether it is a synonym for a described taxon or any literature on it. The name is missing even from the list in Scoble et al. (1999.) This, again, underscores the importance of collecting moths for an accurate description and identification.

***Isturgia* Hübner, [1823] 1816**

Plate 13 (267–269)

***Isturgia disputaria* (Guenée, [1858])**

The various species of *Isturgia* have been broadly placed under five groups by Krüger (2001). One of them is the *Isturgia disputaria* group. We report two taxa that belong to it. Both are tentatively identified, as details of genitalia are not available.

We have identified a female from Talayanai (Plate 13 (269)) as *Isturgia disputaria* Guenée. It is identified by the strong, black fasciae of the forewings. The description of the fasciae matches that given by Hampson (1895). Hampson (1895) also states that the southern Western Ghats forms appear generally paler and ochreous. Krüger (2001) mentions that the HW median line in *disputaria* may be faint or absent, while Hampson records the HW "with sinuous median line". These lines are partly visible in our Plate, but minor variations in fascia could also be a geographical phenomenon, in our opinion.

The second taxon (Plate 13 (267–268)) we report as *Isturgia*—a male and a female observed at Maramalai (a higher elevation site in the buffer zone of the Reserve)—also belongs to the *I. disputaria* group. It bears some resemblance to the former taxon, but has much weaker transverse fasciae. It may be just a form or variation of the latter, but may also be related to or conspecific with *I. pulinda* (Walker, 1860), from Sri Lanka. A year later, Walker (1861) described another *Isturgia, I. deerraria,* from South Africa, which was subsequently reported by several authors ((Agenjo 1974: 4; Herbulot 1978: 161; Fletcher 1978a: 77; Wiltshire 1952: 172; 1980: 197; 1990: 135; Hermosa 1985: 28; Hausmann 1991: 138) in Krüger (2001) as a subspecies of *I. pulinda*. Krüger (2001), after examining the genitalia of the type-specimens, concluded that the African species *I. deeraria* was not conspecific with *I. pulinda*. Based on the fasciae we believe that this *Isturgia* from Maramalai may be related to *I. pulinda* or may even be a new species. The real identity can only be decided after the study of the genitalia of collected Individuals.

Isturgia catalaunaria Guenée, [1858] was also listed as a macariine species from India (Kirti et al. 2019). Krüger (2001) has recorded this to be a misidentification, as this is a species from southern Spain and southern Africa, so extralimital to India.

CONCLUSION

Investigating 390 moths through photographs and without specimens in hand to refer to, was a daunting task. In the absence of specimens, we have attempted to assign as precise species identities as deemed possible, but many uncertainties in species identities can only be clarified through collection and examination of specimens. We have also attempted to compile the many historical records that lay scattered among different resources, and contemporary published papers on Geometridae, for easy access to future researchers. Many geometrids are flower feeders, hence important pollinators of plants in forests. Their presence is likely to help forests flourish. As most geometrids are polyphagous, their varied larval host plants are also crucial, and require protection of their habitats in the Western Ghats, an area of high endemism. Given the diversity observed by the first author in these forests, we hope that these preliminary findings will stimulate further research on the geometrid moths of KMTR.

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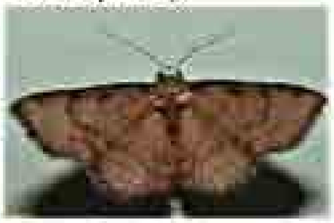
Plate 1. Geometrids of Kalakad-Mundanthurai Tiger Reserve


18. *Scopula* nr *relictata*


19. *Scopula* sp.


20. *Somatina rosacea*


21. *Somatina* nr *plynusaria*


22. cf. *Somatina*.

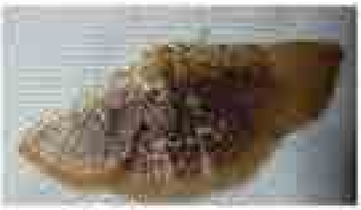
Tribe Sterrhini: 23–32


23. *Idaea gemmaria*

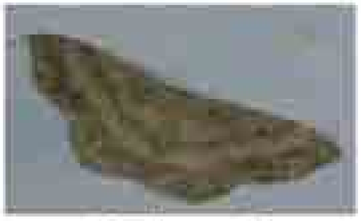

24. *Idaea* nr *gemmaria*

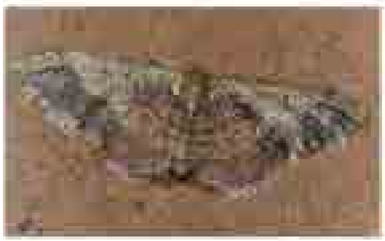

25. *Idaea violaceae*

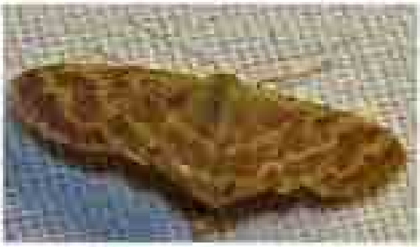

26. *Idaea* sp.4


27. *Idaea* sp.5


28. *Idaea* sp.6


29. *Idaea* sp.7


30. *Idaea* sp.8


31. *Lophophleps phoenicoptera*


32. *Lophophleps purpurea*

Tribe: Timandrini: 33

Unidentified Sterrhinae: 34–36


33. *Timandra* sp.


34.


35.

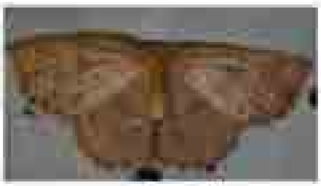

36.

Plate 2. Geometrids of Kalakad-Mundanthurai Tiger Reserve

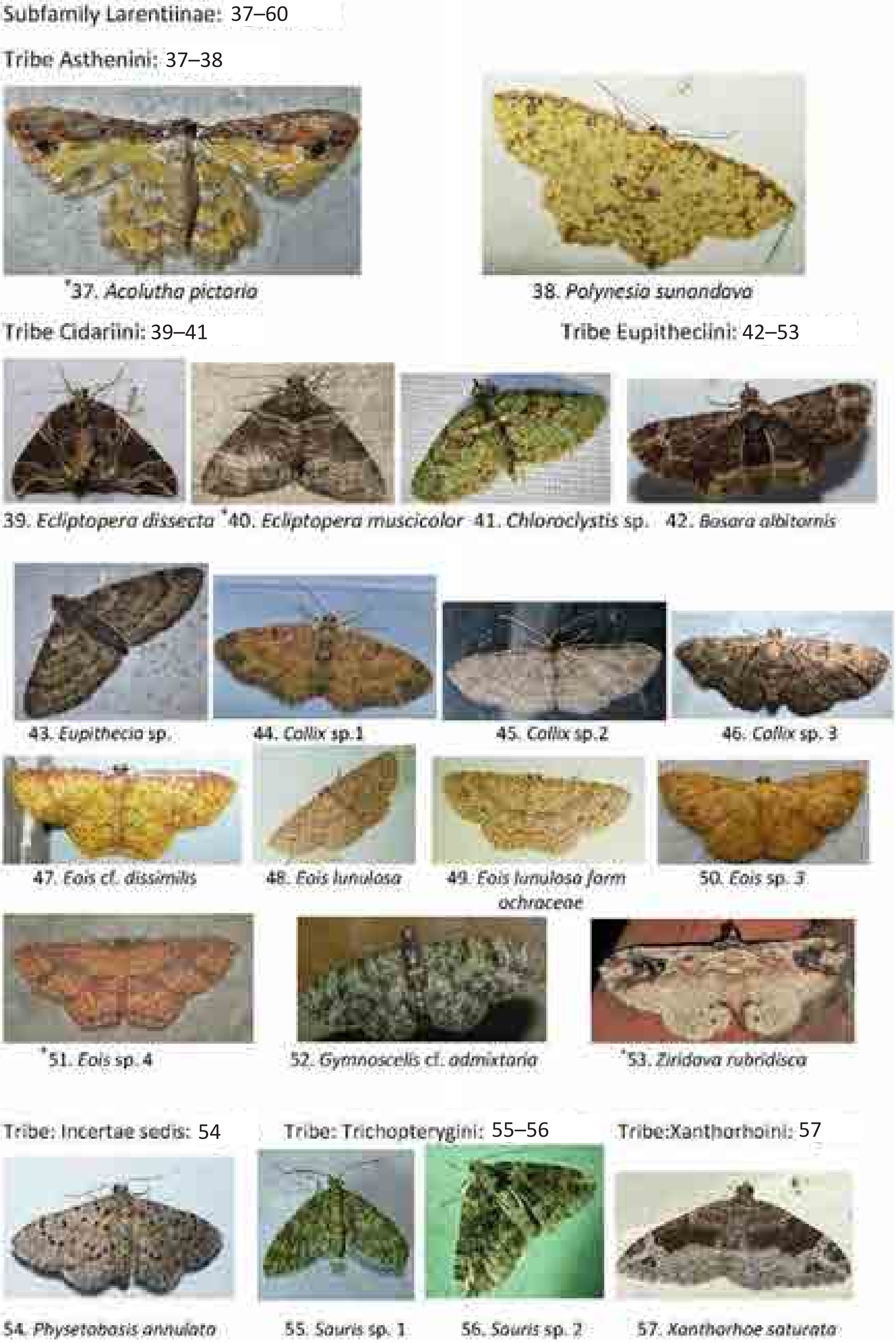
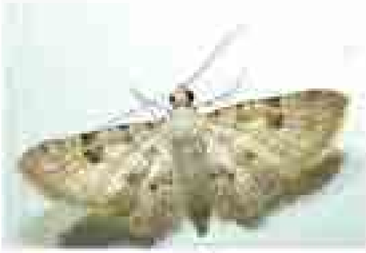
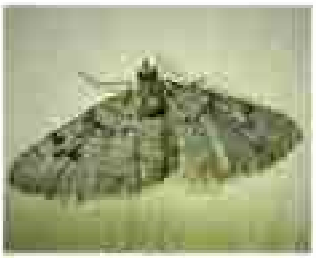


Plate 3. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Unidentified Eupitheciini: 58–60

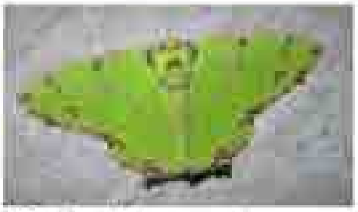

58.


59.


60.

Subfamily Geometrinae: 61–101

Tribe Agathiini: 61–63


61. *Agathia lycaenaria*


62. *Agathia hemithearia*

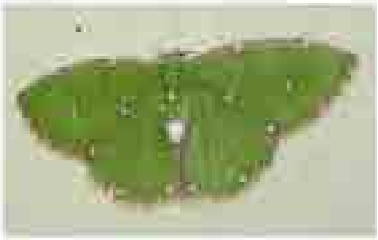

63. *Agathia laetata*

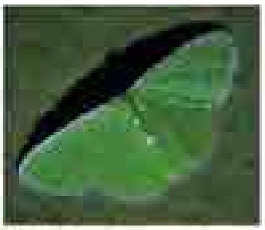
Tribe Archaeobalbini: 64–65


64. *Herochroma* cf. *cristata*


65. *Lophophelma ruficosta*

Tribe: Comibaenini: 66–74

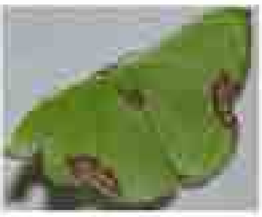

66. *Argyrocosma inductaria*


67 *Chlorochromodes* sp.


68. *Comibaena attenuata*


69. Comibaena cassidara


70. *Comibaena fuscidorsata*


71. *Comibaena integranota*


72. *Comibaena* cf. *striataria*


73. *Protuliocnemis* cf. *biplagiata*


74. *Protuliocnemis partita*

Plate 4. Geometrids of Kalakad-Mundanthurai Tiger Reserve

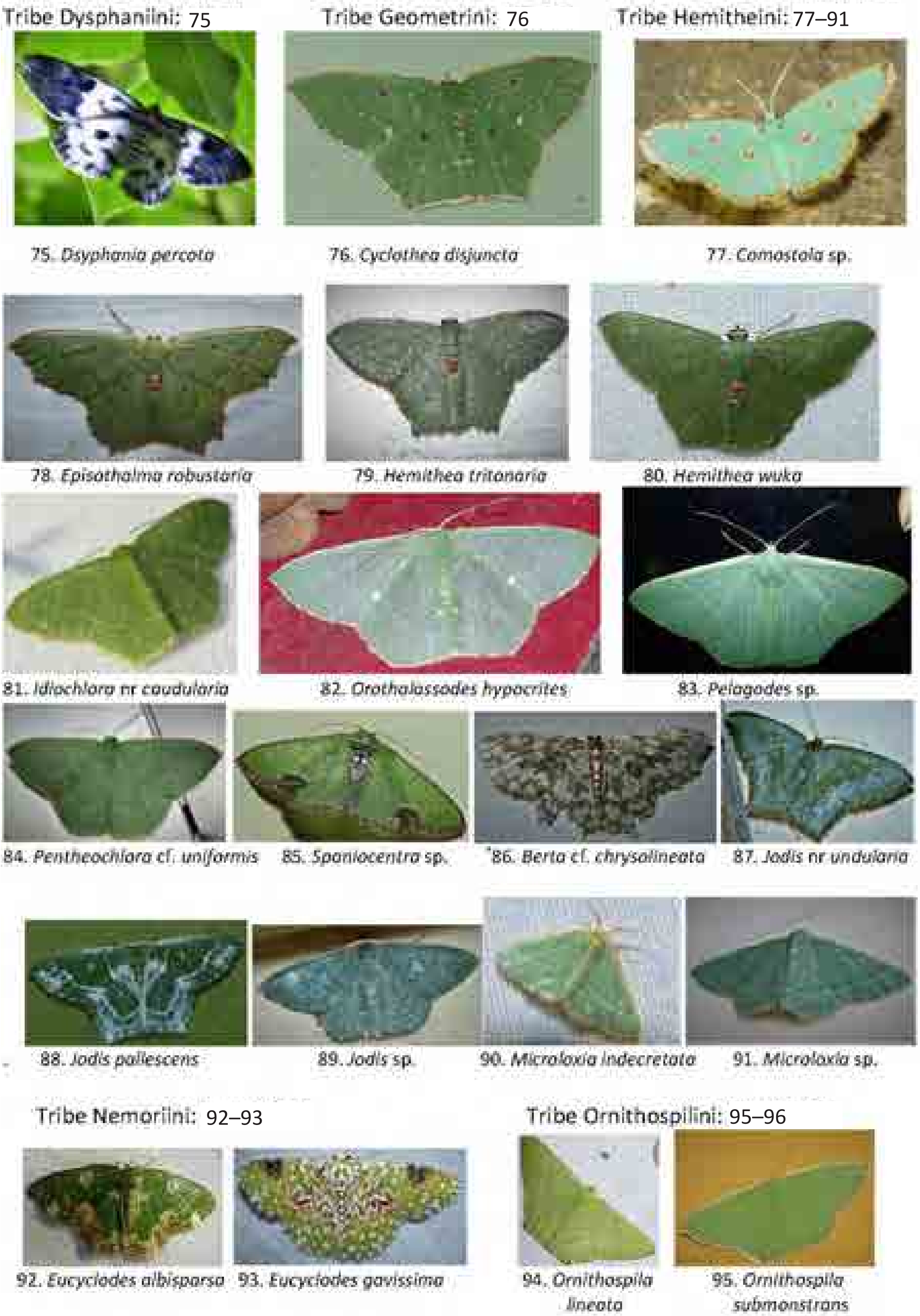
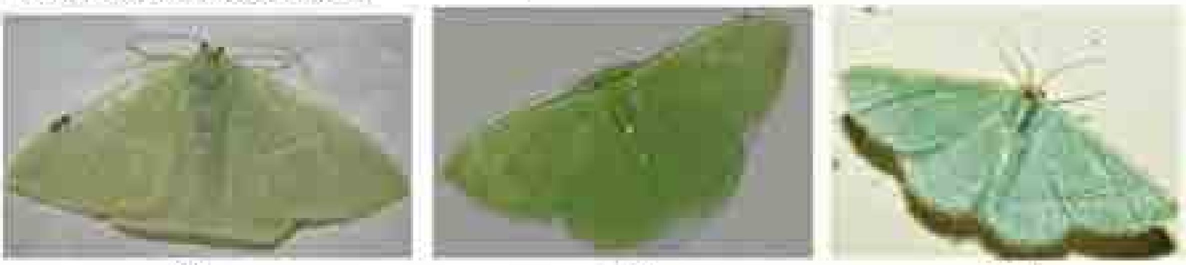


Plate 5. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Tribe Pseudoterpnini: 96–98

96. *Pingasa ruginaria* 97. *Pingasa dispensata* ♂ 98. *Pingasa dispensata* ♀

Unidentified Geometrinae: 99–101



99. 100. 101.

Subfamily Desmobathrinae: 102–105

102. *Derambila fragilis* 103. *Noreia ajaia* ♂ 104. *Ozola microniaria* ♀ 105. *Ozola* sp.

Subfamily Ennominae: 106–274

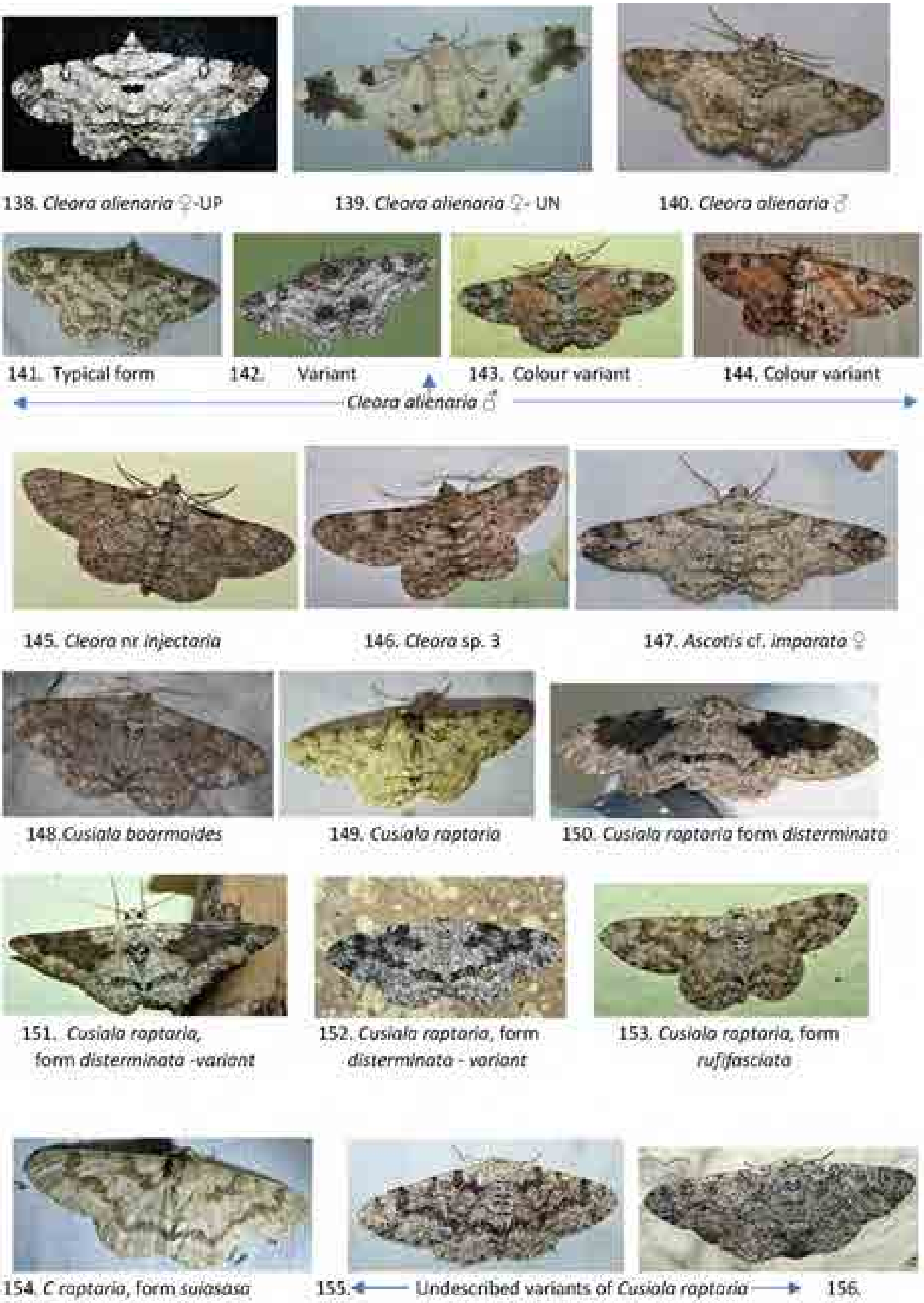
Tribe Abraxini: 106–123

106.*Abraxas leucostola argyrosticta* 107. *Abraxas fasciaria* 108. *Abraxas poliostrota* ♂ 109.*Abraxas poliostrota* ♀

110.← *Abraxas* sp.4 → 111.(UN) 112. ← *Abraxas* sp.5 → 113.(UN) 114.*Abraxas sp.6*(UP)

Plate 6. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 7. Geometrids of Kalakad-Mundanthurai Tiger Reserve



138. *Cleora alienaria* ♀-UP
139. *Cleora alienaria* ♀- UN
140. *Cleora alienaria* ♂
141. Typical form
142. Variant
143. Colour variant
144. Colour variant
Cleora alienaria ♂
145. *Cleora nr injectaria*
146. *Cleora* sp. 3
147. *Ascotis* cf. *imparata* ♀
148. *Cusiala boarmoides*
149. *Cusiala raptaria*
150. *Cusiala raptaria* form *disterminata*
151. *Cusiala raptaria*, form *disterminata* -variant
152. *Cusiala raptaria*, form *disterminata* - variant
153. *Cusiala raptaria*, form *rufifasciata*
154. *C raptaria*, form *sulasasa*
155. ← Undescribed variants of *Cusiala raptaria* → 156.

Plate 8. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 9. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 10. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 11. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 12. Geometrids of Kalakad-Mundanthurai Tiger Reserve

Plate 13. Geometrids of Kalakad-Mundanthurai Tiger Reserve. © Images with * are contributions from Thalavaipandi. All others are those of the first author.

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COMMUNICATION

Roadkills of Lowland Tapir *Tapirus terrestris* (Mammalia: Perissodactyla: Tapiridae) in one of its last refuges in the Atlantic Forest

Aureo Banhos [1], Andressa Gatti [2], Marcelo Renan de Deus Santos [3], Leonardo Merçon [4], Ilka Westermeyer [5], Natália Carneiro Ardente [6], Luis Francisco Oliveira Pereira Gonzaga [7], Lucas Mendes Barreto [8], Lucas Damásio [9], Tomas Lima Rocha [10], Vitor Roberto Schettino [11], Renata Valls [12], Helena Godoy Bergallo [13], Marcos Vinicius Freitas Silva [14], Athelson Stefanon Bittencourt [15], Danielle de Oliveira Moreira [16] & Ana Carolina Srbek-Araujo [17]

[1,8,9,11] Departamento de Biologia, Centro de Ciências Exatas, Naturais e da Saúde, Universidade Federal do Espírito Santo, Alto Universitário, s/nº, Guararema, 29500-000, Alegre, ES, Brazil.
[1,7,10] Programa de Pós-graduação em Ciências Biológicas (Biologia Animal), Centro de Ciência Humana e Naturais, Universidade Federal do Espírito Santo, Avenida Fernando Ferrari, 514, Goiabeiras, 29075-910, Vitória, ES, Brazil.
[2] Instituto Pró-Tapir para a Biodiversidade, Rua Luiz Fernandes Reis, n° 230, 29101-120, Praia da Costa, Vila Velha, ES, Brazil.
[2,16] Instituto Nacional da Mata Atlântica, Avenida José Ruschi, n° 4, 29650-000, Santa Teresa, ES, Brazil.
[3] Laboratório de Ictiologia Aplicada, Universidade Vila Velha, Avenida Comissário José Dantas de Mello, nº 21, 29102-920, Vila Velha, ES, Brazil.
[3] Instituto Marcos Daniel, Rua Fortunato Ramos, n° 123, 29056-020, Santa Lucia, Vitória, ES, Brazil.
[4,5] Instituto Últimos Refúgios, Rua Humberto Balbi, n° 21, Edifício Renê Descartes, sala 208, Jardim Camburi, 29092-080, Vitória, ES, Brazil.
[6,12,13] Programa de Pós-graduação em Ecologia e Evolução, Laboratório de Ecologia de Mamíferos, Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier, n° 524, Maracanã, 20550-900, Rio de Janeiro, RJ, Brazil.
[13] Departamento de Ecologia, Instituto de Biologia Roberto Alcântara Gomes, Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier, n° 524, Maracanã, 20550-900, Rio de Janeiro, RJ, Brazil.
[14,15] Museu de Ciências da Vida, Universidade Federal do Espírito Santo, Avenida Fernando Ferrari, 514, Goiabeiras, 29075-910, Vitória, ES, Brazil.
[17] Programa de Pós-graduação em Ecologia de Ecossistemas e Programa de Pós-graduação em Ciência Animal, Laboratório de Ecologia e Conservação de Biodiversidade, Universidade Vila Velha, Rua Comissário José Dantas de Melo, nº 21, Boa Vista, 29102-920, Vila Velha, ES, Brazil.
[17] Instituto SerraDiCal de Pesquisa e Conservação, Rua José Hemetério Andrade, 570, bloco 06, apto 201, Buritis, 30493-180, Belo Horizonte, MG, Brazil.
[1]aureo.santos@ufes.br (corresponding author), [2]gatti.andressa@gmail.com, [3]mrenansantos@gmail.com, [4]leonardomercon@gmail.com, [5]ilka.westermeyer@gmail.com, [6]natalia_ardente@hotmail.com, [7]luispof@gmail.com, [8]lucasbarreto.bio@gmail.com, [9]damasioler@gmail.com, [10]92.tomas@gmail.com, [11]schettino.vitor@gmail.com, [12]renata.pagotto@gmail.com, [13]nena.bergallo@gmail.com, [14]Marcos.vinicius.freitas.silva@gmail.com, [15]athelson.bittencourt@ufes.br, [16]daniomoreira@gmail.com, [17]srbekaraujo@hotmail.com

Abstract: Highways limit the movement and dispersion of wild animals and contribute to their loss due to roadkills, leading to the isolation and decline of populations, increasing the risk of local extinction. The Lowland Tapir *Tapirus terrestris* is the largest neotropical herbivore-frugivore, and despite its wide distribution in South America it is threatened with extinction. In this study we report six roadkill events of tapirs between 2014 and 2019 in a section of a federal highway crossing the mosaic of Atlantic Forest reserves called Sooretama, one of the last tapir refuges in southeastern Brazil. The traffic in this area is heavy with inadequate speed control, while exotic fruit trees growing along the highway attract wild animals. Water drainage tunnels serve as passageways for some species, including tapirs. However, the tunnels located under the highway are not continuously maintained, reducing its effectiveness. The loss of at least one tapir per year can have serious long-term consequences for one of the last viable lowland tapir populations in the entire Atlantic Forest. Emergency measures are required to avoid vehicle-tapir collisions.

Keywords: Brazil, mitigation measures, road ecology, Sooretama, threatened species.

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INTRODUCTION

Roads and highways lead to habitat loss and fragmentation, create barriers that limit the movement and dispersion of organisms, limit genetic flows, prevent wildlife from accessing resources that are vital for their survival, and cause direct animal mortality due to roadkill incidents, all with negative effects on biodiversity (Forman & Alexander, 1998; Trombulak & Frissell 2000; Coffin 2007; Laurance et al. 2009; Holderegger & Di Giulio 2010). Large mammal populations are among the most negatively affected by the presence of roads, mainly because they travel long distances, cross different roads, and have low reproductive rates and population densities (Fahrig & Rytwinski 2009).

In Brazil, one of the large mammal species affected by highways is the Lowland Tapir *Tapirus terrestris* (Linnaeus, 1758) (Grilo et al. 2018), the largest terrestrial mammal of Neotropics, with a body length of 1.70 to 2.00 m and weight up to 300 kg (Padilla & Dowler 1994; Eisenberg & Redford 1999; Medici 2011). This species presents the largest distribution within the genus and is found in the lowland regions of northern and central South America (Padilla & Dowler 1994; Eisenberg & Redford 1999; Varela et al. 2019). Despite its wide geographic distribution, the species is currently classified as Vulnerable, both globally (Varela et al. 2019) and in the Brazilian territory (Medici 2018). Nevertheless, in the Atlantic Forest, one of the most threatened biodiversity hotspots in the world (Myers et al. 2000), the conservation status of the Lowland Tapir is even more worrying because its habitat has been reduced to a few fragments and its population is extremely small, being reduced to a small number of areas (Medici et al. 2018).

The main conservation threats to the Lowland Tapir are habitat loss, poaching and competition with livestock (García et al. 2012; Medici et al. 2012, 2018; Varela et al. 2019). However, in recent years, roadkill incidents with tapirs have attracted increasing attention due to their negative consequences. In Brazil, tapirs killed by collisions with vehicles have been reported in the Amazon (Carvalho et al. 2014; de Freitas et al. 2017), Pantanal (de Souza et al. 2015), Cerrado (Ascensão et al. 2017), transitional areas between Cerrado and the Atlantic Forest (Cáceres et al. 2010; Cáceres 2011), and the southwestern region of the Atlantic Forest (Medici & Desbiez 2012). These events are even more severe for tapir populations when combined with other threats, especially in the Atlantic Forest, where very few areas support viable populations of more than 200 individuals (Medici et al. 2012).

Here we report tapir roadkills and relate them to the species' high locomotion ability combined with poor road management in one of the last areas with viable Lowland Tapir populations, located in the north of Espírito Santo State, southeastern Brazil (Flesher & Gatti 2010; Gatti et al. 2011; Medici et al. 2012; Ferreguetti et al. 2017), in a complex of protected areas known as Sooretama. Sooretama, which means "land of the animals of the forest" in the Brazilian native language Tupi Guarani (Instituto Brasileiro de Desenvolvimento Florestal 1981), consists of a group of four protected areas amount approximately 53,000 ha. These areas have been recognized as one of the best preserved large lowland forests with high priority for the conservation of large mammals in the biome (Galetti et al. 2009).

METHODS

Study area

We conducted the study in a forest complex formed by Sooretama Biological Reserve (SBR; 27,858 ha), a federal protected area; the Vale Natural Reserve (VNR; 22,711 ha), a private protected area; the Private Natural Heritage Reserves (PNHR) Recanto das Antas (2,212 ha) and the PNHR Mutum-Preto (379 ha) (Figure 1). This contiguous protected areas complex is one of the 77 Atlantic Forest remnants with more than 10,000 ha (Ribeiro et al. 2009), located between the coordinates -18.905458, -40.212713 and -19.244815, -39.945269, in the northern part of the Espírito Santo state, southeastern Brazil, hereon referred as Sooretama (Figure 1).

The Sooretama reserves form one of the largest remnants of Tabuleiro Atlantic Forest, a lowland forest (formed on sedimentary plains originated in the Pliocene) intersected by wide and shallow valleys (Rolim et al. 2016). The climate is tropical with dry winter (Aw) according to Köppen's system (Alvares et al. 2013). Since the 1960's, the Sooretama forest complex has been bisected by the busiest highway in Brazil, the federal BR-101 highway (Instituto Brasileiro de Desenvolvimento Florestal 1981) (Figure 1). Approximately 23 kilometers of BR-101 intersects the SBR buffer zone, with 5 kilometers crossing the interior of SBR (Figure 1).

Data collection

We obtained data on tapirs killed by collisions with vehicles on the section of BR-101 crossing Sooretama between 2014 and 2019. The roadkill events were reported to us by the SBR staff. We visited the sites,

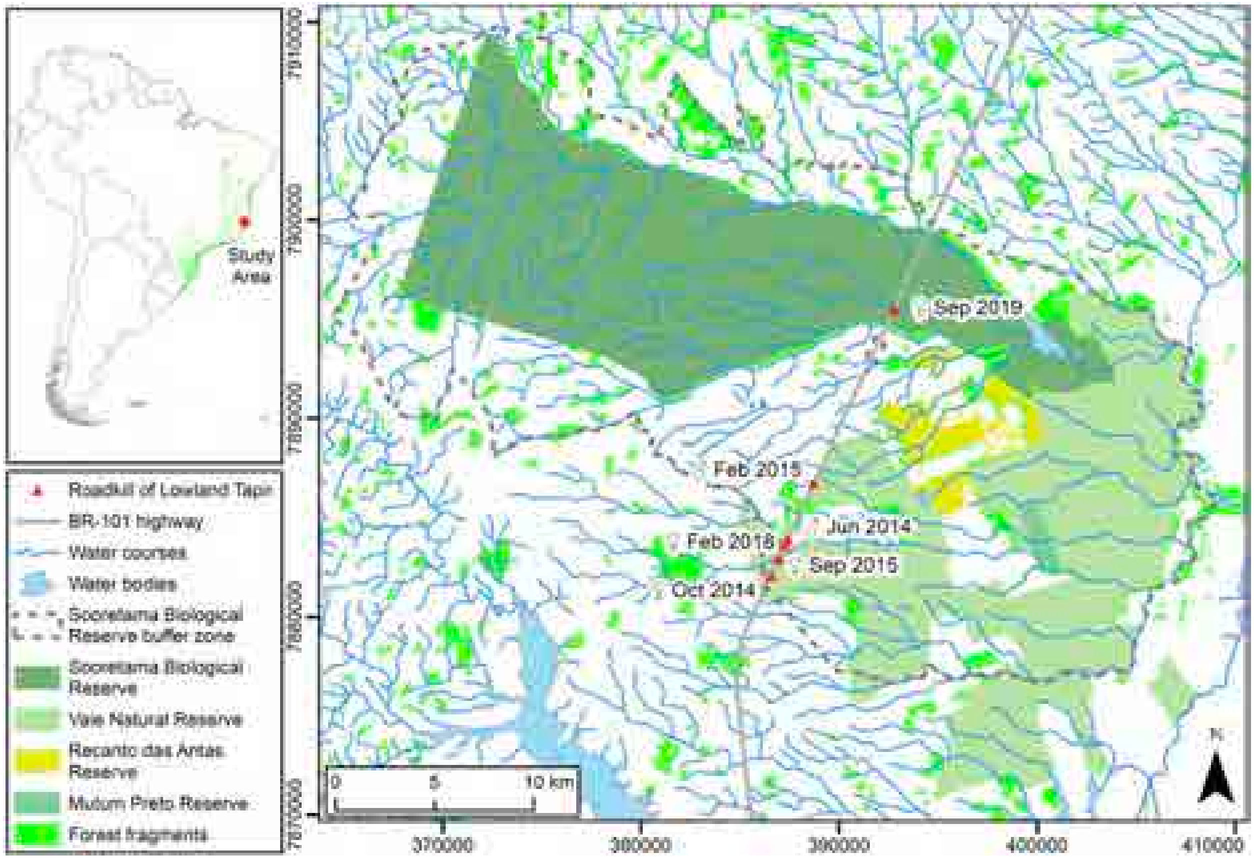

Figure 1. Records of six roadkill events of lowland tapirs in a section of BR-101 highway, crossing the Sooretama complex, in southeastern Brazil.

recorded the date, the location on the highway, and the age class and sex of each animal. Necropsies were performed on individuals that were not in an advanced stage of decomposition. The tapir bones and heads were collected and deposited at the Museu de Ciências da Vida (Museum of Life Sciences), Federal University of Espírito Santo.

RESULTS

We recorded six events of tapir roadkills in the study area: two males (an adult and another juvenile) and four females (three adults and juvenile) (Figure 1; Table1; Image 1). The second roadkilled tapir was a pregnant adult female with a well-developed male fetus (Últimos Refúgios 2014a; Image 2). Two other tapirs were found on the roadside in an advanced stage of decomposition, one on 17 September 2015, and another on 15 September 2019 (Table 1). The roadkill of the last tapir was reported by a highway user who saw the moment of the collision in the late afternoon, days before the animal being found dead. Four confirmed roadkills occurred at night and one afternoon, caused by two cars, two trucks, and one bus (Table 1). Five tapirs were roadkill on the stretch of the highway that cuts through the VNR, in the SBR buffer zone (Figure 1). Only the last roadkill happened within the SBR area (Figure 1).

Table 1. Records of roadkill events of lowland tapirs in a section of BR-101 highway that crossing the Sooretama complex, in southeastern Brazil.

Date	Sex	Life stage	Km	Period	Vehicle type
30.vi.2014	male	adult	119	night	truck
24.x.2014	female	adult	121	night	car
08.ii.2015	male	juvenile	116	night	car
17.ix.2015	female	adult	120	unidentified	unidentifield
17.ii.2018	female	adult	119	night	bus
15.ix.2019	female	juvenile	105	afternoon	truck

Image 1. Photo of juvenile male Lowland Tapir roadkilled at km 116 of the BR-101 highway in Sooretama, on 8 February 2015.

Image 2. Photo of a fetus of a pregnant Lowland Tapir roadkilled at km 121 of the BR-101 highway in Sooretama, on 24 October 2014.

DISCUSSION

In the six decades since its construction, many animals of various species have been killed on this portion of the BR-101 (Instituto Brasileiro de Desenvolvimento Florestal 1981; Klippel et al. 2015; Srbek-Araujo et al. 2015; Damásio et al. 2021). Since 2014, we have followed roadkill records of tapirs to understand their negative effects on the conservation of the species in the forest complex of Sooretama. Roadkill records described in this study are extremely worrisome for the lowland tapir conservation on Espírito Santo, as well as on the Atlantic Forest biome as a whole. There is only one known record from before the monitoring period of a Lowland Tapir killed via a vehicle collision in the neighboring area of Sooretama. This occurred in 1997, when a school bus hit a tapir on an unpaved road located south of Sooretama reserves, in Córrego Farias, municipality of Linhares (Lorenzutti & Almeida 2006). Unlike this isolated record, this study shows that the loss of Lowland Tapir due to vehicle collisions is an old problem in the region, emphasizing the role of this threat in removing individuals of reproductive age from the population of Sooretama.

It is possible that some tapir deaths due to collisions were not recorded. Animals may have died in the forest due to injuries resulting from a collision, or carcasses may have been lost for other reasons. For instance, two tapirs were found only days after they were roadkilled, when the presence of vultures and decaying animal smell near the highway was noticed. Nonetheless, on 21 July 2019 we received notification of another tapir roadkill on BR-101 but its carcass was not found. Thus it is likely that we underestimated the number of tapir roadkills.

Tapir roadkills occurred most often at night and outside of the SBR area, on a stretch of highway within VNR fragmented forest. These factors must be considered in designing mitigation strategies. In addition to tapirs, other large mammals have been killed within the SBR area, including a Jaguar *Panthera onca* in 2000 (Srbek-Araujo et al. 2015) and two Pumas *Puma concolor*, one in 2009 (Srbek-Araujo et al. 2015) and another in 2015 (Últimos Refúgios 2015).

Roadkill events can rapidly reduce tapir population growth and increase the probability of local extinction, especially when adults and sub-adult females are lost (Medici & Desbiez 2012). Tapirs are long-lived and have slow reproductive rates, which makes the species more vulnerable to anthropogenic pressures (Medici & Desbiez 2012; Medici et al. 2012; Varela et al. 2019). In Sooretama, of the six recorded tapir kills, four were adult and sub-adult females. According to Ferreguetti et al. (2017), the population size in Sooretama was 200± 33 individuals, which suggests that the local population is genetically and demographically viable, based on the population viability analysis for the species in the Atlantic Forest (Gatti et al. 2011; Medici & Desbiez 2012). However, the incidence of female roadkill can be a warning for the long-term survival of the population. Tapir population reduction and even extinction can result in the loss of ecological services, such as seed dispersal (Barcelos et al. 2013; Bueno et al. 2013; Giombini et al. 2016; Paolucci et al. 2019), since they are responsible for dispersing seeds of high wood density trees that store tons of carbon, thus providing an ecological service with an estimated worth of billions of dollars (Bello et al. 2015; Peres et al. 2015).

Wildlife underpasses and their use by tapirs on the BR-101 highway

The stretch of the BR-101 that intercepts Sooretama is a straight paved road with 23 water drainage culverts (hereafter "tunnels"), and some of them are used by wild species (Banhos et al. 2020). Five of these tunnels are tall and wide (more than 2 m in diameter) and are frequently used by mammals, such as lowland tapirs. Since 2014, the use of these tunnels by wild animals has been monitored using camera traps, and tapirs were registered using the crossings (Video 1). Despite this, the six killed tapirs were found close to the big tunnels (between 5 m and 800 m away), at km 106, 116, 119, and 120.

Although wild animals are using the tunnels in the area, the lack of maintenance and cleaning of the structures results in tunnels completely obstructed by sediments, branches, and tree trunks, often precluding the use by of wildlife. During the camera trap monitoring period, we did not witness any event of tunnel maintenance or cleaning. Occasionally, we cleaned the tunnels ourselves. On 22 September 2015, a camera recorded an attempt by a tapir to cross the tunnel at km 120, which was blocked by fallen bamboo branches (Video 2). We confirmed in the images of the cameras that the blockade happened on 11 September 2015 and that a tapir went through the tunnel days before, on 8 September 2015. Five meters from the tunnel entrance, a tapir was found dead on 17 September 2015.

Tunnels are often used as wildlife passages and are therefore one of the measures used to mitigate roadkill incidents. Even though the tunnels in BR-101 were not originally installed as a mitigation measure, they are often used for crossings by some species. Thus, these tunnels make the highways less risky for wildlife (Clevenger et al. 2001; Goosem et al. 2001; Cain et al. 2003; Taylor & Goldingay 2003; Dodd Jr. et al. 2004; Ascensão & Mira 2007; McCollister & Manen 2010; Lesbarrères & Fahrig 2012). However, periodic maintenance of the tunnels is necessary so that they can be effectively used by fauna.

Socioeconomic impacts and risks for highway users

The high speed of vehicles is one of the factors that increases the risk of roadkill events (Forman & Alexander 1998; Fahrig & Rytwinski 2009), and the large-sized vertebrates killed along the BR-101 highway in Sooretama in recent years are indicatives of that. It was not uncommon to observe reckless drivers that ignored the speed cameras when they were operating.

From June 2014 and October 2016, we measured the speed of vehicles (including cars and trucks) driving

Video 1. Video of Lowland Tapir crossing the tunnel at km 106 of the BR-101 highway in Sooretama.

Video 2. Video of Lowland Tapir to cross the tunnel at km 120 of the BR-101 highway in Sooretama, which was blocked by fallen bamboo branches, on 22 September 2015.

between the 102 and 107 km stretch of the BR-101 that intercepts Sooretama, in both directions, using a hand-held speed camera (Bushnell®). In addition, in February 2020, we measured speeds at km 102 and km 107. Measurements were conducted in the morning, afternoon, and evening on different days. The maximum speed limit allowed along the 23 km of the BR-101 that intercepts Sooretama is 80 km/h (from km 101 to 102 and km 107 to 124) or 60 km/h (from km 102 to 107, the stretch that intercepts the SBR). From 2011 to 2017 there were electronic speed monitoring devices (radars) at the beginning and end of the 60 km/h stretch, but in 2017, the radars were removed. The speed of 580 vehicles was measured in the 80 km/h limit stretch of the BR-101 that intercepted Sooretama, 70% of the vehicles exceeded the speed limit, the lowest recorded speed was 48 km/h, the highest recorded speed was 170 km/h, and the average speed was 92 ± 20 km/h. In the 60 km/h limit stretch, we measured the speed of 662 vehicles, of which 80% exceeded the speed limit, the lowest recorded speed was 36 km/h, the highest recorded speed was 138 km/h, and the average speed was 76 ± 18 km/h. In February 2020, the speed of 40 vehicles was measured between km 102 and 107, of which 87% exceeded the speed limit. Here, the lowest recorded speed was 54 km/h, the highest recorded speed was 132 km/h, and the average speed was 80 ± 17 km/h. The radars were reinstalled in 2021 and the speed limit was raised to 80 km/h, but we do not assess the speed of vehicles.

Wildlife-vehicle collisions are a huge threat against biodiversity, but they can also cause a great impact on human health and safety because they can result in serious accidents, which risk human health/life and come at high economic costs (Seiler 2005; Huijser et al. 2009; Freitas & Barszcz 2015). For example, accidents with large-sized animals, such as tapirs, can result in serious human injury or death (Freitas & Barszcz 2015). Between 2014 and 2020, over 30 human deaths occurred in accidents at 23 km of the BR-101 in Sooretama. However, it was not possible to confirm whether these accidents involved animals on the road. In a collision with a tapir in Sooretama (on 24 October 2014), the car driver obtained severe injuries and was hospitalized. The resulting costs from vehicle-animal collisions are high, but these accidents can be avoided or reduced by implementing mitigation measures that increase the safety of roads and reduce the damage caused by this type of accident (Huijser et al. 2009).

Emergency measures

The BR-101 poses one of the major threats to the biodiversity of the Sooretama region because of its negative effect on species. In addition, there are concerns about the duplication plan for the BR-101 highway, which could be implemented in the coming years, including the duplication of the stretch that intercepts the protected areas (Srbek-Araujo et al. 2015). Among the proposals to mitigate the impacts of the BR-101 duplication, there is the construction of viaducts for cars and wildlife bridges, or the relocation of the vehicle flow to areas with a lower conservation priority (Srbek-Araujo et al. 2015). However, until the mitigation of the highway expansion is resolved, accidents will continue to kill animals, including lowland tapirs. Thus, due to pending permanent mitigation measures for the highway expansion, emergency measures must be taken to avoid wildlife accidents.

There are several commonly used mitigation measures for reducing wildlife-vehicle collisions (see Goosem et al. 2001; Clevenger 2005; Glista et al. 2009; van der Ree et al. 2009; Lesbarrères & Fahrig 2012; van der Grift et al. 2013; Rytwinski et al. 2016), and high-cost mitigation measures are reported to be more effective in reducing accidents with large mammals (Rytwinski et al. 2016), although they require more planning and time to implement. However, some mitigation measures can be implemented quickly and without high costs, which would substantially reduce fatal accidents (Lester 2015). In 2014, during the workshop "*Impactos da rodovia BR-101 na Reserva Biológica de Sooretama: Estudos, Alternativas e Mitigação*", a multidisciplinary team of experts (see Últimos Refúgios 2014b) recommended the following emergency measures: (1) the maintenance of the drainage culverts to serve as wildlife passages; (2) the elimination of jackfruit trees *Artocarpus heterophyllus*, mango trees *Mangifera indica*, and other exotic fruit trees that grow on the margins of the highway and attract wildlife; (3) a speed limit reduction to 60 km/h along the whole stretch; (4) the installation of speed bumps and electronic speed monitoring devices along the whole stretch; (5) the installation of warning signs informing about the possibility of wildlife crossings and risk of wildlife accidents; and (6) the monitoring of the effectiveness of the implemented mitigation measures (Universidade Federal do Espírito Santo 2014). The mitigation measures were discussed with the Federal Public Prosecution Ministry and agreed upon with the other regulatory bodies, including the National Land Transport Agency and Chico Mendes Institute for Biodiversity Conservation, as well as representatives of the company responsible for the highway administration. However, more than seven years have passed and only one recommendation has been implemented (the removal of fruit trees from km 119 to 123 in August 2018). If all measures had been implemented as proposed, fatal accidents involving wildlife that have occurred in the following years of the workshop could have been avoided. From the proposal of the measures until the conclusion of this article, an average of one tapir died per year.

We agree that the relocation of the BR-101 highway from Sooretama is the best measure to guarantee the conservation of the landscape and local biodiversity for the long term. Sooretama has a long history of protection that precedes the existence of the highway, with all administrative acts that guarantee its conservation documented (Instituto Chico Mendes de Conservação da Biodiversidade 2019; Instituto Brasileiro de Desenvolvimento Florestal 1981). The highway was built across the protected area in the late 1960s, even though this was prohibited by the Forest Code (Instituto Brasileiro de Desenvolvimento Florestal 1981). Furthermore, no documents were found that show the administrative act that allowed the construction of this highway within Sooretama. As a result, the preservation of the local biodiversity is jeopardized because one of Brazil's busiest highways crosses the interior of this protected areas complex.

CONCLUSION

The BR-101 highway represents a great threat for the conservation of the lowland tapir and many other species in the forest complex of Sooretama, one of the last regions that harbors viable tapir populations in the Atlantic Forest. The maintenance of tunnels used by fauna is necessary to mitigate the impact of road, but it is not a definitive solution for the fauna roadkill. In addition to the loss of biodiversity, vehicle collisions with tapirs result in risk to human life, economic losses, and loss of valuable ecological services. Emergency mitigation measures must be implemented to avoid further losses due to the chronic impact of the highway on biodiversity along the stretches that cross the protected areas of Sooretama region. Furthermore, we suggest building a detour to remove the BR-101 highway from within Sooretama.

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Resumo (Português): As rodovias limitam a movimentação e a dispersão de animais silvestres e contribuem para a perda de indivíduos por atropelamento, levando ao isolamento e ao declínio das populações, aumentando o risco de extinção local. A anta brasileira Tapirus terrestris é o maior herbívoro-frugívoro neotropical e, apesar de sua ampla distribuição na América do Sul, está ameaçada de extinção. Neste estudo, nós relatamos seis eventos de atropelamento de antas, entre 2014 e 2019, em um trecho de rodovia federal BR-101 que intercepta um mosaico de reservas da Mata Atlântica, denominado Sooretama, um dos últimos refúgios de antas no sudeste do Brasil. O tráfego de veículos nesta área é intenso, com controle inadequado de velocidade, enquanto árvores frutíferas exóticas crescem ao longo da rodovia atraindo animais silvestres. Túneis de drenagem de água servem de passagem para algumas espécies, incluindo antas. No entanto, os túneis localizados sob a rodovia não recebem manutenção periódica adequada, reduzindo sua efetividade. A perda de pelo menos uma anta por ano pode ter consequências graves a longo prazo para uma das últimas populações viáveis de anta brasileira em toda a Mata Atlântica. Assim, medidas emergenciais são necessárias para evitar colisões entre veículos e antas.

Author details: Aureo Banhos is Associate Professor at Espírito Santo Federal University. His research is focused on Conservation Biology, using genetic, ecological and evolutionary tools to investigate wildlife and generate results applied to environmental management and policy. Andressa Gatti is a researcher fellow of National Institute of the Atlantic Forest-INMA and executive director of Pró-Tapir Institute for Biodiversity, working mainly with ecology and conservation of mammals and their habitats, extinction risk, human-wildlife coexistence, and scientific outreach. Marcelo Renan de Deus Santos is a veterinarian and ecologist. His focus is on wildlife conservation, monitoring the health of wild animals under the vision of One Health, development, and execution of conservation projects. He is the president of Instituto Marcos Daniel, where he coordinates the Chelonia mydas project and the Cherry-throated Tanager conservation program. Leonardo Merçon is a wildlife photographer, graphic designer, and director of Instituto Últimos Refúgios (Last Refuges). Ilka Westermeyer is an international manager, and wildlife moviemaker, and director of Instituto Últimos Refúgios (Last Refuges). Natália Carneiro Ardente is a biologist and ecologist. Her focus is on wildlife conservation, mainly mammals. Luis Franscisco Oliveira Pereira Gonzaga is a biologist and currently is attending post-graduation in animal biology. He works as biology teacher, field biologist, and wildlife photographer. Lucas Mendes Barreto is a biologist, master in tropical biodiversity, experience in road ecology, monitoring and rescue of fauna and environmental education. Currently, he coordinates the field activities of the Armadillo Conservation Project in the Atlantic Forest. Lucas Damásio is a biologist and ecologist. Currently, he works as an Environmental Analyst. Tomas de Lima Rocha is a biologist and zoologist, with emphasis on road ecology and herpetology. Vitor Roberto Schettino is a geologist and experienced in geotechnologies. Renata Valls is a biologist and ecologist. Her research is focuses on landscape ecology and mammals ecology. Helena Godoy Bergallo is Associate Professor at Rio de Janeiro State University and coordinates the Atlantic Forest Biodiversity Research Network program of the Ministry of Science, Technology and Innovation, working in research, training, scientific dissemination and data availability. Her research focuses on natural history, mammal ecology and anthropogenic impacts. Marcos Vinícius Freitas Silva is a biologist. His research is focused on plastination and biological conservation of vertebrates in biological collections, working as intern in Plastination Laboratory from Espírito Santo Federal University. Athelson Stefanon Bittencourt is a biologist and physiologist, and coordinator of the of the Museu de Ciências da Vida (Museum of Life Sciences) and the Plastination Laboratory from Espírito Santo Federal University. Danielle de O. Moreira is a researcher fellow of National Institute of the Atlantic Forest-INMA. Her research is focused on ecology of mammals, ecological niche modeling, extinction risk, human-wildlife coexistence, and history of zoology. Ana Carolina Srbek-Araujo is Titular Professor at Universidade Vila Velha. Her research is focused on ecology and conservation of vertebrates, especially mammals, working mainly with population ecology, trophic ecology, and activity pattern.

Author contributions: Conceptualization, A.B., A.G., M.R.d.D.S, L.M. and I.W.; methodology, A.B., A.G., M.R.d.D.S., N.C.A., H.G.B. and A.C.S.A.; formal analysis, A.B., A.G., M.R.d.D.S., N.C.A., L.F.O.P.G, V.R.S., R.V., H.G.B. and A.C.S.A; investigation, A.B., A.G., M.R.d.D.S., L.M., I.W., N.C.A., L.F.O.P.G, L.M.B., L.D., T.L.R., V.R.S., R.V., H.G.B., M.V.F.S, A.S.B., D.O.M. and A.C.S.A.; resources, A.B., A.G., M.R.d.D.S., H.G.B., A.S.B., and A.C.S.A.; data curation, A.B., A.G., and M.R.d.D.S.; writing—original draft preparation, A.B., A.G., M.R.d.D.S., N.C.A., H.G.B., D.O.M. and A.C.S.A.; writing—review and editing, A.B., A.G., M.R.d.D.S., L.F.O.P.G, H.G.B., D.O.M. and A.C.S.A.; visualization, A.B., A.G., M.R.d.D.S., L.M., I.W., N.C.A., L.F.O.P.G, L.M.B., L.D., T.L.R., V.R.S., R.V., H.G.B., M.V.F.S, A.S.B., D.O.M. and A.C.S.A.; supervision, A.B.; funding acquisition, A.B., H.G.B. and A.C.S.A..

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COMMUNICATION

Scientific contributions and learning experiences of citizen volunteers with a small cat project in Sanjay Gandhi National Park, Mumbai, India

Shomita Mukherjee [1], R. Nandini [2], P.V. Karunakaran [3] & Nayan Khanolkar [4]

[1,3] Sálim Ali Centre for Ornithology and Natural History, Anaikatty, Coimbatore, TamilNadu 641108, India.
[2] Indian Institute of Science Education and Research Tirupati, Tirupati, Andhra Pradesh 517507, India.
[4] Pitrusmruti, Near R.B.I. Colony, Shastri Nagar, Dombivli West, Mumbai, Maharashtra 421202, India.
[1] shomitam@gmail.com (corresponding author), [2] nandinirajamani@gmail.com, [3] karunakaran.pv@gmail.com,
[4] nayankhanolkar@gmail.com

Abstract: We conducted a project on small wild cats in Sanjay Gandhi National Park near Mumbai during 2017–2019 with the participation of 35 citizen volunteers. Volunteers underwent a training period after which they collected scat samples, placed camera traps and participated in data analysis. Volunteers answered a questionnaire to gauge the impact the program had in furthering their interests and knowledge. Nineteen participants responded to the feedback survey. Most indicated an increase in their knowledge of wildlife research, conservation issues and small wild cats. We discuss the value of research projects where citizens can actively participate and learn semi-technical skills.

Keywords: Citizen science, conservation, feedback survey, Rusty-spotted Cat.

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Author details: Shomita Mukherjee is a Senior Principal Scientist at the Sálim Ali Centre for Ornithology and Natural History at Coimbatore, Tamil Nadu in the Division of Conservation Biology. Her current work focusses on the ecology of small cats and the Forest Owlet. R. Nandini is an Assistant Professor at the Indian Institute of Science Education and Research, Tirupati, Andhra Pradesh. Her current work explores adaptations in species to environmental (including climate change) and anthropogenic factors. P.V. Karunakaran is a landscape ecologist working as a Senior Principal Scientist at Sálim Ali Centre for Ornithology and Natural History (SACON). His current areas of research include conservation and management of natural resources, protected area management, community participation in biodiversity conservation, plant taxonomy and GIS and Remote Sensing. Nayan Khanolkar is an Educator, Naturalist and Wildlife photographer. His current assignments include documenting urban leopards, participating in citizen science programs and teaching photography at various colleges across Maharashtra.

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INTRODUCTION

Planning conservation for rare and cryptic species is contingent upon reliable and adequate data, which requires considerable funding and labour over long periods (Buxton et al. 2020). Moreover, especially in human-dominated and privately owned landscapes, ownership of issues related to conservation are crucial for successful outcomes (Cooper et al. 2007). In urban landscapes, although most citizens are aware of the general impacts of human spaces on wild habitats, they are perhaps not aware of how they can contribute towards conservation and generating information (Miller 2005; Bhardwaj & Kumar 2021). Involving citizens in collecting information for scientific endeavours in the field of biodiversity conservation is gaining popularity across the globe (Frigerio et al. 2018), including in India (Surve et al. 2015; Singh 2018; Mukherjee 2019; Srivathsa et al. 2020), especially as climate change and changing land regimes become major issues of concern.

Citizen science with respect to carnivore conservation in India has been conducted in various ways, from using citizen science based web portals and social media for accessing information (Srivathsa et al. 2020) to actively engaging citizens as volunteers on projects to collect primary data (Director & Chief Conservator of Forests et al. 2012; Surve et al. 2015).

Several models of citizen science exist, ranging from simple contributions by citizens to a total involvement by contributing, learning and collaborating (Wiggins & Crowston 2011; Shirk et al. 2012). Some authors stress on the importance of training citizen volunteers in science prior to field collection of data to increase reliability of data collected (Bonney et al. 2014; Frigerio et al. 2018). We employed both the investigative and educational approaches to citizen science (Wiggins & Crowston 2011) during our study.

Study area

The project was conducted in Sanjay Gandhi National Park (SGNP), a protected area of 103.68 km^2, situated between 19.14–19.35 N and 72.98–72.86 E across Thane and Mumbai districts of Maharashtra. It is a popular recreation site among the citizens of Mumbai and experiences a high volume of approximately two million visitors per year (Surve et al. 2015).

Situated at the centre of a bustling and burgeoning metropolis, it is often referred to as the 'green lungs' of the city and figures as a major spot of conflict for space (Munde & Limaye 2013; Surve et al. 2015; Phadke 2019). This protected area faces several threats, the major ones being encroachment due to urbanisation and Leopard *Panthera pardus* incursions into residential complexes located close to the Park, perhaps in search of food (Director & Chief Conservator of Forests et al. 2012; Surve et al. 2015; Anthony 2020). This led to the formation of a popular citizen-based project 'Mumbaikars for SGNP' by the Maharashtra Forest Department, in which citizens together with ecologists and sociologists assist the forest department to gather information on the Leopard (Director & Chief Conservator of Forests et al. 2012; Surve et al. 2015). However, there are several small carnivores which co-exist with the Leopard, and very little is known about their distribution and status within the Park and surrounding areas. Among these is the Rusty-spotted Cat *Prionailurus rubiginosus*, the smallest cat in the world, with a geographical distribution restricted to India, Sri Lanka and Nepal (Mukherjee et al. 2016). It is listed under Schedule I of the Indian Wildlife Protection Act (1972), categorised as Near Threatened in the IUCN Red List (Mukherjee et al. 2016) and included as a species of conservation importance in the SGNP Management Plan for 2013–2023 (Munde & Limaye 2013). Most citizens of Mumbai are perhaps not aware of the species, of its presence in the Park and how science can contribute to its conservation.

We aimed to bridge the gap in information and awareness through a citizen science participatory project by training citizen volunteers in various aspects of small cat biology, techniques in researching them and issues related to the conservation of small wild cats. The project spanned a period of two years and five months, from March 2017 to September 2019, during which volunteers collected samples and generated data. We conducted a questionnaire survey to gauge the response of the volunteers to their experience in participating in the project. This paper discusses the results of the questionnaire survey.

MATERIALS AND METHODS

A call for volunteer participation on the project was advertised informally over social network platforms and through existing volunteer groups in SGNP. Those interested were inducted into the training program. In March and April 2017, four classroom and three practical training workshops, each lasting four to five hours, were held for volunteers in forest range offices and in the field in SGNP. Classroom training included basic lectures and discussions on cat behaviour, physiology and morphology, the importance of scat samples in studying carnivore ecology, protocols for collecting scat and the rationale behind it, basics of molecular analysis of scat for species assignments, basics of geographic information system (GIS) applications and their importance in conservation and research, basics of study design for scat collection and camera trapping, habitat monitoring and the importance of collecting information on habitat variables. During practical field sessions, volunteers were taught how to locate scat with explanations related to carnivore behaviour, identify tracks and signs of various species, operate GPS units as well as Android applications of GPS on mobile phones, use the mobile phone application CanopyApp (Version 0.0.2, University of New Hampshire 2015) for monitoring canopy cover, operate and place camera traps, label samples and camera traps with explanations on the importance of good practices.

Volunteers were divided into three groups based on the location of their residence and proximity to each of the three forest ranges, which they later visited for collecting data. Each group had a team leader who monitored progress and report to the principal investigator (PI). Necessary permits were obtained from the forest department for each volunteer to enter the Park and access areas that are prohibited to tourists. These permits were always carried by the volunteers when they entered the Park for sampling. The groups self-organised into sub-groups and went on scat collection trips every weekend, either on one or both days, for seven months excluding the monsoon months from June to September. Volunteers uploaded all information on field work including date, time, name of the forest range visited, grid cell number, geo-coordinates, photographs of scat samples collected with their identity number and details to the Android based software EpiCollect5 (Aanensen 2009) in a format provided by the PIs. This enabled the PIs to access, download, monitor and check data online at any point of time.

A subset of the scat collecting team volunteered for camera trapping exercises. These consisted mainly of students who were interested in wildlife careers and received additional training. Volunteers interested in participating in further analysis of samples travelled to Sálim Ali Centre for Ornithology and Natural History, where they received training in genetic analysis for assigning scat to predator species, diet estimation through scat analysis, relevant statistics using the statistical package R (R Development Core Team 2014) and basic GIS tools for mapping.

At the end of the project, a feedback survey was conducted through an online questionnaire with options for picking a score as well as descriptive comments sent to volunteers to seek their opinion on the training imparted, their expectations and if they were met through this project, and their overall experience during this duration (Appendix 1). The feedback was analysed through chi-square and paired Wilcoxon signed-rank tests.

RESULTS

A total of 35 citizens from various professions volunteered for the training sessions and project work of the SGNP Small Cat Project. While most volunteered for the scat collection trips, only three volunteered for camera trapping and two for further analysis in the laboratory. Volunteers collected 126 scat samples from the three Ranges of SGNP and set up camera traps in 39 locations for a total of 1,056 camera trap days.

One of the volunteers completed her Master's dissertation on the diet of the Rusty-spotted Cat based on scat collected (Gawari 2018). This was perhaps the first systematic analysis of the diet of the species. Another volunteer completed his internship with data collected on the project and participated in analysing camera trap data. The camera trapping exercise revealed the presence of 20 taxa, including domestic species such as goats, cattle, dogs and cats along with considerable movement of humans throughout the Park. It also generated information on the distribution of other wild carnivores, e.g., Ruddy Mongoose *Urva smithii*, Small Indian Civet *Viverricula indica* and Common Palm Civet *Paradoxurus hermaphroditus* within SGNP, which are often neglected in conservation schemes across the country, largely due to the lack of information on them.

A total of 19 participants from the SGNP Small Cat Project responded to the survey. Most participants (47%) were in the age group 20–25 years, followed by the age group 25–30 years (21%), and 16% of respondents being younger (15–20 years) or older (30–40 years). Most were students at the undergraduate level (58%) or postgraduate level (16%). Twenty-one percent of the participants defined themselves as persons whose primary occupations were in wildlife, environment or science-related professions. Only one participant was employed in a profession different from the above.

The most significant motivation for participating in the SGNP Small Cat Project was to learn more about wildlife science (90%), followed by the desire to broaden personal horizons and learn a new skill (74%) (Chi-square value= 18.15, df= 5, p value <0.05) (Figure 1). Sixty-three percent of the participants stated that they were motivated by the need to understand conservation issues better. Many participants simultaneously expressed an interest in the three motivations listed above, while 47% of the participants also declared that a motivation was to obtain training and certification of wildlife research. Participants were least motivated by the access this project gave them to otherwise inaccessible parts of the National Park.

Most participants believed that there was a significant increase in their knowledge of wildlife research and science because of the program (paired Wilcoxon test, V= 153, p-value= 0.0002244), with most stating that their knowledge of wildlife was very low prior to the program (Figures 2, 3). They stated that through the project they gained information on the process of conducting research on small cats and other small carnivores and were made aware of modern techniques used in the field and laboratory as well as the ethics involved in data collection for research (Table 1).

When asked to rate their knowledge of conservation issues pertaining to Mumbai city, both before and after the program, participants stated that they felt significantly more aware after the program (paired Wilcoxon test, V= 136, p-value= 0.0002804). While almost all participants were moderately aware of conservation issues around Mumbai, their knowledge of the nuances and complexities involved in science and conservation increased after their participation in the project (Table 1).

Participants stated that their knowledge of small cats and conservation issues pertaining to small cats was significantly greater after the project (paired Wilcoxon test, V= 190, p-value= 0.0001044). Prior to the project, most participants rated themselves as knowing nothing or little about small wild cats. Participants stated that they learnt about how small wild cats coexist with larger predators and how they also live in proximity to human settlements (Table 1).

DISCUSSION

During this project, we established that citizens in Mumbai were interested in exploring how wildlife research is conducted and that they wanted a stake in the process of doing research and conservation. In the past, the Mumbaikars for SGNP project involved citizen volunteers on some aspects of a study focussed on the Leopard and its prey species (Director & Chief Conservator of Forests et al. 2012; Surve et al. 2015). In the current project, we took this approach a step

Table 1. Comments received from volunteers on their overall experience of volunteering on the project.

Training Topic	Comments
Wildlife Research and Science	“The small cat survey was a unique project and I got the opportunity to learn certain nuances of camera trapping, reading animal tracks and signs and conservation genetics.”
	“The entire process of mapping, finding out possible locations for looking up for scats and learning about how genetics can help in identifying species responsible for scat deposition was very much educational. This project helped me in developing an understanding of how Ecosystem services work.”
	“I learned about how the work happens from collecting samples to lab. I hope someday I will be able to do it also and also the usage of different apps for making our data collection work easier.”
	“Wildlife research is serious business. Zero tolerance for ethical mistakes like data manipulation, etc as it may completely change the outcome of a project.”
	“I got to learn about method of scat collection and mapping the habitat and factors related to it.”
	“I joined for a short period of time but I learnt how to identify basic mammal scats, spotting various animals not just small cats but other animals/birds in the park. Got exposure to various, wildlife population density measuring techniques, scat collection techniques, conducting transects etc. It was overall a complete experience with some phenomenal sights in the park.”
	“Systematic approach towards assessment of population dynamics with supplementary behaviour study and optimum use of advanced technology.”
	“It requires a lot of patience, deep understanding of the subject and that the efficient management of data and drawing conclusions forms the core of any research”
	“I learned about how to locate and collect carnivore scat in wild and upgraded my camera trapping techniques.”
	“I learned about data collection, diet analysis using scat samples, mapping, data analysis, habitat and diet of small cats, interpretation and execution of research work in scientific manner, conservation issues regarding cats(both big and small).”
	“How to handle camera traps, what is meant by scat collection”
Conservation issues	“Through this program I learned about the proximity in which leopards, small cats & other wildlife are living to humans. It showed me with evidence as to how much we human are squeezing the forests of SGNP “.
	“I learnt the difficulty involved behind the scenes, the science of conservation and how a non-invasive method works.”
Small cats	“I have learnt how small cats are co-existing with other larger carnivores of SGNP. Also how human settlements are indirectly helping to support the population of small cats.”

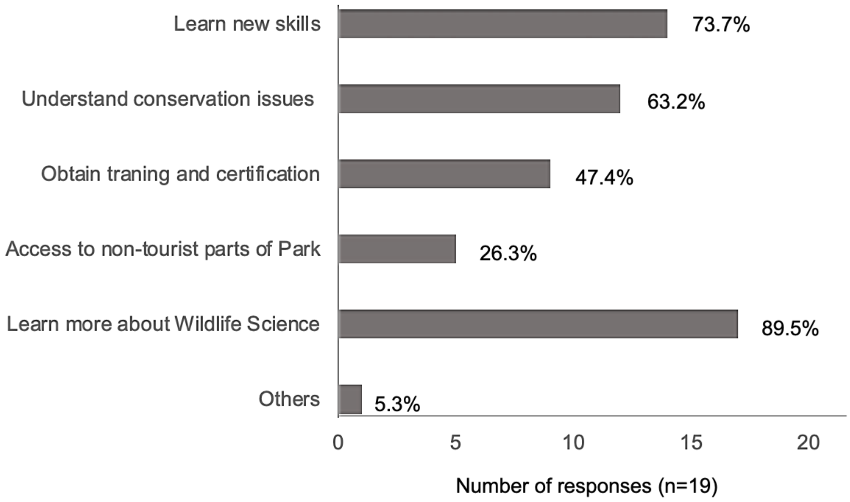

Figure 1. Responses of volunteers on their motivation to join the project.

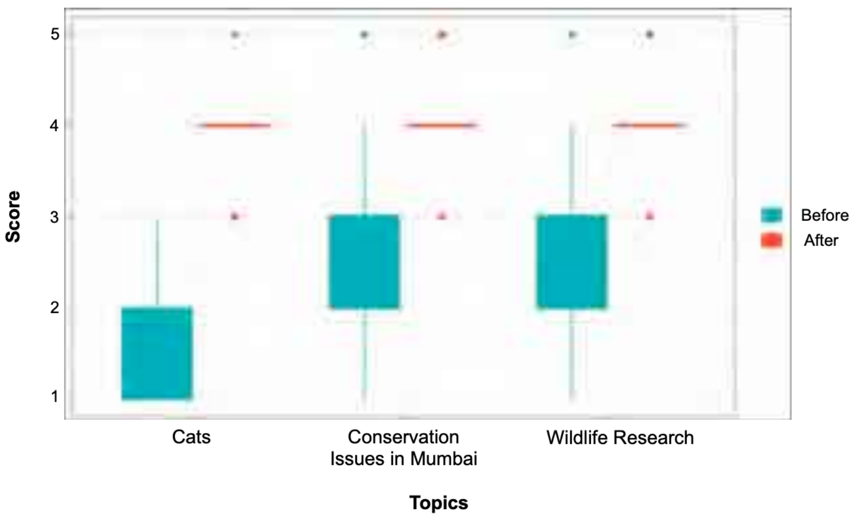

Figure 2. Responses of 19 volunteers on knowledge gained on various topics from participating in the project.

further by involving citizen volunteers in most aspects of the project and, providing them with some training in semi-technical skills. Moreover, this project was related to a small and little known carnivore, which could induce varied levels of interest among citizen volunteers. We were interested in knowing what motivated them to join the project and if and how the project helped them enhance their knowledge and meet their goals.

Understanding motivations of citizen participants to join science projects can help in refining the way in which citizen science projects are conducted to tailor them to specific needs and make them more popular (Schuttler et al. 2018). Our study had largely young, college going volunteers motivated to learn about wildlife science and acquire new skills. Participants felt that the training and involvement in the project significantly increased their knowledge of small wild cats, techniques used to study them and conservation issues in Mumbai. Prior knowledge on these issues varied considerably among participants but most gave a high score of 4 for knowledge attained after participating in the project (Figure 2).

Since the major focus of the project was gathering information on small wild cats in SGNP, the training was very specifically focussed on certain topics. Similar future projects involving citizen volunteers could incorporate a survey before the training to gauge the requirements of the group, and if possible, cater to different needs and

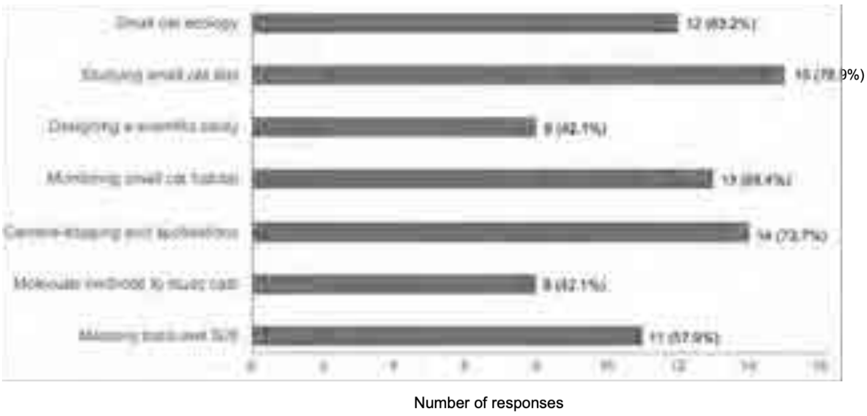

Figure 3. Responses of volunteers on knowledge gained on specific topics taught during classroom/discussion sessions.

offer options for participating in the project. For example, some participants were happy to volunteer for just the scat collection, and the training sessions for them could be focused on that topic. Targeted communication and training as a means of increasing motivation among volunteers was recognised elsewhere (Frigerio et al. 2018). As expected, fewer volunteers were interested in being involved in the more advanced and time intensive techniques such as molecular analysis of scat and GIS applications.

We observed that training using mobile phone apps gained much interest among volunteers, especially the younger ones, since these were more informal and less intimidating. Similarly, training in Forest Rest Houses and on field as opposed to traditional classrooms was also very popular with the younger age groups for the same reasons. Using a mobile app such as Epicollect5 enabled the investigators to check activity and data quality periodically and make course corrections through team leaders if any errors were found. Initially, there were several errors in data entry and recording, which were communicated to the volunteers, and necessary corrections were made. For example, uploading good pictures of scat on Epicollect5 following the protocols that were set with a ruler, GPS reading and the vial with date and id clearly visible enabled us to rectify errors made in recording identification of scat. Without these, the scat samples would have to be discarded, resulting in a waste of effort and samples, especially when studying a rare species. The usefulness of Epicolelct5 as a user-friendly app for citizen science projects are acknowledged by other studies as well (Frigerio et al. 2018).

Due to the relatively short period of the study and a rapid enrolment of volunteers, we could not reach out to a wider set of citizens with more varied backgrounds and age groups. Further, a relatively small proportion of volunteers responded to our questionnaire survey. Despite this, from the responses received, the project provided a platform for a few citizens to be trained in various aspects of small wild cat and small carnivore research. The project also provided an opportunity to learn new skills, especially for some volunteers who hope to build their careers in the field of wildlife research and conservation. This group of volunteers can form a pool of trained citizens who can be opted into various monitoring programs to aid Park management whenever required. However, such programs should be continued not just for additional information on rare species in and around the Park but also for increasing the pool of volunteers from various backgrounds, with refresher courses in training, to make a stronger impact on conservation.

Caveats

A major caveat in citizen science based studies is the quality and reliability of data because citizens may not be trained in collecting scientific information and would vary in their interest, motivations and knowledge levels (Lukyanenko et al. 2016). We tried to overcome this by using the Epicollect5 application to check for errors in reporting details of samples collected. Nevertheless, other probable issues such as failing to notice scat in the field when they were present could not be addressed and which may have reduced the number of samples obtained and hence data generated. Extending the duration of such projects to include a rigorous training period with intermittent checks and refresher sessions may produce better results.

Due to the nature of some of the training courses which required a certain level of educational background, we could not involve the locals who lived within the Park in the project. Future projects could consider focussed training and partitioning the roles of volunteers based on other issues such as interest, language of instruction and education background to make the citizen science angle of the projects more inclusive and holistic. This would be especially beneficial since locals would have additional knowledge of the region and observation and detection abilities that even experts may lack (Lukyanenko et al. 2016; Tengö et al. 2021).

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COMMUNICATION

Seasonal food preferences and group activity pattern of Blackbuck *Antilope cervicapra* (L., 1758) (Mammalia: Cetartiodactyla: Bovidae) in a semi-arid region of western Haryana, India

Vikram Delu [1], Dharambir Singh [2], Sumit Dookia [3], Priya [4] & Kiran [5]

[1,2,4,5] Department of Zoology and Aquaculture, Chaudhary Charan Singh Haryana Agricultural University Hisar, Haryana 125004, India.
[3] University School of Environment Management, Guru Gobind Singh Indraprastha University, New Delhi 110078, India.
[1] vikramdelu29@hau.ac.in (corresponding author), [2] dharambir.titu@gmail.com, [3] sumitdookia@gmail.com, [4] priya@hau.ac.in,
[5] kiranyodha3@gmail.com

Abstract: To evaluate food preferences and group activity patterns, a fragmented population of Blackbuck *Antilope cervicapra* was selected for observation in a semi-arid ecosystem of western Haryana. A field survey was conducted fortnightly, from dawn to dusk, between September 2019 and August 2020, covering every season. Scan sampling and quadrat methods were used to record data on group size and vegetation. Group sizes ranged from 3 to 72 individuals. Based on visual observation, blackbuck seasonally consumed 26 species belonging to 25 families with varied preferences, out of a total of 53 plant species documented from the study site. Some plant species with high medicinal and therapeutic values were preferred, including *Artemisia scoparia, Cucumis callous, Ziziphus jujuba*, and *Ziziphus nummularia*. Unlike most herbivores, Blackbuck also consumed the toxic and medicinally rich *Calotropis procera*. We suggest that zoos which house blackbuck include these preferred wild plant species in their diet. Observations on group activity were analyzed on hourly, monthly and seasonal bases, and converted into time percentages. Group foraging activity was at a maximum in the monsoon (62%) and minimum in winter (50%), followed by resting: maximum in winter (21%) and minimum (12%) in monsoon, largely influenced by food availability. Foraging/walking ratio was at a maximum (5.2) in monsoon and minimum (3.1) in winter, and was correlated with the number of group sightings (maximum in winter and minimum in monsoon) in nearby farmland, when the animals faced food scarcity in their natural habitat and fed on crops.

Keywords: Farmland, foraging activity, herbivores, medicinal, monsoon, natural habitat, observation, population, scarcity, vegetation.

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INTRODUCTION

The Blackbuck *Antilope cervicapra* (Linnaeus, 1758) is endemic to the Indian subcontinent. The adult male (subspecies *rajputanae*) weighs 34 to 45 kg, while females weigh 31 to 39 kg (Ranjitsinh 1989). This antelope shows sexual dimorphism even at the age of 4–6 months when horns start growing in males; at maturity males become conspicuously colored and have long horns (Shrestha 2003). The coats of adult males are striking black or dark brown with white underparts, while the coat of females and immature males varies from tan to darker brown. Blackbucks live in open habitats such as grasslands, bush, and dry thorn scrub (Schaller 1967). The species was once distributed throughout western Pakistan from the foothills of the Himalaya from Punjab through Uttar Pradesh in India to the Terai zone of Nepal, West Bengal (India) to Bangladesh (Lydekker 1924). It is currently listed as Least Concern (LC) on the IUCN Red List (IUCN SSC Antelope Specialist Group 2017), but earlier it was categorized as Near Threatened (NT) (Mallon 2008). It is listed in Appendix III in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), and as a Schedule I species with highest protection level in India under the Indian Wildlife (Protection) Act, 1972. The recent improvement in the conservation status of Blackbuck is probably due to unintentional creation of more suitable open habitat by converting dense scrub land and woodland to agricultural areas (IUCN SSC Antelope Specialist Group 2017).

Various ecological and behavioural aspects of Blackbuck have been studied in India (Gupta & Bhardwaj 1990; Gehlot & Jakher 2007, 2011; Kumar & Rahmani 2008; Dookia et al. 2011; Gangotri & Gangotri 2014; Baskaran et al. 2016; Prashanth et al. 2016; Debata 2017; Sagar & Antony 2017) and also in Khairapur, Bardia District, Nepal (Pradhan et al. 1999; DNPWC 2012). In Haryana, Ranjitsinh (1989) reported 2,410 Blackbuck from Hisar district alone, from a total of 4,852 Blackbuck in the state, making Hisar a high-density blackbuck area. So far, no detailed account of its foraging behavior has been documented in western Haryana.

The human population explosion, large-scale poaching, destruction of natural habitats for commercial cultivation, grazing activities and human habitation have caused Blackbuck to disappear from many areas. The total population is estimated at 35,000 mature individuals by IUCN (2017). Our primary census survey revealed that the isolated Blackbuck populations in Fatehabad, Hisar are in close proximity to villages dominated by the Bishnoi community, and in some parts of southern Haryana Blackbuck share their habitat with Nilgai *Boselaphus tragocamelus.* The main threats are habitat destruction, barbed wire fencing, feral dogs, and illegal hunting.

Blackbucks are mainly diurnal, but sometimes also active at night (Long 2003). They are gregarious (Schaller 1967) and mostly live in groups of single or mixed sexes numbering from 15 to several thousand animals. Densities are 0.5–3 per ha (Long 2003). Their diet includes grass, cereal crops and forbs, and they also browse on bushes (Long 2003). Blackbuck is reported as a crop pest in many habitats, where it eats mainly the young shoots of cereal and pulses, in particular sorghum and millet (Chauhan & Singh 1990).

Seasonal or interannual variation in availability of resources suggests the presence of behavioral, physiological and morphological adaptations in consumers (Van Schaik et al. 1993) and may influence the composition of vertebrate faunal communities (Fleming et al. 1987). Furthermore, certain species of plants provide alternative food sources during times of food scarcity, and thus may be vital for population survival (Terborgh 1983). Group sizes increase with habitat openness and resource availability. This information can be helpful to assess the habitat requirements of animals, predict their presence or abundance in other areas and the potential effects of habitat transformation (Arthur et al. 1996; Rı´os-Uzeda et al. 2006), and to support wildlife management plans (Morrison et al. 2006).

The present study was carried out to characterize blackbuck habitats, activity patterns and resource usage in a patch of natural vegetation in a human-dominated landscape outside the protected area network in the semi-arid region of western Haryana. This information will guide long-term conservation of the state animal of Haryana.

Description of Study Area

The study site is situated in Badopal village of Fatehabad district, commonly called 'Blackbuck habitat Badopal' in the Western part of the state Haryana of India (29.418N, 75.576'E). The surrounding villages including Badopal are dominated by the Bishnoi community which has high reverence and tolerance towards blackbuck. Total area of study site is approximately 2.41 km^2 including the area acquired by government to build a residential colony. The rest of the land is owned by local farmers. The study also extended further into the surrounding area of habitat under cultivation of different seasonal crops.

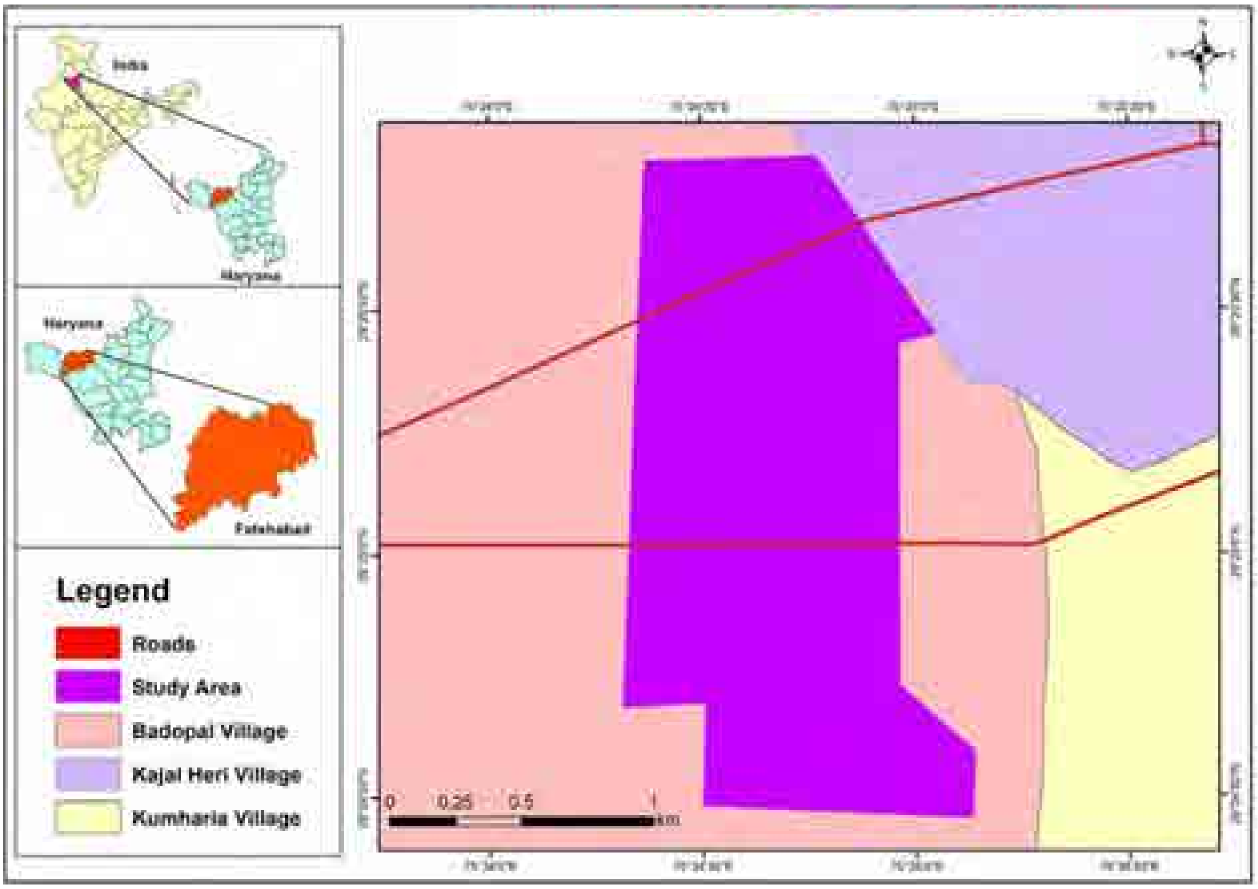

Figure 1. Study site map in Badopal village of Fatehabad district, Haryana, India.

Historical Background (Blackbuck Habitat Badopal)

The study site was selected in 2012 by Nuclear Power Corporation Limited (NPCIL) for construction of a residential colony on 183 acres (0.76 km^2) of private and Panchyat land near Badopal village of District Fatehabad. The site was enclosed with blade wire fencing, resulting in the death of several blackbuck. This situation met strong resistance and criticism by locals from Bishnoi communities along with other wildlife organizations, and a case was filed with the National Green Tribunal (NGT) which resulted in no further infrastructure being built by NPCIL. The site is now governed and managed by the district administration, and the blackbuck habitat is still in need of the development of a conservation plan by the state government. Wildlife Institute of India (2015) did a reconnaissance and recommended this area, including adjoining private land, as a community reserve for conservation of blackbuck.

The study area lies in biogeographic province 4-A, Semi-arid, Punjab Plains (Rodgers et al. 2000), and the 'Trans-Gangetic Plains Regions' agroclimatic zone under the 'Arid to Semi-arid' climatic region, which is characterized by scanty rainfall, aridity and extremes of temperature. The vegetation comprises predominantly xerophytes and is characterized as 'tropical desert thorn'. This site is a natural patch surrounded by a semi-arid agro-ecosystem. Adjoining fields are used for growing crops such as wheat, maize, other cereals, cotton, and pulses. Apart from Blackbuck, the habitat also supports Nilgai, Desert Fox *Vulpes vulpes pusilla,* Asian Palm Civet *Paradoxurus hermaphrodites,* Indian Hedgehog *Paraechinus micropus*. Important reptiles include Monitor Lizard *Varanu* ssp., Indian Cobra *Naja naja.*

METHODOLOGY AND MATERIALS

Blackbuck group activity patterns

There are four seasons: monsoon (June to August), autumn (September to November), winter (December to February), and summer (March to May). Field observations were made from dawn to dusk from September 2019 to August 2020. Field visits were conducted fortnightly during each season to record the behavior and feeding preferences of Blackbuck. Except winter, the observations were taken during three diurnal phases: morning (0630–1000 h), noon (1200–1400 h), and evening (1600–1900 h). There was a slight change in timing during winter to 0800–1100 h, 1300–1500 h, and 1600–1830 h in morning, afternoon, and evening, respectively. Group activity patterns were recorded using the scan sampling method (Altman 1974). The sampling time was 15 minutes continuously with a sampling interval of 10 minutes. The observations recorded for the group activity were analyzed on hourly, monthly, and seasonal basis.

$$\text{\% Activity of group} = \frac{\text{Number of animals engaged in a particular activity in a sample}}{\text{Total number of animal engaged in all activities in a sample}} \times 100$$

The group activities were categorized as foraging, walking, resting, scanning/standing, social activities (playing, fight display, sexual activities, and grooming) and other activities (urination, defecation, marking, ear threat, and object aggression).

We calculated annual error mean squares (percentage time) and error degree of freedom applying Duncan Multiple Range Test (DMRT) using SPSS version 21.0 considering season(s) as replication and group activities as treatments.

Vegetation sampling and food preferences

Vegetation composition was recorded by randomly sampling 10 quadrats of 20×20m. The tree composition of each quadrat was counted whereas shrubs and herbs were counted within sub-quadrates of 5×5m and 1x1m respectively. The density (D) of the flora was analyzed following Phillips (1959) and Mishra (1968).

Foraging activity was observed using binoculars. After each feeding bout and once the animals moved, the plant species eaten by the group were recorded. Diet preferences were also recorded by calculating the number of attempts by the animals to consume a particular plant species in a particular season. For this purpose we used quadrat sampling for the area left and right of a line transect.

Note: Guidelines issued by the Ministry of Health and Family Welfare, Government of India to combat COVID-19 were strictly followed during field visits during the lockdown period.

Optical equipment

A Nikon COOLPIX P900 digital camera and Nikon ACULON binoculars (8×42, 8°) were used for photography and taking observations from long distances so as not to disturb the normal activity of the animals.

RESULTS

Floral Composition

Plant species documented from the study site included 14 trees, five shrubs, 31 herbs, and three climbers. Among the trees, maximum density was demonstrated by *Acacia senegal* (200 individuals/ha) followed by *Melia azedarach* (27.5 individuals/ha). Density of dominant shrubs, herbs and climbers were: *Parthenium hysterophorus* (6170 individuals/ha), *Artemisia scoparia* (13,200 individuals/ha), and *Citrullus colocynthis* (702.5 individuals/ha).

Frequency class distribution

Frequency class distribution of different plant species is shown in Figure 2.

Out of 53 plant species identified in the habitat, it was observed that blackbuck largely prefer 26, as shown in Table 1.

Blackbuck browsing on trees varies according to season, with a maximum in summer and winter. The preference for trees depends mainly on the availability and height of the tree. Data suggests that the preferred parts of *Acacia senegal* and *Prosopis cineraria* were leaves, whereas in case of *Prosopis juliflora* and *Ziziphus jujuba,* leaves, pods and fruits were preferred. *Prosopis juliflora was* ignored during the monsoon season due to availability of preferred food in ample quantity.

Only three species of shrub were eaten by Blackbuck: *Calotropis procera, Maytenuse marginata, Ziziphus nummularia.* The literature available so far on blackbuck has not reported *Calotropis procera* as a forage species, but our field investigation revealed that in summer and winter preferences for *Calotropis* were medium and high respectively, and low in monsoon and autumn. Blackbuck mainly feeds on the leaves of this species during scarcity of other food.

A total of 18 species of herb were mainly foraged on by the blackbucks especially in the monsoon and autumn season (Table 1), Grasses like *Cynodon dactylon*, *Eragrostis* spp., *Dactylocteniuma egyptium*, *Digera muricata, Digitaria* spp., *Cyperus rotundus* were preferred in every season. *Aerva javanica* and *Artemisia scoparia* are dominant herbs but consumed only when the preferred grasses are not available especially in autumn and to some extent in winter.

Most herbs were dominant in monsoon and autumn season but either become dry or unfavorable for

Table 1. Food preferences of Blackbuck during different season: M—Monsoon | S—Summer, Au—Autumn | W—Winter | LP—Low Preference | MP—Medium Preference | HP—High Preference | NR—Not reported in that season | L—Leaves | SM—Stem | F—Fruits | P—Pods | WP—Whole Plant | *—Non native.

	Name of the plant	Family	Majoring in the season (mainly vegetative phase)	Seasonal food preference				Parts eaten
				M	Au	W	S	
A.	**Trees**							
1	*Acacia senegal*	Mimosaceae	All	LP	LP	HP	HP	L
2	*Prosopis cineraria*	Mimosaceae	All	LP	LP	MP	MP	L
3	*Prosopis juliflora* *	Fabaceae	All	NR	LP	MP	HP	L & P
4	*Ziziphus jujuba*	Rhamnaceae	All	LP	NR	NR	MP	F
B.	**Shrubs**							
5	*Calotropis procera*	Asclepiadaceae	All	LP	LP	HP	MP	L
6	*Maytenuse emarginata*	Celastraceae	All	NR	LP	LP	MP	L
7	*Ziziphus nummularia*	Rhamnaceae	All	MP	MP	HP	HP	L & F
C.	**Herbs**							
8	*Aerva javanica*	Amaranthaceae	Au	NR	LP	NR	NR	L
9	*Artemisia scoparia* *	Asteraceae	M & Au	MP	MP	LP	NR	L & S
10	*Boerhavia diffusa*	Nyctaginaceae	M	LP	LP	NR	NR	L
11	*Cynodon dactylon*	Poaceae	S, M, Au	HP	HP	NR	HP	WP
12	*Cyperus rotundus*	Cyperaceae	M & Au	HP	HP	NR	NR	WP
13	*Dactyloctenium aegyptium* *	Poaceae	Au	LP	MP	NR	NR	WP
14	*Digera muricata*	Amaranthaceae	M	LP	LP	NR	NR	WP
15	*Digitaria* spp.	Poaceae	M	MP	LP	NR	NR	WP
16	*Eragrostis* spp.	Poaceae	Au	LP	MP	NR	NR	WP
17	*Euphorbia prostrata* *	Euphorbiaceae	M	LP	MP	NR	NR	WP
18	*Indigofera linnaei*	Fabaceae	M	LP	NR	NR	NR	WP
19	*Heliotropium europaeum*	Boraginaceae	Au	NR	LP	NR	NR	WP
20	*Chenopodium album*	Chenopodiaceae	M and Au	LP	LP	NR	NR	WP
21	*Pupalia lappacea*	Amaranthaceae	Au	LP	LP	NR	NR	SM & L
22	*Setaria virdis*	Poaceae	M & S	MP	MP	NR	NR	WP
23	*Tephrosia purpurea*	Fabaceae	M & Au	LP	MP	NR	NR	L & P
24	*Trianthema portulacastrum*	Aizoaceae	M	MP	LP	NR	NR	WP
25	*Xanthium strumarium* *	Asteraceae	M & Au	LP	LP	NR	NR	WP
D.	**Climbers**							
26	*Cucumis callosus*	Cucurbitaceae	S & M	LP	LP	NR	MP	F

feeding during winter and summer (Table 2). Many plant species listed in Table 1 are also consumed by nilgai, so interspecific competition between Blackbuck and Nilgai may result in resource partitioning. Crop raiding increases during winter and summer seasons (Table 3).

Group activity pattern

Seasonal variations in group activity of the blackbuck were recorded (Figs. 3 and 4)

The annual data suggests that maximum time (62%)

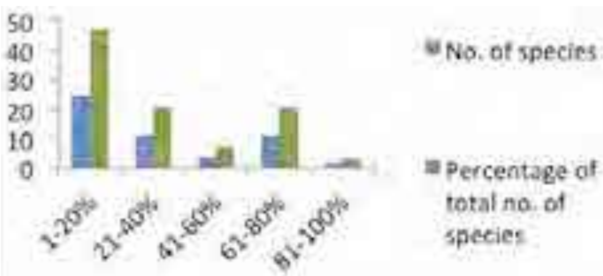

Figure 2. Frequency class distribution of plant species showing the number of species and percentage of the total number of the species.

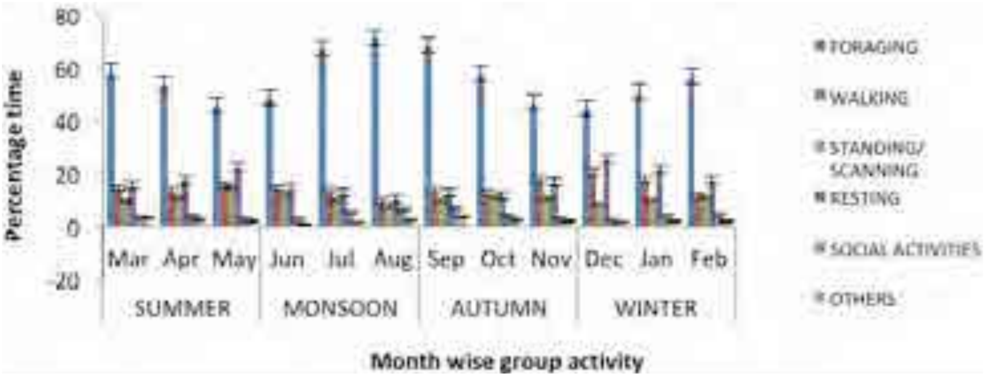

Figure 3. Percentage time versus monthly group activity by Blackbuck (Error bars with standard error).

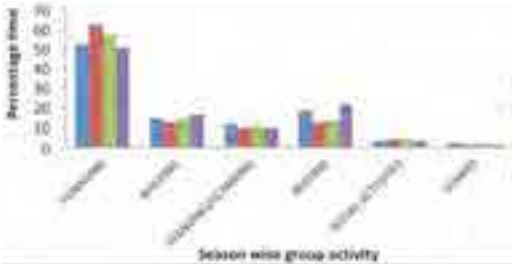

Figure 4. Percentage time spent on a particular group activity by season.

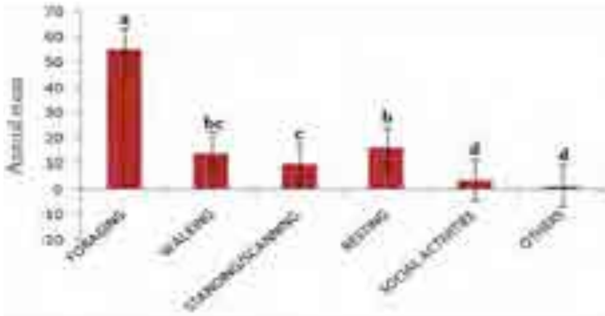

Figure 5. Annual mean of group activity (treatment bars with different letters differ significantly at $P \leq 0.05$ based on Duncan Multiple Range Test.

Table 2. Most dominant vegetation during all seasons, except trees, in descending order, and their interactions with Blackbuck. Some plant species were dominant in two seasons with varying densities.

Dominant flora covering the habitat in particular season			
A. Monsoon			
Scientific name	**Category**	**Food preference**	**Remarks**
Artemisia scoparia	Herb	Yes	Low preference for food in monsoon
Verbesina encelioides	Herb	No	Full bloom make the landscape helpful during parturition of females but inhibits communication and restrict establishment of territory by adult males and makes them vulnerable to feral dogs attacks.
Cyperus rotundus	Herb	Yes	One of the favorite diet items
B. Autumn			
Artemisia scoparia	Herb	Yes	Medium food preference in late autumn
Verbesina encelioides	Herb	No	Drier in late autumn, no direct use; hindrance for territory establishment.
Pupalia lappacea	Herb	Yes	Low preference, drier during late autumn, no use when completely dry.
C. Winter			
Pupalia lappacea	Herb	Yes	The habitat was mostly covered with this herb in dry condition during extreme winter. Low food preference in autumn and monsoon season.
Verbesina encelioides	Herb	No	2nd most dominant in habitat, mostly dry and used for preorbital marking.
Artemisia scoparia	Herb	Yes	Dried, preferred as a secondary food
D. Summer			
Verbesina encelioides	Herb	No	High density during late summer, no direct use except to hide the infant by females during initial days of nurturing
Parthenium hysterophorus	Shrub	No	No direct use but advantageous for feral dogs for attacking blackbucks.

was spent for foraging activity during monsoon followed by autumn (57%), summer (52%), and winter (50%) (Figure 4). Foraging activities were directly related to availability of food. Blackbuck spent more time resting in winter than in other seasons.

Diurnally, maximum number of crop raids (28 raids/sighting) were observed in winter followed by summer (22 raids/sighting) and minimum (11 raids/sighting) in monsoon (Table 4). Public opinion around the study site revealed that the crop raids were more prominent at night than in daytime.

The foraging to walking ratio

The foraging to walking ratio is a very important factor to evaluate the foraging success and assessment of habitat in terms of food availability. The animals spent more time walking in winter and summer season during less availability of food. The foraging to walking ratios for monsoon and autumn were 5.16 and 4.07 respectively, higher than summer and winter ratios of 3.71 and 3.12, respectively.

It was observed that blackbuck group composition and population fluctuation are also affected by crop patterns in the region due to high nutritional value of agricultural crops. The recorded data indicates a strong relationship between the foraging walking ratio and crop raiding during different season (Table 3).

All the annual group activities were statistically significant (p <0.05) except social and other activity. Foraging activity was maximum followed by resting, walking, standing/scanning (Figure 5). As per the recorded data, animal spent >3.0 times on foraging, fulfilling their food requirement to performing all other such activities.

Conservation implications

Based on our primary census survey, and the reconnaissance study of Wildlife Institute of India (2015) the Blackbuck populations in the districts of western Haryana are fragmented and distributed in small isolated patches surrounded by high human habitation and intensive agricultural practices. All these small size populations in villages like Mangali- Rawat Khera, Balsamand, (Hisar) Dhangar (Community Reserve for Blackbuck, 25 acres (2019)), Badopal (Current study site) (Fathehabad) harboring in same climatic semi-arid conditions and plant communities. Due to agricultural revolution and better irrigation system in Haryana, currently these sites have no true grasslands as preferred by the blackbucks, so the species have only options to feed on available plant species and consumed on crops to fulfill its nutritional demands. Therefore, the feeding pattern of the species has adapted according to the changing climatic and floral compositions during time and space.

Table 3. Diurnal seasonal data of foraging walking ratio and group sighting in nearby agricultural lands.

Season	Foraging walking ratio(within habitat) (A)	No. of group sighted ranging from (3-38) in adjoining agricultural field in a radius of 0.05 km to 4 km (B)
Summer	3.71	22
Monsoon	5.16	11
Autumn	4.07	15
Winter	3.12	28
Pearson Correlation between (A) and (B)	-0.947^{NS}	

DISCUSSION

Meeting nutritional demands is the most essential task for any animal (Parker et al. 2009). Challenges faced by ruminant herbivores are mainly linked to forage quality (Drent & Prins 1987; Illius & Gordon 1992), because green plants provide a relatively small yield of nutrients and require complicated mechanisms of fiber digestion based on microbial fermentation (Van Soest 1994). Selecting forage with high protein and low fiber content optimizes nutrient and energy intake and also reduces retention time, thus increasing intake capacity (Van Soest 1994; Mysterud et al. 2001). Additional selection criteria include the dietary need for essential minerals and secondary metabolites (Cassini 1994). Habitat use results from multiscale and multifactorial processes (Senft et al. 1987; Bailey et al. 1996; Van Beest et al. 2010) and its outcome in terms of individual movement and distribution depends on habitat use by multifactorial processes the outcome of which depended on the variations of landscapes of food in space and time (Mueller & Fagan 2008).

Foraging patterns and food preferences of blackbuck have been studied in Rajasthan and southern India, but without relating feeding data to group activity patterns. Unlike chinkara *Gazella bennettii*, Blackbucks are not found in true deserts, but attain their highest densities in semi-arid grassland-scrub systems where they prefer short grasslands (<50 cm) and avoid wooded habitats and grasslands above shoulder height (Jhala

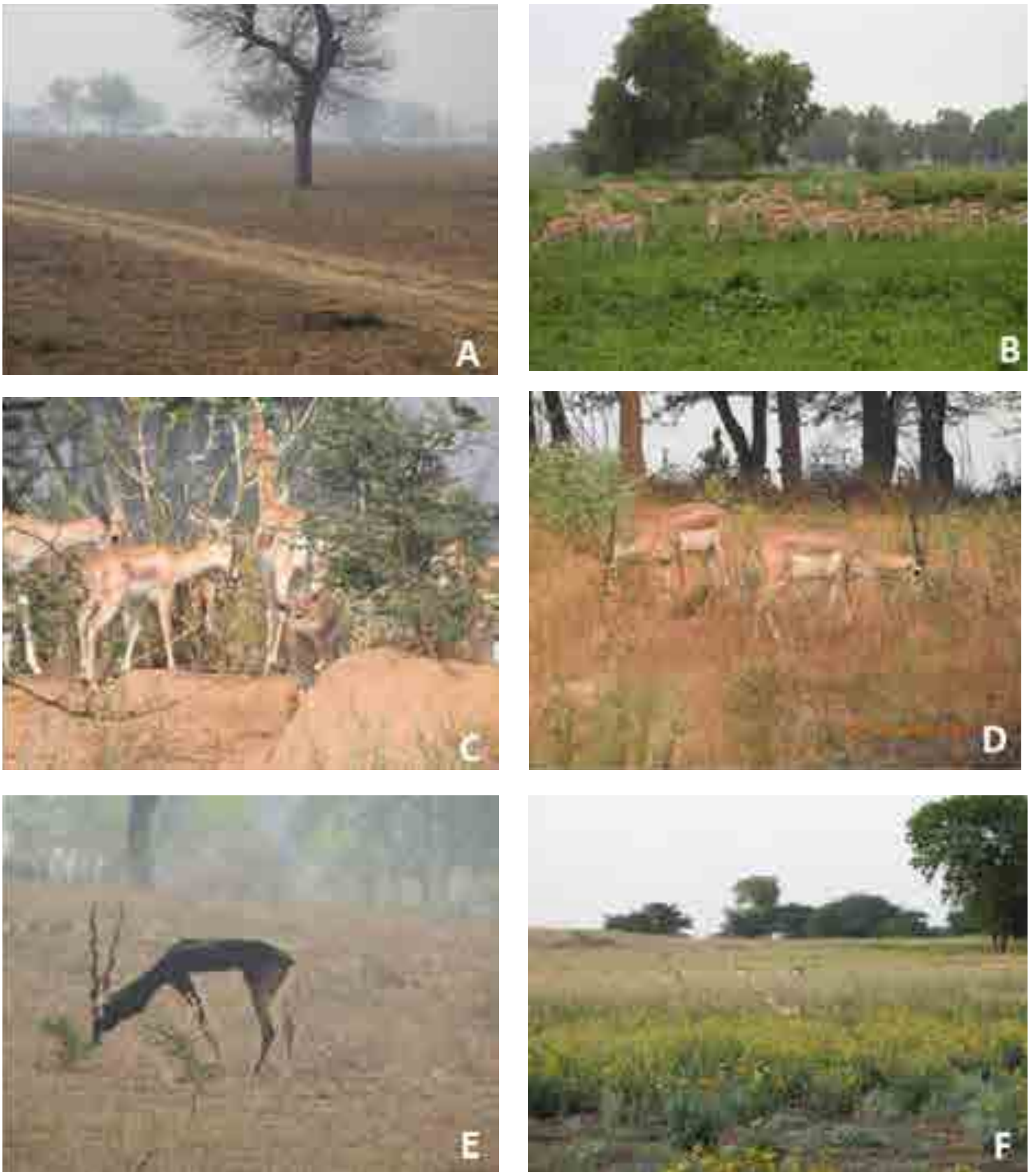

Image 1. A—Habitat view in February 2020 | B—Harem/family/mixed herd during monsoon season (July 2020) | C—Females foraging on *Calotropis procera* (late November 2019) | D—Two male blackbuck (age 2–3 years) nibbling on *Artemisia scoparia* (Autumn) | E—Adult male blackbuck browsing on *Acacia senegal* (late Autumn) | F—Habitat dominated with *Verbesina encelioides* in April 2020. © Vikram Delu.

1991). Their diet primarily consists of grasses so there is profound seasonality in their nutritional ecology. Pods and fallen leaves of trees such as *Acacia* species and *Prosopis juliflora* are favored in summer, and *Dichanthium annulatum* during monsoon season (Jadeja et al. 2013). Berseem *Trifolium alexandrinum* and oats *Avena sativa* are provided as food sources for blackbuck in captivity (Pathak et al. 1992). Foraging activity is at a minimum during summer, a little higher during winter and at a maximum during the monsoon season (Nair

1975; Chattopadhyay & Bhattacharya 1986; Kumar 1993). However, in this study foraging activity was slightly higher in summer than winter. Blackbucks have access to high quantity and quality forage during the monsoon (June–August) and early autumn (September) and in summer (March–April) coinciding with periods of maximum grass growth, the other months remain more or less dry to varying degrees.

Blackbucks are adapted to grassland ecosystems, and have evolved to conserve water by increasing the urea concentration in their urine and water reabsorption from their feces (Jhala et al. 1992). The protein content of the blackbuck diet drops significantly (<4%) in summer, well below the maintenance requirement for ruminants which is 5.5–9 % (Robbins 1983). During this period, protein digestibility is negative, i.e., Blackbuck loses more protein via feces than they can obtain from the forage. The digestibility of dry matter declines from a high of 76.5 % during the monsoon to a low of 32 % during summer. Blackbuck adapt to this low-quality diet by reducing intake from over 130g/kg 0.75 during the monsoon to less than 20g/kg 0.75 during summer (Jhala 1997).

During the present investigation the animals showed selectivity in food choices from available food in the habitat. It was also noted that blackbuck feed on *Calotropis procera* which is generally not eaten by herbivores due to the high concentration of alkaloids.

The present study suggests that the level of selectivity of food is not fully related to the dominance of plant species in a particular season. For example, *Verbesina encelioides, Parthenium hysterophorus* dominated in summer and *Verbesina encelioides* was the second most dominant in the monsoon but these plants were not the preferred food items of blackbuck. Similar variations in the diet of the Blackbuck have been reported in northwestern, central, and southern India and in parts of Nepal (Jhala 1997; Mahato et al. 2010; Jhala & Isvaran 2016).

Like most tropical ungulates, the body condition of Blackbuck cycles from good (during monsoon and autumn) to poor (during late summers and winter) due to the utilization of body fat and muscle proteins. To compensate their food requirements the animal shows physiological and behavioral adaptations by shifting to browsing instead of grazing and more crop raiding was reported during summer and winter. The feeding to walking ratio observed in the present study was higher in monsoon and autumn than in summer and winter and the number of crop raids were lower in monsoon and autumn than summer and winter. Our findings are supported by the observations of Hofmann (1989) that Blackbuck face a more prolonged period of low nutrition during hot summer and dry winter in comparison to other tropical ungulates studied in Africa as the dry spell in India lasts for over nine months as compared to 4–6 months in Africa. Blackbucks are unusual as they are relatively small (with correspondingly higher energy requirements) and have specialized on a low-quality forage source, i.e., grasses. A data set of the dietary preferences of mammalian species can be useful in elucidating a wide range of ecological processes, such as predator-prey interactions (Sinclair 2003; Jones & Safi 2011) and eco-morphological diversification (Davies et al. 2007).

CONCLUSION

The food preferences and behavior of a species are determined by the biogeographic region, climatic factors, food availability, prey-predator base and interspecific competition. Blackbuck diets are influenced by all these parameters. The present study is first of its kind in western Haryana on dietary choice, seasonality of available food items and behavioral shift from grazing to browsing by Blackbucks and will assist development of a scientific conservation plan for the many fragmented population of this species in and around Haryana. We would like to suggest that zoos of India which hold Blackbuck should include these preferred wild plant species in Blackbuck diet. The present study also emphasizes to the district and state authorities to notify and conserve this habitat as a community reserve and to include participation by local people to strengthen community-based wildlife conservation in the area.

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Hindi: कृष्ण मृग (*एंटीलोप सर्विकाप्रा*) की खाद्य वरीयताओं और समूह गतिविधि प्रतिरूप का मूल्यांकन करने के लिए, पश्चिमी हरियाणा के अर्ध-शुष्क पारिस्थितिकी तंत्र की एक खंडित आबादी का क्षेत्रीय सर्वेक्षण सितंबर 2019 से अगस्त 2020 के बीच, सुबह से शाम, वर्षभर हर ऋतु में पाक्षिक रूप से किया। समूह के आकार (3 से 72) और वनस्पति पर आंकड़े एकत्रित करने के लिए स्कैन सैंपलिंग और क्वाड्रैट विधियों का उपयोग किया गया तथा दृश्य अवलोकन के आधार पर यह पाया कि कृष्ण मृग अध्ययन स्थल से प्रलेखित कुल 53 पौधों की प्रजातियों में से 25 परिवारों की 26 प्रजातियों को विभिन्न प्राथमिकताओं के साथ खाते हैं। जिनमें उच्च औषधीय और चिकित्सीय मूल्यों वाली कुछ पौधों की प्रजातियों को प्राथमिकता दी गई जैसे *आर्टेमिसिया स्कोपरिया, कुकुमिस कॉलस, ज़िज़िफस जुजुबी* और *ज़िज़ीफस न्यूमुलेरिया*। अधिकांश शाकाहारी जीवों के विपरीत, कृष्ण मृग ने विषाक्त और औषधीय रूप से समृद्ध आक (*कैलोट्रोपिस प्रोसेरा*) का भी सेवन किया। हमारा सुझाव है कि जिन चिड़ियाघरों में काले हिरण है, वे इनके आहार में इन पसंदीदा जंगली पौधों की प्रजातियों को शामिल कर सकते हैं। समूह गतिविधि प्रतिरूप का विश्लेषण प्रति घंटा, मासिक तथा ऋतु आधार और समय प्रतिशत में परिवर्तित कर किया गया। भोजन की उपलब्धता बड़े पैमाने पर प्रभावित करते हुए देखा गया, मॉनसून में समूह भोजन गतिविधि अधिकतम (62%) और सर्दियों में न्यूनतम (50%) इसके बाद विश्राम सर्दियों में अधिकतम (21%) और मानसून में न्यूनतम (12%), था। भोजन /चलने का अनुपात मानसून में अधिकतम (5.2) और सर्दियों में न्यूनतम (3.1) था, जो आसपास के खेत में समूह देखे जाने की संख्या (सर्दियों में अधिकतम और मानसून में न्यूनतम) के साथ सहसंबद्ध था। जब जानवरों को प्राकृतिक आवास में भोजन की कमी का सामना करना पड़ता है तब वे फसलों को खाते हैं।

Author details: Vikram Delu, Priya and Kiran are pursuing PhD at Department of Zoology & Aquaculture, COBS&H, CCS HAU Hisar under the supervision of Dr. Dharambir Singh, Asstt. Professor in Zoology who has specialized in animal behavior, fish nutrition and ornithology. Dr. Sumit Dookia, Asstt. Professor, University School of Environment Management, GGSIP, Govt. of NCT of Delhi has specialized in wildlife sciences especially mammalian ecology of Thar Desert.

Author contributions: VD & DS designed the research plan, DS guided the research. VD collected the field data and wrote draft of the manuscript. DS & SD analyzed the data and finalize draft of the manuscript. SD added scientific inputs and also advised during research and writing period. Priya and Kiran helped in data collection and manuscript writing.

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COMMUNICATION

Studies on the habitats of Grey Francolin *Francolinus pondicerianus* (J.F. Gmelin, 1789) (Galliformes: Phasianidae) in northern districts of Tamil Nadu, India

M. Pandian

No. F1901, AIS Housing Complex, Natesan Nagar West, Virugambakkam, Chennai, Tamil Nadu 600092, India.
pandian.m14@gmail.com

Abstract: This paper pertains to the habitats of the Grey Francolin *Francolinus pondicerianus* with specific reference to populations, habitat type, vegetation, foraging, impact of human dwellings, and probable threats to populations in 20 villages covering four northern districts of Tamil Nadu, India. A total of 252 individuals were enumerated. During the non-breeding season, birds move in small groups of 2–6. Of four habitats identified, the maximum number of 143 birds was observed foraging in grasslands, while 61 were seen in dry fallow agricultural lands, 37 in dry lakes/canals, and 11 in harvested fields. No significant association was observed between habitat type and bird behaviour. They feed on termites and spilled paddy grains. Males have repeated loud calls and fight with each other. Four species of tall grasses, six of stunted trees and two shrubs were identified to provide bird habitat. Birds preferred to live away from human dwellings, with 193 found 1,000 m away from settlements. The study area continues to be a suitable habitat for Grey Francolin populations, hence this habitat needs protection.

Keywords: Call bouts, foraging behaviours, habitat types, human dwellings, probable threats.

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Author details: M.Pandian has completed MSc., PhD., in Botany and BLIS from University of Madras and Bachelor of Education (BEd) from Annamalai University, Chidambaram and now serves in Tamil Nadu Police Department. His area of interest is ecology and nesting biology of birds and published a few papers on House Sparrows, Baya Weavers, Munias, Ring-necked Parakeets, and Indian Flying Fox.

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INTRODUCTION

The Grey Francolin *Francolinus pondicerianus* (J.F.Gmelin, 1789) (Aves: Galliformes: Phasianidae) is native to India, Pakistan, Sri Lanka, Nepal, and Iran, and has been introduced into Bahrain, British Indian Ocean Territories, Mauritius, Oman, Qatar, Seychelles, United Arab Emirates, United States (BirdLife International 2018), and the Andaman & Chagos islands (Rasmussen & Anderton 2005; Loustace-Lalanne 1962). Fuller et al. (2000) stated that this species occurs worldwide except in the Sahara desert, the Arctic and colder regions. It occurs throughout India except in the high Himalaya, with few records in the northeastern parts (India Biodiversity Portal 2021). The birds are largely greyish-brown, rufous, and chestnut above, mottled, barred, and vermiculated with buff and black galliform (Sathyakumar & Kalsi 2007). They are omnivorous (Chaudhry & Bhatti 1992) and prefer seeds, grains, ants, and termites (Hussain et al. 2012). Sexes are alike, but males are slightly larger and have sharp spurs (Islam 1999). During non-breeding seasons, they move in groups (Rasmussen & Anderton 2005), each group consisting of 4–8 birds (Grimmett et al. 1998; Wijeyamohan et al. 2003). Breeding occurs between April–September in India (Rasmussen & Anderton 2005), and March–October in Pakistan (Roberts 1991). Ali (1945) and Sharma (1983) observed nests of *F. pondicerianus* in grasslands, ploughed fields, and dry scrub, while Bro et al. (2004) noted nests in standing crops in France. The clutch size varies from six to eight eggs (Jerdan 1864; Edwards 1933; Tiwari 1999). The female alone incubates eggs for 18–19 days (Ali & Ripley 1983; Roberts 1991). Studies and observations have been carried out on Grey Francolin populations in Coimbatore wetlands (Pramod 2011), Vaduvoor Bird Sanctuary (Gokula & Raj 2011), Sirumalai (Santharam et al. 2014), and Anaikatty hills of Tamil Nadu (Divyapriya & Pramod 2019).

The populations of Grey Francolin have been declined due to various causes. Based on the agent-based model (ABM) study, Topping et al. (2010) stated that landscape modifications and climate change are causing population decline. Habitat destruction, intensive farming, use of pesticides, hunting, and nest predation were stated reasons for population decline in the U.K. (Potts 1986; Roberts 1991; Aesbischer & Potts 1995; Southerton et al. 2010), western Europe (Bro et al. 2004), Pakistan (Khalil et al. 2015), and India (Whistler 1949). The global population size of this species has not been quantified, but it is reported to occur in most parts of its range (DelHoyo et al. 1994). The IUCN Red List considers it as 'Least Concern' (BirdLife International 2018).

The population size of Grey Francolin has not been quantified (BirdLife International 2018). Studies have, however, been conducted on the habitats and behaviours of this species but no literature is available about these aspects of this species in the northern districts of Tamil Nadu. Hence, the present study was carried out to fill these gaps by studying the habitats and foraging habits of this species, size of flocks and roosting patterns in five villages each in Ranipet, Tiruvallur, Tiruvannamalai, and Villupuram districts of Tamil Nadu in India, with the following objectives: (1) assess numbers of individuals in the rural landscape of the study area; (2) identify preferred habitat types with key plant species used for shelter; (3) assess human impact on bird habitats; and (4) identify key local threats.

MATERIALS AND METHODS

Study Area

The current study was carried out in 20 villages, five each in Tiruvallur (13.083^{0}N, 79.543^{0}E), Ranipet (12.948^{0}N, 79.319^{0}E), Tiruvannamalai (12.491^{0}N, 79.1097^{0}E), and Villupuram (11.940^{0}N, 79.486^{0}E) districts of northeastern Tamil Nadu (Figure 1). These districts spread over 15,560 km^2, with a human population of c. 94,80,000. Agriculture is the primary occupation of the residents, and the major crops are paddy *Oryza sativa* L., jowar Sorghum *bicolor* (L. Moench.), pearl millet *Pennisetum glaucum* (L.)R.Br., finger millet *Eleusine coracana* Gaertn., sugarcane *Saccharum officinarum* L., groundnut *Arachis hypogaea* L., and green gram *Vigna radiata* (L.)R.Wilczek. Vegetables, ornamental flowers, and fruits are also commonly cultivated in the study area. The maximum and minimum temperatures are 36 ^{o}C and 20 ^{o}C, respectively, and the average annual rainfall is 1,060 mm (www.tn.gov.in).

Methods

With help from three farmers, potential habitats for the Grey Francolin were identified in 20 villages surveyed during the non-breeding season from November 2019 to March 2020. Birds are usually active in the morning and evening from 0600–0900 h and 1500–1800 h (Gould 1966; Mahmood et al. 2010), thus field investigations were focused during these times. Based on information on the habitats of birds, each village was monitored for three days consecutively. Population size, including juveniles/chicks, was determined using the total count method (Bibby et al. 2000). Movements of birds were observed using binoculars without causing disturbance. Data were

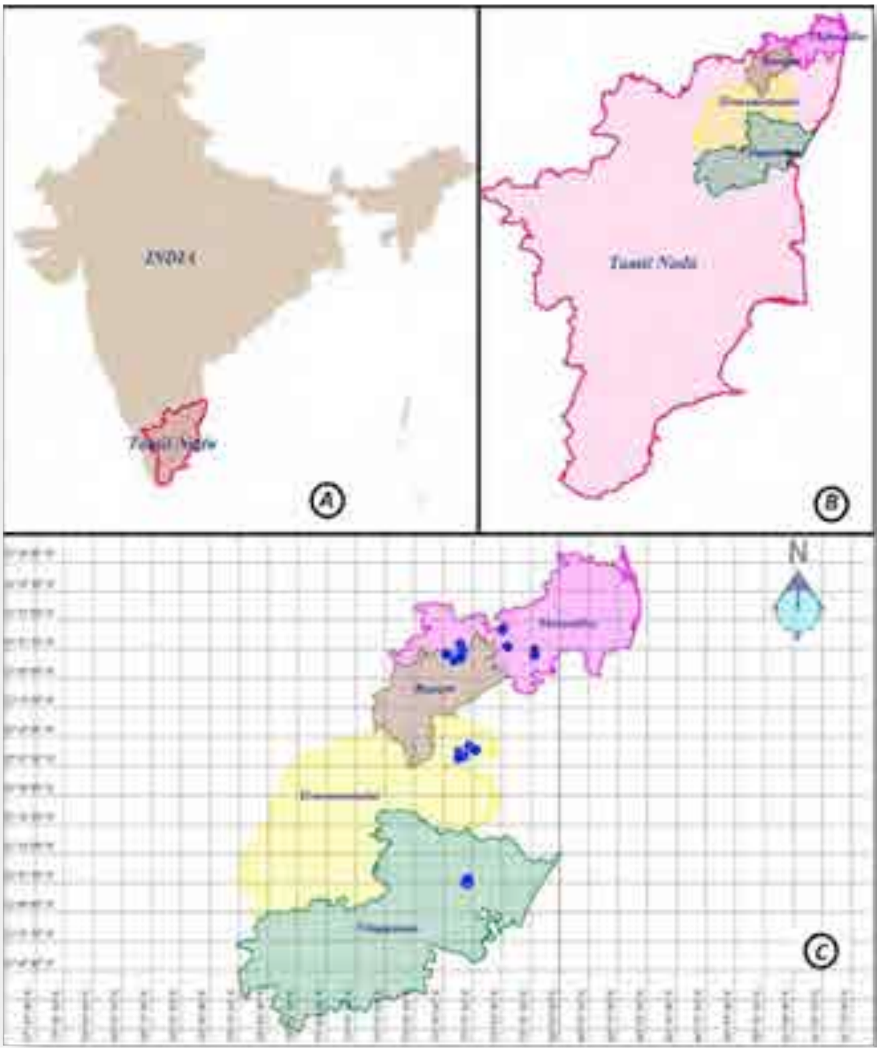

Figure 1. Study area map: A—India map showing Tamil Nadu | B—Tamil Nadu map showing the four selected districts | C—Map of the four districts indicating villages.

collected on group size, foraging behaviour, call bouts, fighting between males, roosting, vegetation types, type of habitats, and probable local conservation threats. GPS coordinates were recorded where birds appeared in agricultural fields, near water bodies, residential areas, and temples/buildings. Trees and tall grasses providing shelter to the birds were identified using Gamble (1915, 1921, 1928) and Nair & Henry (1989). Pearson Chi-square analysis was used to test the significance between different types of habitats and behaviours of Grey Francolin. Collected data were tabulated, analyzed and shown as graphical representation. Photographs and videos were taken using Nikon P1000 digital camera.

RESULTS AND DISCUSSION

A total of 252 Grey Francolin individuals, including 16 juveniles/chicks, were observed in 20 villages covering four districts. A maximum of 93 birds were enumerated in Tiruvallur district, followed by 70 birds in Ranipet, 54 in Villupuram, and 35 in Tiruvannamalai district. Of the 252 birds counted, 16 were juveniles/chicks found along with adult birds in five villages (Table 1). Availability of fallow lands, bushes, and less threat from hunters may be responsible for the existence of considerable populations of this species in the study area. In the present study the enumerated birds were found in small groups of 2–6 individuals. This observation matches the findings of Rasmussen & Anderton (2005), Grimmett et al. (1998), and Wijeyamohan et al. (2003).

Table 1. Details of *Francolinus pondicerianus* individuals counted in the study area.

District	Name of the villages	No. of adult birds counted	No. of juveniles/chicks counted	Total no. of birds counted	District wise no. of birds counted
Tiruvallur	Periyakadambur	18	6	24	93
	Thiruvalangadu	14	3	17	
	K.K. Chatram	12	0	12	
	Selai	28	0	28	
	Ekattur	12	0	12	
Ranipet	Minnal	9	0	9	70
	Narasingapuram	16	3	19	
	Gudalur	12	0	12	
	G.R. Pet	21	0	21	
	Salai-Vedal	7	2	9	
Tiruvannamalai	Valarpuram	8	0	8	35
	Velianallur	11	0	11	
	Kaazhiyur	7	0	7	
	Irumanthangal	4	0	4	
	Pandiyambakkam	5	0	5	
Villupuram	Mayilam	20	0	20	54
	Sendur	13	2	15	
	Pathiripuliyur	6	0	6	
	Vilangampadi	5	0	5	
	Edapalayam	8	0	8	
Total	**20**	**236**	**16**	**252**	**252**

Type of habitats

One-hundred-and-forty-three foraging birds were observed in grasslands (Figures E, F), followed by 61 in fallow agricultural lands, 37 in dry lakes/canals, and 11 in harvested fields (Table 2). Grey Francolins live in bushes consisting of stunted trees, shrubs/herbs/grasses, and adjoining sites such as grasslands, fallow agricultural lands, lakes/canals, and harvested fields for foraging. Chi-square analysis to test the significance between type of habitats and behaviours of bird yielded a p value of 0.503, hence we conclude that no significant association exists between the type of habitats and behaviors of bird such as foraging, fighting, and roosting in the study area. There was no variation in the number of birds observed roosting and the number observed fighting in lakes and canals. Based on row percentage, 87% of foraging birds were found in grasslands, indicating this habitat provides ideal shelter (Table 3).

Of the 252 birds enumerated, 87% were observed foraging in various habitats (Figure 2). They come out of the bushes in the morning between 0545 and 0600 h, complete foraging and take shelter in the bushes before 0900 h. On spotting anthropogenic disturbances such as agricultural workers, general public or vehicular movements in the vicinity of foraging sites, they ran swiftly and hid in the tall grasses or bushes. Their foraging activities were found to extend between 0600 and 0900 h and 1600 and 1800 h. No birds were found in open places between these two time segments. Study of foraging behaviours reveals that birds dig the soil using beak and claws to find seeds, worms, and insects (Image

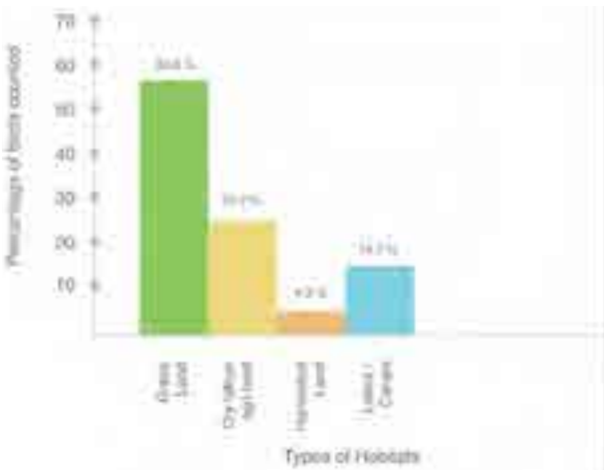

Figure 2. Percentage of *Francolinus pondicerianus* individuals observed on various habitats.

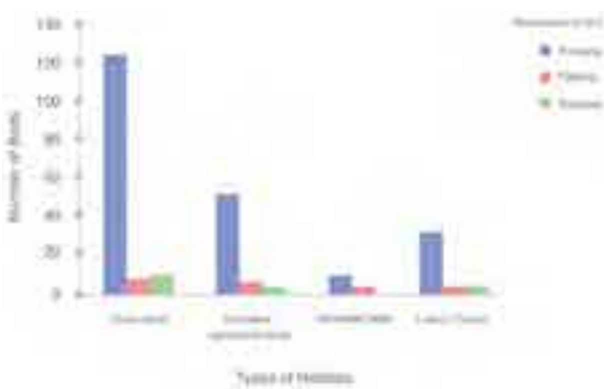

Figure 3. Type of habitats and number of birds found foraging, fighting, and roosting.

Table 2. Details of observance of *Francolinus pondicerianus* populations in various habitats in the study area.

	Type of habitat	Total no. of birds		Foraging		Fighting		Roosting	
		Count	%	Count	%	Count	%	Count	%
1	Grasslands	143	56.8	124	56.7	8	44.5	11	73.4
2	Fallow fallow agricultural lands	61	24.2	53	24.2	6	33.3	2	13.3
3	Harvested fields	11	4.3	9	4.1	2	11.1	-	-
4	Lakes/Canals	37	14.7	33	15.0	2	11.1	2	13.3
	Total	**252**	**100**	**219**	**100**	**18**	**100**	**15**	**100**

Table 3. Chi-Square test for association between type of habitats and observed behaviours of *Francolinus pondicerianus* in the study area. The values within ( ) and [ ] refer to row and column percentages, respectively.

Type of habitats	Behaviours of bird			Total	Chi-Square Value	p-Value
	Foraging	Fighting	Roosting			
Grasslands	124 (86.7) [56.6]	8 (5.6) [44.4]	11 (7.7) [73.3]	143 (100.0) [56.7]	5.321	0.503
Dry fallow agricultural lands	53 (86.9) [24.2]	6 (9.8) [33.3]	2 (3.3) [13.3]	61 (100.0) [24.2]		
Harvested fields	9 (81.8) [4.1]	2 (18.2) [11.1]	0 (0.0) [.0]	11 (100.0) [4.4]		
Lakes/Canals	33 (89.2) [15.1]	2 (5.4) [11.1]	2 (5.4) [13.3]	37 (100.0) [14.7]		
Total	219 (86.9) [100.0]	18 (7.1) [100.0]	15 (6.0) [100.0]	252 (100.0) [100.0]		

1b,c,d). Grey Francolin individuals preferred seeds, grains, worms, ants and termites in India (Jerdon 1864) and in Pothwar region of Pakistan (Hussain et al. 2012). In the current study, the foraging sites (6) in Mayilam and Selai villages were examined between 0600 and 0800 h when the birds were found active at the foraging sites. The study revealed that there were termite nests on the dead plant materials covered with thin layer of wet soil. In Pathiripuliyur village Grey Francolin individuals were found foraging on spillover paddy grains in the harvested paddy fields. Hence, observation of foraging on termites and paddy grains in the present study matches with the findings of Jerdon (1864) and Hussain et al. (2012). The details of other prey of this bird warrant further elaborate study.

Among the 252 Grey Francolin individuals studied, nine pairs of males were found fighting in open land in the early morning. For 21 fights observed, the duration ranged from 5 to 15 minutes, and the number of fights per pair varied from 1 to 4. No fights were observed in the evening during the study period. When they noticed humans in the vicinity males stopped fighting temporarily and took cover in the bushes, then later emerged to make loud calls and continue fighting until further disturbances occurred in the vehicular traffic or other human activities (Image 1f). The maximum of such fighting by male individuals were observed in grasslands (four pairs), followed by dry fallow agricultural lands (three pairs) and two pairs each in harvested fields and dry lakes/canals, respectively. All such fights were observed in open places and the reason could be either territorial or breeding or both, and this aspect requires further study. Study on the call sounds reveal that the males have repeatedly produced calls in a sequence of calling bouts ranging from four to seven bouts at a time by stretching their neck. Males call more frequently at sunrise and sunset (Ali & Rilpey 1983; Johnsgard 1988). In the present study also males were found making such loud calls both during their morning and evening forages and hence it matches with the observations of the above authors. Rana et al. (2007) had stated that the dawn calling by these birds in Haryana (India) might have been linked to the transmission of messages for marking their territorial jurisdiction. The pattern of maintaining territorial jurisdiction and the pattern of dawn calls of males in the present habitat requires further study (Image 1a).

Only 15 birds were found roosting during the afternoon between 1600 and 1800 h. Fourteen birds were found on the stunted *Prosopis juliflora* (Sw.) DC. trees and one bird was on liana *Tinospora cordifolia* (Thunb.) Miers. Except during foraging and fighting, it was difficult to spot the birds in their habitats because they hide/take cover in the tall grasses and bushes (Image 1).

Plants providing habitat

Trees with stunted growth interspersed with tall, thick grasses forming dense vegetation in the study area becomes a suitable habitat for this bird. The study reveals that thick growth of tall grasses such as *Cymbopogon coloratus* (L.) Speng., *Chrysopogon zizanioides* (L.) Roberty, *Chloris inflata* (L.) Sw., and *Aristida setacea* L. were found in the study area. In between grasses, small and stunted tree species such as *Prosopis juliflora* (Sw.) DC., *Azadirachta indica* A.Juss., *Canthium coromandelicum* L., *Lantana camera* L., *Vitex negundo* L., *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb., *Ziziphus jujuba* Mill., and *Capparis sepiaria* L. were identified. High density of Grey Partridge *Perdix perdix* were found in the herbaceous and farmland habitats in Prague of the Czech Republic (Salek et al. 2004). Husain et al. (2012) have stated that these birds preferred to live in scrub vegetation in Pothwar plateau in Pakistan. In Sri Lanka, they occur in the habitats with dwarf bush and thorn scrub vegetation (Wijeyamohan et al. 2003). It was observed that Grey Francolin individuals roost on short trees and shrubs in India (Sangha (1987) and in Pakistan (Roberts 1991). Hence, in the present study the occurrence of sizeable populations of Grey Francolin in the grassland habitats with bushes containing short trees and shrubs corroborates the findings of Sangha (1987), Roberts (1991), Salek et al. (2003), and Wijeyamohan et al. (2003). These bushes might have protected the birds from predators such as dogs and raptors and also protected their chicks from house crows, and hunting by local villagers. Hence, four species of tall grasses such as *C. coloratus*, *C. zizanioides*, *C. Inflata*, and *A. setacea*, six species of trees and two species of shrubs provide suitable habitat for this species. In addition tall grasses in the habitats afford camouflage to the birds.

When analysing the relationship between the sites of observance of birds and the nearest human residences, it was observed that a maximum of 117 birds (46%) were found more than 1,000 m away from human settlements. Seventy-six birds (30%) were found between 751 and 1,000m, 21 birds (8.3%) between 501 and 750 m, 26 birds

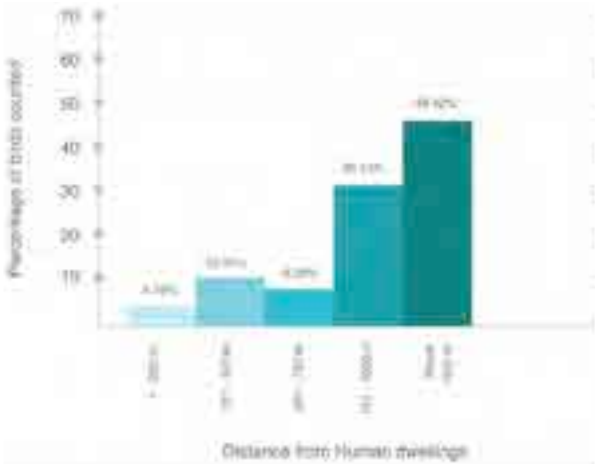

Figure 4. Relationship between distance from nearest human dwellings and number of birds enumerated.

(10%) between 251 and 500 m, and 12 birds between 1 and 250 m from human settlements as observed in the study. The existence of 77% of birds (n= 193) located 750 m away from human dwellings reveals that they preferred the rural landscape (Figure 4). The study also reveals that the average flush distance of this bird from human beings is 80 m.

Conservation issues

Two incidents of dogs chasing Grey Francolin were noted in Narasingapuram, and one each in Mayilam and G.R. Pet villages, between 1700 and 1800 h. A trap net placed by hunters in the grassland of Mayilam village was found on 10 March 2020; no trapped birds were found and traps were not observed in other habitats/villages during the study period. Habitat destruction, intensification of agriculture, and indiscriminate use of pesticides have been linked to francolin population decline in Pakistan (Roberts 1991), and Khalil et al. (2015) stated that hunting, predation and increasing agricultural activities caused population decline in Salt range, Pakistan. Hunting, nest predation and agricultural practices have been linked to declining populations in the United Kingdom (Potts 1980, 1986; Aesbischer & Potts 1995; Southerton et al. 2010) and in western Europe (Bro et al. 2004), while landscape modifications, climate change and predation have reduced populations worldwide (Topping et al. 2010). In India, Grey Francolin continue to be hunted for food (Long 1981), with use of low nets being prevalent (Whistler 1949). Observation of hunting/trap nest in the habitat and the impact of urbanization and intensification of agriculture on the populations of this species in Tamil Nadu warrants further study.

Image 1. Behaviours of *Francolinus pondicerianus* individuals: a—Male calling | b—Pair foraging near dried lake | c, d—A foraging pair | e—An individual observed in an abandoned stone quarry in grassland | f—Males fighting with each other. © M. Pandian.

CONCLUSION

The present investigation of 20 villages in four districts of northern Tamil Nadu enumerated 252 Grey Francolin in habitats that by order of preference included grasslands, dry fallow agricultural lands, dry lakes/canals and harvested crop fields, with birds showing a preference for areas distant from human dwellings. Males made calling bouts in the morning and evening forages, probably to mark their territories via fighting. Hunting and dogs may pose threats to populations in the study area. Further study on the population dynamics, geospatial analysis of nests, and their breeding biology at various habitats covering larger areas in the state may throw more light on the exact population status of this bird. This will require sustained surveys and monitoring of populations during the breeding and non-breeding seasons. Efforts should also be taken to protect existing habitats from widening of roads, urbanization, industrialization, and hunting by villagers. A management plan could be devised for the area, considering the anthropogenic and natural stresses that bird habitats are currently subjected to.

Local community, particularly traditional hunters, should be sensitized to understand the importance of this bird species and their need to preserve the populations of Grey Francolin. A detailed and systematic survey on the population dynamics, foraging behaviours and anthropogenic impact on their populations covering the entire state may be carried out to help in drafting an action plan to conserve the declining populations of this native species.

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Recovery of vulture population in roosting and scavenging areas of Bastar and Bijapur, Chhattisgarh, India

Sushil Kumar Dutta [1], Muntaz Khan [2], P.R.S. Nagi [3], Santosh Durgam [4] & Surabhi Dutta [5]

[1,4] Department of Zoology, Govt. P.G. College, Jagdalpur, Bastar, Chhattisgarh 494001, India.
[2] Department of Zoology, Kalahandi University, Bhawanipatna, Kalahandi, Odisha 766001, India.
[3] Veterinary Hospital-Bastar, Bastar, Chhattisgarh 494223, India.
[5] Institute for Excellence in Higher Education, Bhopal, Madhya Pradesh 462016, India.
[1] dutta.sushil1962@gmail.com (corresponding author), [2] soneyal@yahoo.co.in, [3] prsn67@gmail.com, [4] santoshdurgam1996@gmail.com, [5] dutta.surabhisur@gmail.com

Abstract: Chhattisgarh is home to seven of the nine vulture species in India. One reason for this high vulture diversity is the presence of large herds of bovines numbering over 11 million individuals (ratio of human to bovine population is approximately 0.38), from which carcasses are disposed off in the open for scavengers. The late 1990s saw large scale decimation of vulture population, and since then there have been few studies with no sighting estimates available. In this study, concurrent sighting records were collected from different locations of southern Chhattisgarh and corroborated to develop conservative sighting estimates for sympatric populations of *Gyps bengalensis* and *Gyps indicus*. We present the first report on population recovery, with an estimated 30–35 *Gyps bengalensis* & 20–25 *Gyps indicus* in/ around Rudraram of Bijapur and 18 *Gyps bengalensis* & five *Gyps indicus* at Jamguda village of Bastar. Krishna Swami Gutta hill is identified as a nesting-roosting habitat for both species, for which six scavenging areas were identified in Bastar and Bijapur districts. The human/bovine population ratio for Bastar is 0.4, similar to the state ratio, while in Bijapur the ratio is 1.07, which justifies considering Bijapur as a conservation refuge. The few vultures that survived the diclofenac catastrophe in wild habitats most likely consumed wildlife carcasses that sustained a residual population. In these areas, the age-old practise of disposing off dead domesticated bovines away from settlements near reserve forests may also have supported the recovery of vulture population.

Keywords: Bovines, concurrent, diclofenac, diversity, *Gyps bengalensis*, *Gyps indicus*, habitat, nesting-roosting, sighting, sympatric.

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Author contributions: SKD—supervised the study, identification of roosting and scavenging areas of vultures, conducted the vulture enumeration survey, collected information on daily movement of vultures from various sources, photographic documentation, compilation of data and drafted the research paper. MK—formulated the survey plan, protocols, participated in the survey, correlated information on vulture and habitat, analysis-interpretation of research data and finalized the research paper. PRSN—participated in the survey, photographic documentation, studied the bovine carrion in the study area and gave vital inputs for this research paper. SaD—MSc student participated in the survey to collect information on vultures from his designated survey site, photographic documentation and enumerated vulture numbers. SuD—graduate student participated in the survey and collected information on vulture from her designated survey site and enumerated vulture numbers.

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INTRODUCTION

Chhattisgarh is a land of dense forests, hill ranges, valleys, sheer cliffs, vast grasslands, agricultural land, waterfalls, and water-bodies. The estimated human population was 29 million for 2020 (Unique Identification Aadhar India updated 31 May 2019), with a rural population of about 22 million (i.e., 77 %). People generally maintain large herds of bovines totalling over 11 million animals (Livestock Census 2019) for agriculture and milk. The ratio of human to bovine population for Chhattisgarh state is approximately 0.38. Cattle are maintained largely on grazing, with basic shelters at night. Bovine death rates are relatively high owing to various factors. Many domestic bovines turn feral and enter forests, there are occasional outbreaks of disease since widespread vaccination is impractical, there are few veterinary personnel, many people prefer cheap traditional treatments over modern drugs, and most villages are far from the reach of emergency veterinary help. Dead animals are disposed off in a designated communal place on the outskirts of Bastar and Bijapur villages, where scavengers including vultures, feral carnivores and crows congregate.

Of the 22 vulture species worldwide, nine are resident to India, and seven—Indian Scavenger Vulture *Neophron percnopterus ginginianus* Latham, 1790; Oriental White backed Vulture *Gyps bengalensis* Gmelin, 1788; Indian Long-billed Vulture *Gyps indicus* Scopoli, 1786; Indian Griffon Vulture *Gyps fulvus fulvescens* Hume, 1869; Cinereous Vulture *Aegypius monachus* Linnaeus, 1766; and Black or King Vulture *Sarcogyps calvus* Scopoli, 1786—have been reported from Chhattisgarh (Ghosh et al. 2008). Information on vulture population and diversity for Chhattisgarh is scant from the southern part of the state.

Before the introduction of diclofenac (an anti-inflammatory drug) in India during the 1990s vultures were recorded in large groups and were common sight in many localities, but the following years witnessed a continuous and drastic decline in vulture populations (Prakash et al. 2003). In 2004, Dr. Lindsay Oaks and his team found that diclofenac causes fatal renal failure in vultures. A simulation model demonstrated that if only 1 % of the carcasses were contaminated by diclofenac, Indian vulture populations could decline 60–90 % annually, and it was reported that 10 % of carcasses in India were contaminated (Green et al. 2004). In 2006, the Government of India banned the manufacture, marketing and use of diclofenac. Following this ban, the declining population of *Gyps bengalensis* slowed, but infrequent use of diclofenac continued (Prakash et al. 2012). Populations of White-rumped Vulture, Long-billed Vulture, and Slender-billed Vulture crashed during the mid-1990s throughout the Indian subcontinent, and the International Union for Conservation of Nature (IUCN) listed all of these species as 'Critically Endangered' (Birdlife International 2021). This study estimates vulture population in Bastar and Bijapur district of Chhattisgarh and attempts to correlate contributory factors for recovery post the decimation of the mid-1990s.

The White-rumped Vulture is identifiable by a conspicuous white ruff at base of neck, white inner thighs, a prominent broad white band on under-wings and 12 tail feathers. Head and neck are destitute of feathers and tinged pink, and the bill is dark at the tip and paler at the base with dark ceres. The nostril openings are slit-like. In flight, the white under-wing coverts are highly visible. The Long-billed Vultures is characterized by a narrow elongated head, long naked neck and head covered with woolly down sporting a prominent lanceolate ruff of feathers (longer in juvenile) at base of neck, and a long yellowish bill. It sports 14 tail feathers. The upper wings are sandy brown and darker head, have a buff ruff at the back of neck, feathers of back are sepia brown. *Gyps indicus* is smaller in size than *Gyps bengalesis*. Both are sociable, nest and roost communally on trees and cliffs (Grimmett et al. 2011; Naroji 2011). Both the species are medium-sized Old World vultures. White-rumped Vulture is native to southern and southeastern Asia. Long-billed Vulture is native to southern Asia.

MATERIALS AND METHODS

Opportunistic documentation of vultures in 2011–2016 gave the impetus to undertake dedicated surveys from June to October 2020, and in January 2021 in Bastar and Bijapur district of Chhattisgarh. Garmin GPSMap 78s was used to record the sighting position, Nikon Aculon A211 10–22 X 50 binoculars were used for spotting and identification of species. A Canon EOS 70D with an EF300mm f/4L IS USM lens and extender EF 1.4 X III were used for photographic documentation. The surveys were conducted in designated dead animal disposal places near villages. Concurrent sighting information was collected from different locations and corroborated to evolve conservative sighting estimates for vultures.

Study area

Two southern districts of Chhattisgarh; i.e., Bastar and Bijapur were covered to record the population of

Figure 1. Outline map of Chhattisgarh districts with study area of vultures shaded green (Source: Wikipedia)

vultures (Figure 1). Bastar district covers an area of 6,596.90 km². The district is bounded on east by Odisha, north by Kondagaon district, west by Narayanpur and Dantewada, and south by Sukma. It is situated at a height of 606 m plateau from sea level. Kanger Ghati National Park (also called Kanger Valley National Park) is a protected area in the Bastar district of Chhattisgarh.

Bijapur district covers an area of 6562.48 km^2. The district is bounded on east by Dantewada and Sukma districts, north by Narayanpur district and Maharashtra, west by Maharashtra and south by Telangana. The major river is Indravati and flows through Bastar, Dantewada and Bijapur uniting with Godavari near Bhadrakali River. The district is a rocky hilly terrain with an altitude ranging 177–599 m. District is covered by rich and thick dense mixed forest interspersed by moist and intermediated forest with diverse forest species. Indravati Tiger Reserve (Biosphere reserve), lies within this district with high and rocky hills.

OBSERVATION

Sightings of vultures in Bastar

Bastar district has a human population of 0.83 million as per 2011 census, and more than 70 % are tribal. The domesticated livestock population (cows and buffalos) is 0.34 million as per the 20th Livestock Census, 2019. The ratio of human population to cattle population for Bastar district is approximately 0.4. Bastar district is covered with very and moderate dense forest of 3072.34 km^2 or 47 % (Indian State of Forest Report 2019).

The first and third author sighted 18 *Gyps bengalensis* and five *Gyps indicus* at Jamguda village of Bastar district in 2011 during post-mortem of 12 bovines succumbed to sudden death, and second sighting of one individual vulture gliding and soaring was recorded during 2015. Vultures sighted in Bastar are both resident and migrant. Sporadic records are available of their earlier sightings with no estimates of vultures.

Sightings of vultures in Bijapur

Bijapur district has human population of 0.26 million (2011 census), and more than 70 % are tribal. The domesticated livestock population (cows and buffalos) is 0.28 million as per the 20th Livestock Census, 2019. The ratio of human population to cattle population for Bastar district is approximately 1. Moderate/dense forest cover is 4,975 km^2 or 76 % (Indian State of Forest Report 2019). Frequent and regular sightings of White-Rumped Vulture and Indian Vulture have been made in this area.

Occasional Sightings of vultures in Dantewada

On 04 February 2020, one migrating sub-adult Himalayan Griffon found in Geedam (18.974°N, 81.399°E), a village in Dantewada district. A group of crows attacked the vulture which succumbed to injuries even after its treatment in the zoo.

Table 1 presents chronological sighting records of vultures in Bastar and Bijapur (Image 4–8). Image 1, is GoogleEarth Map showing the sighting locations of *Gyps bengalensis* and *Gyps indicus* in Bastar and Bijapur districts. Figure 2, is a graphical presentation of vulture population in various roosting and scavenging sites.

DISCUSSION

Informal interviews with forest department personnel and local people of rural villages near Rudraram and Cherpalli revealed that vultures nest on Krishna Swami Gutta hill on the plain between the cliffs, 30–50 m above ground level. The hill is located south of Cherpalli in Bijapur district. Consistent sightings of vultures were documented in Bijapur district from March 2016, with photographic documentation and GPS co-ordinates.

Table 1. Chronological sighting record of vultures in Bastar and Bijapur.

Date	Time	District	Location	Species wise number of individuals		Position Landed / perched / gliding / soaring
				Gyps bengalensis	*Gyps indicus*	
31 Jul 2011	1208	Bastar	Jamguda village 19.30333°N 81.96555°E	18	5	Landed Perched
?? 2015	1545	Bastar	Bastar village	1	0	Gliding and soaring
05 Mar 2016	1142	Bijapur	Cherpalli 18.83246°N 80.43249°E	4	0	Gliding and soaring
06 Jun 2020	1128	Bijapur	Indravati Tiger Reserve, 18.81324°N 80.47578°E	13	12	Landed
12 Jun 2020	1103 1630	Bijapur	Rudraram 18.83700°N 80.41471°E	30–35 3–4	20–25 1–2	Landed Perched
13 Jun 2020	1115	Bijapur	Rudraram 18.83702°N 80.41475°E	18–20	15–17	Landed
14 Jun 2020	1600	Bijapur	Rudraram 18.83758°N 80.41465°E	4–5	2	Gliding and soaring
30 Jun 2020	1428	Bijapur	Krishna Swami Gutta hill 18.79739°N 80.41125°E	6–7	3	Gliding and soaring
22 Jul 2020	0921	Bijapur	Rudraram 18.83681°N 80.41521°E	2	0	Landed
24 Aug 2020	1122	Bijapur	Rudraram 18.83695°N 80.41392°E	10–12	0	Landed and perched
03 Sep 2020	0928	Bijapur	Rudraram 18.83682°N 80.41521°E	30–31	18–20	Landed
01 Oct 2020	1015	Bijapur	Rudraram 18.83711°N 80.41482°E	17–19	10–12	Landed
12 Jan 2021	1000	Bijapur	Rudraram 18.83711°N 80.41482°E	13	4	Landed Perched

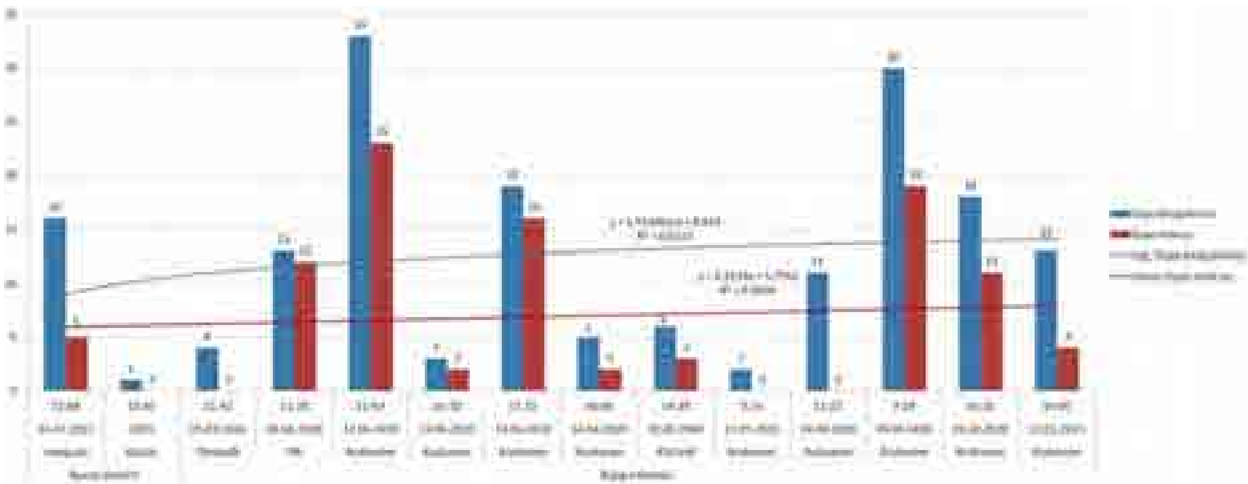


Figure 2. Graph represents vulture population in scavenging and roosting sites of southern Chhattisgarh (ITR – Indravati Tiger Reserve, KSG hill – Krishna Swami Gutta hill).

Image 1. Google Earth map of vulture sighting locations in Bastar and Bijapur district of southern Chhattisgarh.

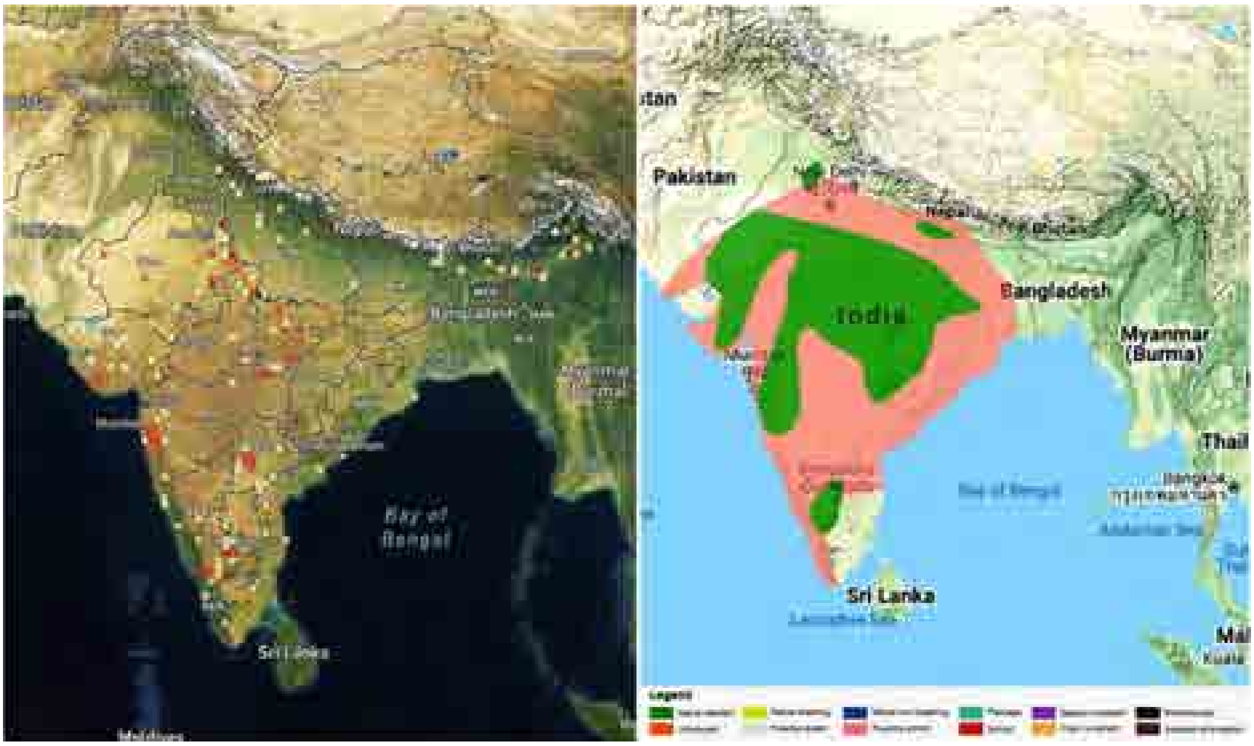
Primary food source for both species of vultures are carcasses of Wild Asian Buffalo, Indian Bison, Nilgai, Blackbuck, Chausinga, Sambar, Chital, Indian Muntjac, Indian Spotted Chevrotain, and Wild Boar in reserve forest (Wildlife Officials, pers. comm. 27th July 2020). Both species of vultures in outskirts of reserve forest feed on carcasses/carrion of domesticated bovines.

Estimates of vulture sightings started from 2011 at Jamguda village, with 18 *Gyps bengalensis* and five *Gyps indicus*. A single individual was sighted gliding and soaring in 2015 at Bastar village of Bastar district of southern Chhattisgarh. In 2016, four *Gyps bengalensis* were sighted at Cherpalli in the Bijapur district. In 2020, frequent sighting of vultures were encounter at various locations in the Bijapur; 13 *Gyps bengalensis* and 12 *Gyps indicus* were sighted at Indravati Tiger Reserve (Buffer Area). More and regular sightings were recorded in Rudraram; 30–35 individuals of *Gyps bengalensis* and 20–25 individuals of *Gyps indicus* were sighted at Rudraram and Krishna Swami Gutta hill often referred as nesting-roosting habitat was visited and confirmed. Both species are now exploring six identified scavenging areas and possibly homing range of both species covers Bastar and Bijapur district of southern Chhattisgarh. Rudraram and Krishna Swami Gutta hill are two hot spot for these species. These observations are an indication of population recovery of both *Gyps bengalensis* and *Gyps indicus*. This sighting result as seen from the logarithmic trend lines in the graph is in conformity with the surveys conducted in 2011 by Prakash and his research team. The population of vulture species remains low, but the decline has slowed and may even have reversed for *Gyps bengalensis* in India (Prakash et al. 2012).

In recent times vultures have been sighted in good numbers, often in the outskirts of remote villages surrounded with dense trees, higher cliffs and flat-tops on higher rocky hills, particularly near protected areas and far from urbanization. These habitats must have served as last refuges for those few vultures that survived the Diclofenac era. The factors contributing to the recovery of vulture population in Bastar and Bijapur district are:

a) Conducive habitable places for resting and breeding in Bijapur district, is the first and foremost

(A) Source: India Biodiversity (B) Source: BirdLife International 2021
https://indiabiodiversity.org/biodiv/species/show/239129 [Accessed date Jan 7, 2021]
Image 2. A—Map of India showing no record of *Gyps bengalensis* in Chhattisgarh | B—Map of India showing no records of *Gyps bengalensis* in southern Chhattisgarh.



(A) Source: India Biodiversity (B) Source: BirdLife International 2021
https://indiabiodiversity.org/species/show/239132 [Accessed date Jan 7, 2021]
Image 3. A—Map of India showing no record of *Gyps indicus* in Chhattisgarh | B—Map of India showing records of *Gyps indicus* in Bijapur and Bastar districts of Chhattisgarh.

important factor for survival and population recovery of vultures. The numbers of vultures were so low that not a single sighting report from this areas exists from 2005–2011 (Image 2 and 3 except for *Gyps indicus* by BirdLife International).

b) Availability of adequate dead wildlife carcasses in these wild habitats (Indravati Tiger Reserve and Kanger Valley Tiger Reserve) likely sustained the decimated vulture population. Forest staff confirm that mortality of wild animals due to natural factors in protected areas is sufficient to sustain present vulture population. Carcasses of wild beasts and feral domesticated animals in the protected areas and peripheral remote village areas are generally free of Diclofenac contamination. This has ensured a safe and continuous source of food, but vigilance against misuse of Diclofenac is necessary to ensure conservation and recovery of vulture populations.

c) The ban on veterinary use of Diclofenac (i.e., from May 2006 till date) by the Indian Government might had a positive impact on recovery of vulture population, as witnessed in Bastar and Bijapur districts of southern Chhattisgarh. Two years after the ban, 1,150 of 1,251 liver samples from livestock carcasses collected across India between August 2007 and June 2008 were negative (Saini et al. 2012). Similarly, Cuthbert et al. (2011) reported that the concentration of diclofenac before and soon after the ban was 10.8–10.7 %, but had dropped to 6.5% in 31 months after the implementation of the ban, leading to a drop in the annual death rates of vultures from 80 % to 18 %.

d) Traditional practises of disposing off dead bovines in designated communal sites in rural villages. An average of 10 bovines (i.e., 2–3 per month) are disposed in each village during the dry season, and 4–5 (i.e., 1–2 per month) in the wet and cold seasons. This is an important contributing factor for recent sightings of vultures in Bastar and Bijapur district.

The southern Chhattisgarh region is possibly a migratory route of vultures. On 04 February 2020, one migrating sub-adult Himalayan Griffon was recorded in Geedam village of Dantewada district. The repeated sightings of vultures around the same area and their nesting in the Krishna Swami Gutta hill is an opportunity to plan for the conservation of both species *Gyps bengalensis* and *Gyps indicus* vultures in India.

Suggestions

1. The traditional practise of disposing off dead bovines free of diclofenac contamination should be promoted in other designated communal sites instead of burying - to ensure a safe, constant source of food enabling vulture populations to grow further.

2. Camera traps should be fixed in nesting, roosting and scavenging areas to monitor inter and intra species interactions.

3. Long-term vulture monitoring projects should be undertaken; fitting of satellite telemeters on discrete population in roosting and scavenging areas for understanding movements, other parameters and physical challenges due to vast home range.

4. Krishna Swami Gutta hill must be designated as a 'Vulture Sanctuary' to protect the nesting sites of these vultures.

5. Vigilance and legal actions should be adopted on any diclofenac use in veterinary. Sensitization of chemists and drug associations, pharmacists, veterinary councils and farmers should be undertaken along

Image 4. Himalayan Griffon *Gyps himalayensis*.

Image 5. Vulture sighting at Jamguda, Bastar.

Image 6. Vulture sighting at Indravati Tiger Reserve, Bijapur. © Forest Officials of Indravati Tiger Reserve.

Image 7. Vulture sighting at Rudraram, Bijapur.

Image 8. Vulture sighting at Krishna Swamy Gutta Hill, Bijapur.

with understanding the implications of substitute of diclofenac drug in veterinary use. Lead contamination is also a serious concern for vultures and need to be monitored for future of vultures recovery.

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Author details: Dr. S.K. Dutta, Assistant Professor in the Department of Zoology, Govt. P.G. College, Jagdalpur, Bastar, Chhattisgarh. His field of research interest is animal diversity, ecology of amphibians and herpetofauna. In recent years, he avidly explores the avifauna diversity in southern Chhattisgarh. Guide students in their project works. Dr. M. Khan, Assistant Professor in the Department of Zoology, Kalahandi University, Manikya Vihar, Bhawanipatna, Kalahandi, Odisha. Research interest is Cetacean diversity, population, behaviour, ecology of aquatic ecosystem, ecosystem services, Fish and Fisheries. Experienced in Crocodiles, Marine turtles and Migratory birds research. Guide undergraduate students in project work. Dr. P.R.S. Negi is a Veterinary Surgeon in Bastar Veterinary Hospital, Bastar, Chhattisgarh and dedicated to animals health issues with a passion for wildlife. His research interest is avifaunal diversity, captive/pet animal nutrition, health issues and monitoring prevalence zoonotic diseases. Mr. S. Durgam is a student of M. Sc Zoology from Govt. P.G. College, Jagdalpur, Bastar, Chhattisgarh and a resident of Bijapur district. He pursued his research-intern in this work. Has developed research interest to continue this study and survey on Vultures in Bijapur District of Chhattisgarh. Ms. S. Dutta is an undergraduate student from Institute for Excellence in Higher Education, Bhopal, Madhya Pradesh. She has keen passion and research aptitude for wildlife and conservation. She monitors avifaunal diversity of Bastar District.

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COMMUNICATION

A geographical assessment of Chariganga and Arpara Beel (wetlands) of Nadia, West Bengal as a habitat of wetland birds

Mehedi Hasan Mandal [1], Arindam Roy [2] & Giyasuddin Siddique [3]

[1] Department of Geography, Krishnagar Govt. College, Krishnagar, Nadia, West Bengal 741101, India.
[2,3] Department of Geography, The University of Burdwan, Burdwan, West Bengal 713104, India.
[1] hasanmhm86@gmail.com (corresponding author), [2] a.roy.sc@gmail.com, [3] gsbu2008@gmail.com

Abstract: The present study attempts to assess the impact of human intervention on the population, distribution, and habitat perspectives of the water birds found in and around Chariganga and Arpara 'Beel' wetlands, leftover channels of the River Bhagirathi. The point count method was adopted during field surveys conducted from April 2019 to March 2020. These wetlands are the natural habitats for 37 species of wetland birds belonging to 18 families and 11 orders, of which 26 species are residents, three are summer migrants, and eight are winter immigrants. The wetlands also harbour 10 bird species whose population is globally declining over the last few decades. Relative Diversity index unveils that among waterfowls Ardeidae is the dominant family. Species richness reaches its peak in winter, and is least during the monsoon. Empirical observation documented one Vulnerable (Greater Adjutant) and one Near Threatened (Black-Headed Ibis) species residing on the banks and adjoining paddy fields. Indiscriminate extraction of wetland products by local people, along with agricultural expansion towards the waterfront of the wetlands, has deteriorated the health of those wetlands and threatened the existence of waterbirds, especially shorebirds. Populations of 22 species living in water edge areas has changed conspicuously owing to cultural and economic activities of neighboring human groups. We suggest improving the ecological balance of the wetlands and restraining further degradation through proper management to preserve avian diversity.

Keywords: Arpara Beel, Avian diversity, Chariganga, relative diversity index, species richness, water birds.

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Author details: Mehedi Hasan Mandal, Assistant Professor, completed his M.Phil. from the University of Burdwan in 2017 on the dynamism of the oxbow lakes of Bhagirathi River. At present, he is engaged in assessing and enumerating the indigenous avian diversity and their ecological importance of the floodplain wetlands of Lower Ganges Basin, which has far been neglected by the locals due to ignorance. Arindam Roy is presently working as a Senior Research Scholar in the Department of Geography, the University of Burdwan. He has completed M.Sc. from the University of Calcutta in 2014 with certain expertise in environmental geography. Professor Giyasuddin Siddique has been working in the Department of Geography, the University of Burdwan, since 1999. He is keenly interested in field-based research on forests, ecology and many other contemporary environmental issues.

Author contributions: MHM, AR, and GS has collectively designed the study and collected the data/information through field investigation in different periods. MHM analyze the data and wrote the paper. AR and GS have also incorporated their inputs to improve the quality of the article. All authors read and approved the final manuscript.

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INTRODUCTION

Natural wetlands benefit nearby human communities and serve natural environments in various ways. Floodplain wetlands are among the most productive and species-rich lacustrine ecosystems (Kingsford et al. 2016). As an ecotone located between terrestrial and aquatic ecosystems, wetlands provide enriched habitat for numerous unique, rare, and threatened species of birds, mammals, fish, amphibians, insects, and plants (Stella et al. 2011; Garg 2015). Therefore, they are often judiciously considered as 'Ecological Hotspots' (Ward & Stanford 1995) or 'Biological Supermarkets' (Chen & Zhang 2001; Chen & Lu 2003). Among the sheltered species, water birds possess an important place because of their crucial ecological roles and very useful ecosystem services to the human communities (Bibi & Ali 2013).

The bird species directly or indirectly dependent upon the permanent or semi-permanent water bodies, either sweet or saline, for feeding, breeding and nesting may be grouped as water birds (Kumar & Gupta 2013). As a natural ally of wetland ecosystems, water birds help sustains the ecological balance of the habitats by performing various key functions (Mistry et al. 2008; Slabbekoorm & Ripmeester 2008). They occupy multiple trophic levels of grazing and aquatic food chain and maintain the diversity of other organisms with commensalism (Sharma & Saini 2014). They also help in pest control, propagule dispersal, and nutrient cycling, retarding potential disease outbreaks in and around the wetlands (Green & Elmberg 2014). Waterbirds have been one of the chief sources of feathers, meat and eggs (Krcmar et al. 2010), and they also contribute to cultural or religious values in different parts of the world (Kear 1990).

The habitat preference of birds depends upon various factors, including depth and quality of water, availability of food, nature of vegetation for shelter, degree of human intervention, and the presence of predators and inter-species competitors (Stewart 2001). Owing to their high mobility, birds react quickly to changes in habitat quality (Puri & Virani 2016), thus they are considered to be useful bio-indicators of ecosystem integrity, quality, health and productivity (Kumar & Gupta 2013; Mazumdar 2017). Recent worldwide loss and degradation of wetlands have conspicuously affected water birds through gradual shrinkage in the area and quality of their habitats.

India hosts diverse and unique waterbird species because of its diversity in topography and climate (Prasad et al. 2002). Several studies (Khan 2010; Rajashekara & Venkatesha 2010; Kumar et al. 2016; Kar & Debata 2018) have searched out in-depth accounts of avian species (especially winter migrants) of different wetlands of the country and also endeavored to trace the impact of human intervention on their abundance, density, distribution, and composition. The floodplain wetlands aligned on both sides of river Bhagirathi over the riparian tract of the lower Gangetic plain of West Bengal are a biologically prolific and rich repository of biological diversity (Mukherjee 2008). Various ornithological works have been carried out in different water bodies interspersed over the southern portion of the Bengal delta. The ecological diversity of two oxbow lakes (floodplain wetlands), located at the southeastern part of the Ganges delta has been comprehensively studied by Khan (2002), while the diversity of waterfowl at SantragachiJheel has been studied by Mazumdar et al. (2005). Further, Mazumdar et al. (2007) also assessed and enumerated the composition and diversity of migratory waterbirds in six different wetlands, namely, Nalban Bheri, Santragachi Jheel, Saheb Badh, Bakreshwar Barrage, Tilpara Barrage, and wetlands inside Ballavpur Wildlife Sanctuary of southern West Bengal. On the other hand, Mukhopadhyay & Mazumdar (2019) nicely presented the habitat-wise distribution of birds species in and around the lower Gangetic delta.

Despite facing immense anthropogenic pressures, these wetlands host a wide variety of 'wetland birds' species, both resident and migratory, throughout the year (Mazumdar & Saha 2016). There is a lack of complete accounts of the biological resources of those wetlands, except for Purbashali Lake (Chupi Beel) on the right bank of the river. As a wintering site for migratory birds, Chupi has drawn attention from scholars, whereas other wetlands, including the Arpara Beel and Chariganga, have failed to do so. The composition, distribution, diversity, abundance and threats of the water birds at Purbasthai Oxbow Lake have been extensively evaluated by various studies (Ganesan & Khan 2008; Chowdhury 2015; Ghosh 2016; Mandal 2017; Debnath et al. 2018; Mandal & Siddique 2018; Mandal et al. 2018). The ecological and economic significance of Arpara Beel and Chariganga wetlands is thus yet to be evaluated properly. This study aims to prepare a comprehensive checklist of the water birds found in and around these wetlands, and to assess bird abundance and the effects of human interventions in their habitat.

MATERIAL AND METHODS

Study area

Arpara Beel and Chariganga, two hook-shaped floodplain wetlands at the left bank of the river Bhagirathi in the moribund part of the Ganga Delta (Bagchi 1944) have been selected as the area under study. Given the administrative location, they are situated in the western part of Nakashipara Block of Nadia District, West Bengal (Figure 1). Given that geomorphological specificity, these wetlands are palaeochannels of river Bhagirathi and have been originated through dynamicity of lateral channel shifting with the simultaneous erosion-accretion process. Though direct connectivity with the Bhagirathi River keeps the Chariganga wetland perennial, its water cover area gets receded at dry seasons. The Arpara Beel, on the other hand, is semi-permanent since most of it dries up during summer. Delinked from the prime course of the river, this abandoned channel normally receives no inflow. Both wetlands achieve their full storage capacity only in the monsoon period, when they receive a massive influx of river water. Such spatiotemporal alterations have obvious impacts upon water birds, as well as on the availability and utility of ecosystem services offered by the lake.

Methods of data collection and analysis

Primary data on bird species in the wetlands were collected via frequent field visits and empirical observations once each month from April 2019 to March 2020. The counting process was carried out in the morning and afternoon (i.e., 0600–1000 h and 0400–0600 h) (Kumar & Sharma 2019) following the point count method (Issa 2019; Volpato et al. 2009). A comprehensive checklist of the birds encompassing their common (local) name, scientific name, taxonomic position (orders, families, and species), dispersal status, habitat location, status according to the International Union for Conservation of Nature and Natural Resources (IUCN), global trends of the population, was prepared, according to the works of Praveen et al. (2016), and Issa (2019). The birds are also classified into four sub-groups like Very Common (VC) (nearly 80–100 % during field visit), Common (Co) (50–79.9%), Fairly Common (FC) (20–49.9%), and Rare (Ra) (< 19.9%) based on the frequency of observation (Khan & Nahar 2009).

The relative abundance of bird species was computed with the help of the formula proposed by Torre-Cuadros et al. (2007):

$$RDi = \frac{n}{N} \times 100$$

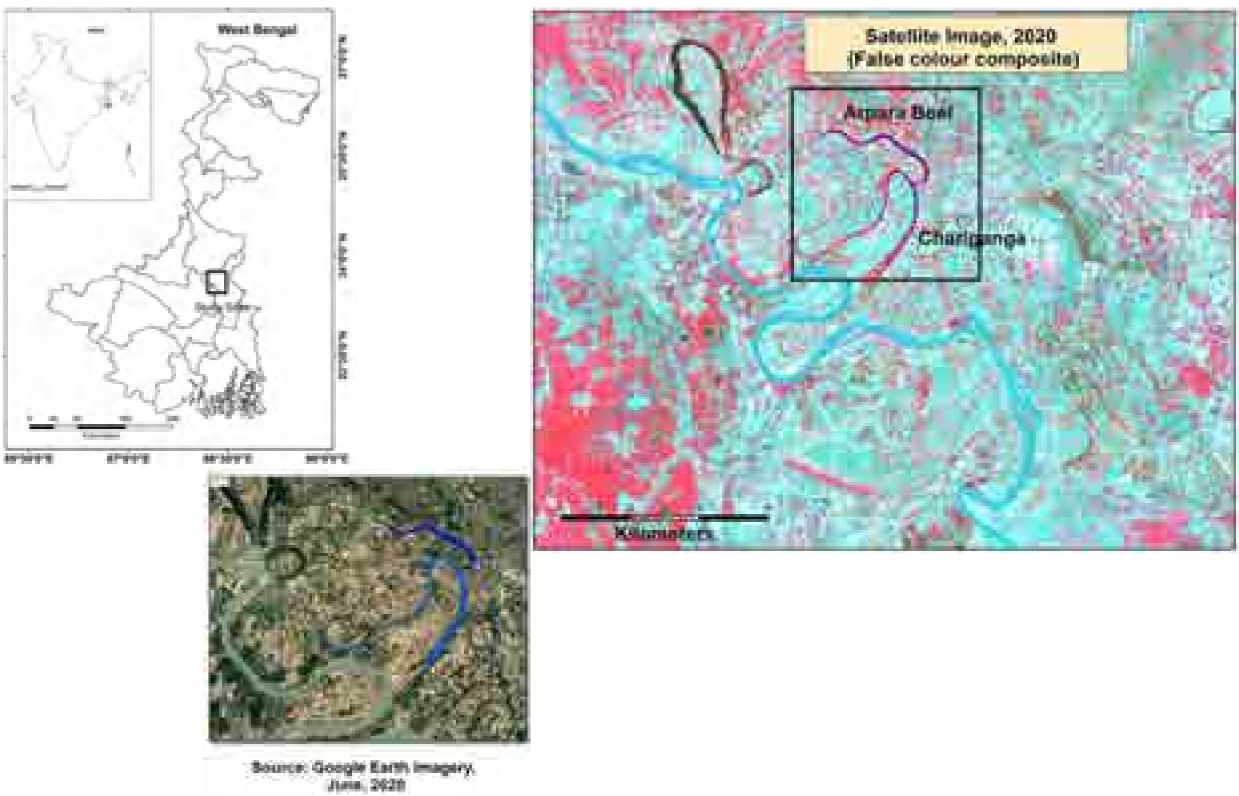

Figure 1. Location of the studied wetlands.

Where, n= Total number of birds in a species, and N= total number of birds across all species

One way ANOVA has been employed to find out the level of seasonal variation in species richness of birds after examining the normality of data through the Shapiro-Wilk test. The entire observation period has been divided into three prominent seasons, i.e., summer or pre-monsoon (April–May), monsoon (June–October), and winter or post-monsoon (November–March) for this purpose.

Subsequently, exhaustive interviews and focus group discussions were also carried out with the nearby people who frequently use these wetlands to assess the degree of people-wetland interdependence and to identify the consequent threats towards the wetlands as a habitat of the wetland birds.

RESULTS

Composition and relative abundance of water birds

Both the selected floodplain wetlands harbour diverse species of plants (hydrophytes) and animals, especially avifauna. These sweet water storages assure ample food and adequate shelter which attract a wide variety of resident waterbird species to settle here throughout the year. Besides, they provide favorable feeding ground to the migratory bird species, especially in the winter season. A total of 37 avian species from 18 families and 11 orders were observed and documented during the survey period, though distinctive variations in species composition between these two wetlands were also documented. All 37 species are found at Chariganga, while 21 species from 14 families were sighted in Arpara Beel. Several common water birds like Little Grebe, Grey Heron, Cotton Pygmy Goose, Yellow Bittern, Indian Black Ibis, Purple Swamphen (or Western Swamphen), White-breasted Waterhen, Indian (Common) Moorhen, and Common Snipe are noticeably less in number in the concerned wetland; moreover, the surveyors couldn't find any member of avian families like Podicipedidae, Rallidae, Scolopacidae, and Hirundinidae in Arpara Beel.

A checklist comprising the order, family, local name, scientific name, dispersal status, habitat location, abundance, IUCN status (2017) and the global trend of populations of the identified bird species is tabulated in Table 1.

The relative diversity of bird families found in both the wetlands is depicted in Figure 2. It has been found that Ardeidae is the most common and abundant family (RDi value: 21.62) which comprises eight species (three types of heron, four types of egrets, and one type of bittern). Followed by Rallidae and Alcedinidae with four species each, with an RDi value of 10.81). It is noticeable that the members of the Rallidae family were not found in and around Arpara Beel. Nearly nine avian families like Podicipedidae, Charidriidae, Scolopacidae, Accipitridae, Hirundinidae, Cisticolidae, Apodidae, Pandionidae, and Meropidae having only one species each have shown the least diversity (RDi value: 2.70) whereas six families' (i.e., Anatidae, Ciconidae, Jacanidae, Threskiornithidae, Phalacrocoracidae, and Motacillidae) represent moderate abundance with RDi value of 5.41 (Figure 2).

Status of water birds

The water birds identified at the selected wetlands have been categorized based on four criteria: A. dispersal status, B. habitat location, C. local abundance, D. trend of the global population, and E. IUCN conservation status.

Most of the wetlands in India provide shelters to a large variety of resident birds (Mukhopadhyay & Mazumdar 2017). The wetlands represent the same status as $3/4^{th}$ of the avifauna found in the area is resident. Among the 37 bird species, the number of winter migrant species are eight (21.62%) at Chariganga and 5 (13.51%) at Arpara Beel, whereas the three summer migrant species (8.11%) and two (5.41%) at Chariganga and Arpara Beel respectively. Common Snipe, Large Egret, White Wagtail, Citrine Wagtail are the common winter migrants found in the selected area. On the contrary, Lesser Whistling Duck and Cotton Pygmy-goose generally come during the summer season. Nowadays, they have even been reported in the winter season too. Besides, Egrets, Kingfishers, Pond Herons, Black-headed Ibis, Little Grebe, Bronze-winged Jacana, etc are the resident birds of the wetlands and they have frequently been seen during the field survey. The resident avian species comprises nearly 70.28% and 37.84% of the observed avifaunaat Chariganga and Arpara Beel, respectively (Figure 3).

Nearly 59.46% of bird species of Chariganga and 32.43% of Arpara Beel prefers to live in the banks of water bodies. Primarily, long-legged waders and shorebirds (like Asian Openbill, Grey Heron, Black-headed Ibis) have been found to wade in the muddy or sandy bank areas in search of food. Often, they have been observed in the adjoining paddy fields too. On contrary, almost 13.51% and 5.41% of avian species (like Lesser Whistling Duck, Cotton Pygmy-goose, Little Grebe, Indian Cormorant, and Little Cormorant), respectively, in Chariganga and Arpara Beel have been recorded in open water. Remaining birds species (like Palm Swift and various Kingfishers) generally reside in the nearby trees and shrubs, which constitute

Figure 2. Relative diversity of the bird families recorded in and around Chariganga and ArparaBeel during April 2019 to March 2020.

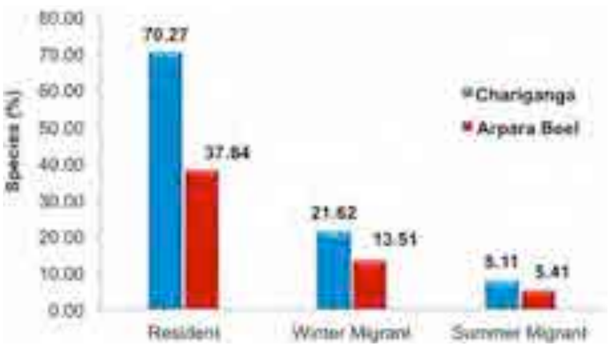

Figure 3. Dispersal Status of the wetlands' birds found in and around Chariganga and ArparaBeel during April 2019 to March 2020.

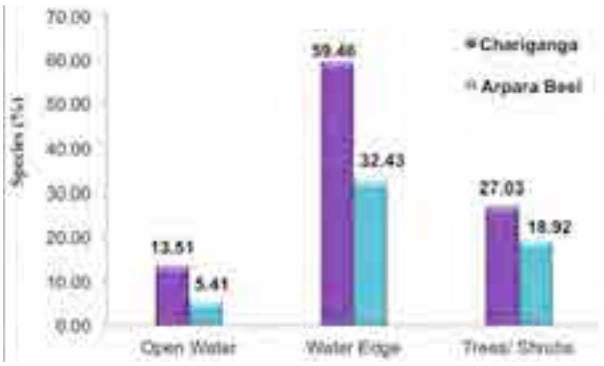

Figure 4. Habitat location of the wetlands' birds found in and around Chariganga and Arpara Beel during April 2019 to March 2020.

nearly 27.03% and 18.92% of identified species of the selected wetlands respectively (Figure 4).

Figure 5 shows the abundance status of recorded species. The proportion of birds in four abundance categories at Chariganga are: 30% Very Common, 13% Common, 30% Fairly Common, and 27% Rare. In Arpara Beel the distribution among these categories was 19%, 11%, 11%, and 16%, respectively, while 43% of available birds were rarely seen during the survey.

Among recorded species 27% of birds at Chariganga and 16% at Arpara Beel have shown negative trends in global population, whereas 11% and 5.4% of birds in the wetlands have shown a positive trend worldwide. Ten species found in the area have shown a gradual decrease in their global population over the past years. Therefore, the importance of the wetlands is irrefutable as the abode of globally declining species. Further, it is worth mentioning that the growth trends of the population are still unspecified at the global level, which is 57% and 30% of the birds at Chariganga and Arpara Beel, respectively (Figure 6).

As stated earlier, the studied wetlands harbor various unique as well as endangered avian species. One classic example is Greater Adjutant, found at both the wetlands, and which has been enlisted as Vulnerable by the IUCN in 2017. The Black-headed Ibis, fall under the Near Threatened category of IUCN (2017), which has also been observed at both of the wetlands.

Temporal variation of bird species

The acquired result of One way ANOVA has depicted highly significant variation (p-value <0.001 at 0.05 significance level) in the seasonal species richness for both the wetlands. The month-wise variation of

Table 1. Checklist of bird species found in and around the studied wetlands during April 2019 to March 2020.

Order	Family	Species/ Common name	Scientific name	Chariganga	Arpara Beel	Dispersal Status	Habitat Location	Abund-ance	IUCN status	Global Population Trend
Podicipediformes	**Podicipedidae**	Little Grebe	*Tachybaptus ruficollis*	√	X	R	OW	VC	LC	↓
Pelecaniformes	**Phalacrocoracidae**	Indian Shag	*Phalacrocorax fuscicollis*	√	√	WM	OW	C	LC	?
		Little Cormorant	*Microcabro niger*	√	X	R	OW	VC	LC	?
	Ardeidae	Grey Heron	*Ardea cinerea*	√	X	R	WE	FC	LC	?
		Indian Pond Heron	*Ardeola grayii*	√	√	R	WE	VC	LC	?
		Night Heron	*Nycticorax nycticorax*	√	√	R	WE	FC	LC	↓
		Cattle Egret	*Bubulcus ibis*	√	√	R	WE	VC	LC	↑
		Intermediate Egret	*Ardea intermedia*	√	√	WM	WE	C	LC	↓
		Great Egret	*Ardea alba*	√	X	WM	WE	FC	LC	?
		Little Egret	*Egretta garzetta*	√	X	R	WE	VC	LC	↑
		Yellow Bittern	*Ixobrychus sinensis*	√	X	R	WE	FC	LC	?
	Threskiornithidae	Indian Black Ibis	*Pseudibis papillosa*	√	X	R	WE	R	LC	↓
		Black-headed Ibis	*Threskiornis melanocephalus*	√	√	R	WE	R	NT	↓
Ciconformes	**Ciconidae**	Asian Openbill Stork	*Anastomus oscitans*	√	√	WM	WE	VC	LC	?
		Lesser Adjutant	*Leptoptilos javanicus*	√	√	R	WE	R	VU	↓
Anseriformes	**Anatidae**	Cotton Pigmy-goose	*Nettapus coromandelianus*	√	X	SM	OW	C	LC	?
		Lesser Whistling Duck	*Dendrocygna javanica*	√	√	SM	OW	VC	LC	↓
Gruiformes	**Rallidae**	Water Cock	*Gallicrex cinerea*	√	X	R	WE	FC	LC	?
		Purple Swamphen	*Porphyrio porphyrio*	√	X	R	WE	R	LC	?
		White-breasted Waterhen	*Amaurornis phoenicurus*	√	X	R	WE	FC	LC	?
		Indian Moorhen	*Gallinula chloropus*	√	X	WM	WE	R	LC	?
Charadriifofmes	**Jacanidae**	Bronze-winged Jacana	*Metopidius indicus*	√	√	R	WE	VC	LC	?
		Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	√	√	SM	WE	C	LC	↓
	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	√	√	R	WE	R	LC	?
	Scolopacidae	Common Snipe	*Gallinago gallinago*	√	X	WM	WE	FC	LC	?
Passeriformes	**Hirundinidae**	Barn Swallow	*Hirundorustica*	√	X	R	T	FC	LC	↓
	Motacillidae	White Wagtail	*Motacilla alba*	√	√	WM	WE	FC	LC	→
		Citrine Wagtail	*Motacilla citreola*	√	√	WM	WE	R	LC	↑
	Cisticolidae	Plain Prinia	*Prinia inornata*	√	√	R	T	C	LC	?
Coraciiformes	**Alcedinidae**	Pied Kingfisher	*Ceryle rudis*	√	√	R	T	VC	LC	?
		Common Kingfisher	*Alcedo atthis*	√	√	R	T	VC	LC	?
		Stork-billed Kingfisher	*Pelargopsis capensis*	√	X	R	T	R	LC	↓
		White-breasted kingfisher	*Halcyon smyrnensis*	√	X	R	T	VC	LC	↑
Accipitriformes	**Accipitridae**	Indian Shikra	*Accipiter badius*	√	√	R	T	R	LC	→
	Pandionidae	Osprey	*Pandion haliaetus*	√	√	R	T	R	LC	?
Coraciiformes	**Meropidae**	Green Bee-eater	*Merops orientalis*	√	√	R	T	FC	LC	?
Apodiformes	**Apodidae**	Asian Palm Swift	*Cypsiurus balasiensis*	√	√	R	T	FC	LC	?

Dispersal status: R—Resident | SM—Summer Migrant | WM—Winter Migrant | Habitat Location: OW—Open Water | WE—Water Edge | T—Trees and Shrubs | Abundance: VC—Very Common | C—Common | FC—Fairly Common | R—Rare | IUCN Status: LC—Least Concern | NT—Near Threatened | VU—Vulnerable | Trend: ?—Unknown | ↑—Increasing | ↓—Decreasing | →—Stable.

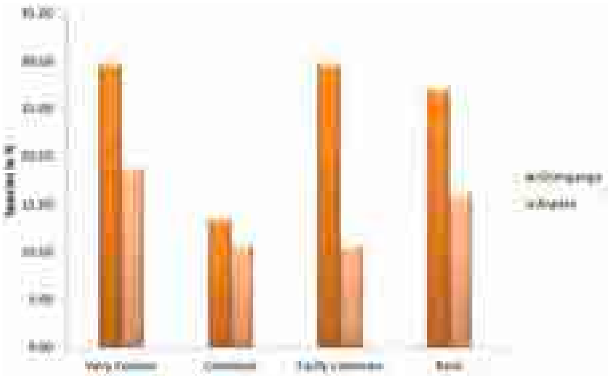

Figure 5. Local abundance status of the wetlands' birds found in and around Chariganga and Arpara Beel during April 2019 to March 2020.

Figure 6. Global trend of population of the wetlands' birds found in and around Chariganga and Arpara Beel during April 2019 to March 2020.

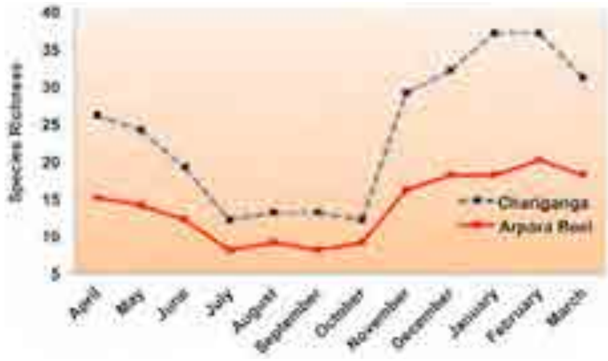

Figure 7. Month wise Variation of Species Richness of the wetlands' birds found in and around Chariganga and Arpara Beel during April 2019 to March 2020.

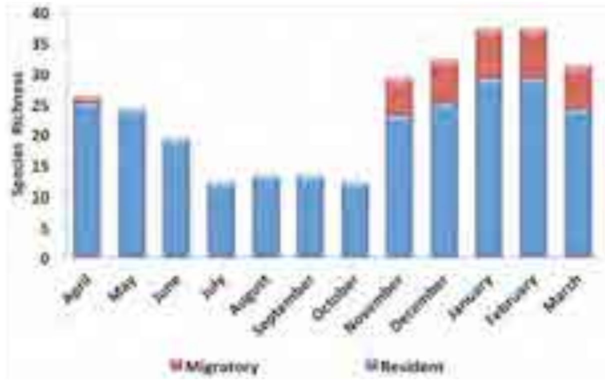

Figure 8. Influence of Winter Migrants in Species Richness of the wetlands' birds found in and around Chariganga and Arpara Beel during April 2019 to March 2020.

abundance of birds species in both the wetlands has been shown in Figure 7. It reveals that the species richness of both the wetlands is comparatively higher during the winter season (November to February), which declines during the monsoon period. A mild but fair inflow of winter migratory birds naturally enhances the species affluence as well as the birds' population (Figure 8). The species richness in Chariganga reaches its crest (N= 37) during January and February, whereas the least richness (N= 12) has been recorded in July and October. Similarly, the maximum and minimum abundance of birds' species at Arpara Beel has been observed in February (N= 20) and months of July and September (N= 8), respectively.

DISCUSSION

The availability of food, preference of habitat location, area of food collection and wading, depth and quality of water, presence of hydrophytes, and nature of the habitat have determined the temporal variation of abundance as well as species richness (Saygili et al. 2011) in and around the lakes under study. The waterfowls of the Anatidae family prefer deep, open water areas clear from submerged/floating hydrophytes (Benoit & Askins 1999; Kumar & Sharma 2019), while the Jacanidae family requires plenty of floating vegetation for food and shelter (Grimmet et al. 2011). Naturally, their occurrences are less and spatially more confined within the habitat. Thus the relative abundance of some birds' families, i.e., Ardeidae, Rallidae, and Alcedinidae is comparatively higher than others in both of the wetlands. Moreover, human activities adversely affect and restrict the abundance of some families like Charidriidae, Scolopacidae, Motacillidaeetc (Mandal & Siddique 2018). The abundance of Swamphens, wagtails and waders is controlled by the availability of food at the nearby agricultural fields (Ringelman 1990). As the average depth in most parts of these wetlands decreases the availability of invertebrates increases (Murkin &

Kadlec 1986), which attracts various birds like egrets and herons of the Ardeidae family, for which the family has recorded its higher abundance. The abundance of Common Moorhen and White-breasted Waterhen birds of the Rallidae family is high at Chariganga because a large part of the water body is covered with dense water hyacinth, water lily, and various types of weeds that attract those birds. But, in the case of Arpara Beel, the Rallidae family is absent, as the maximum part of the wetland either contains shallow water or has been altered into the land (Image 1).

The species richness in both of the wetlands reached its maximum in the winter season due to the arrival of migratory birds. Generally, the winter migrants came into the area in November and some of the species reside here till the end of April. The following diagram (Figure 8) illustrates how the species richness gets influenced by thewinter migrants. But, the utilization of the wetlands for 'boro' (winter paddy) production significantly interrupts the arrival of migratory birds (Image 2).

The massive influx of river water and precipitation in the monsoon helps the full storage condition of the water bodies. Even the low lands, agricultural fields, and shallow surface depressions in and around the selected wetlands often get inundated under stagnant water. Thus, the habitat area of the resident bird's species has seasonally expanded due to the creation of new/ alternative living spaces. The bird's species spread over the vast areas, which has naturally reduced their density in the concerned lake areas. Therefore least species richness has been enumerated during the monsoon months (June to October). On the contrary, the majority of smaller wetlands become dried up in summer, and various birds species gather at the larger wetlands. The water areas become confined in some definite spots (portions) of the wetlands during dry spells (summer and winter) of the year. Under such peculiar circumstances, the gathering of birds' species becomes restricted near the water dots of the wetlands. During this period, summer migrants like Lesser Whistling Duck, Cotton Pygmy Goose, and Pheasant-tailed Jacanas arrive in these wetlands.

Nearly half of the world's wetlands have been lost in the 20th century, and the remaining face serious threats by anthropogenic interventions (Fraser & Keddy 2005). Such loss and degradation have negatively affected the population and distribution of water birds, as they greatly depend upon the wetland habitats for survival (Ma et al. 2010). Since their origin, the concerned wetlands have been rapidly modified by the diverse socio-economic activities of the nearby human group. Focus group discussions and field surveys unveil that these wetlands provide an array of ecosystem services, from provisioning material resources to intangible cultural services, which put a significant impact on the economic and cultural livelihood patterns of the local people. Mandal et al. (2020) have identified 33 ecosystem services (encompassing eight provisioning, 10 regulating, five cultural, and 11 supportive services), extended by these selected wetlands. The local people interact with the wetlands in 13 ways to collect the benefits of the ecosystem services. They have acquired various wetland products like green leafy vegetables, fish, freshwater, forage, fuel, medicinal herbs, humus, and mud. The agrarian community of the area utilizes the wetlands as chief sources of irrigation and often uses the shallow bank areas as crop fields or seedbeds. As a result the collection and extraction of wetland ecosystem services by local people adversely affect the wetlands as the habitat of water birds. But the utilization pattern has shown distinctive changes during the dry and wet spell of the year with the seasonal transformation of the lakes. Both the wetlands have turned into the rich fishing ground during monsoon days with the significant influx of water from the river Bhagirathi, while maximum portions of these two lakes become dried up during dry spells of the year. In such a situation, the local farmers have temporarily altered a considerable proportion of these wetlands into agricultural fields by encroaching and reclaiming the area of the wetlands. Such man-made seasonal transformation destroys the ecological setting of the habitat and has posed serious threats to the existence of the floral and faunal community, especially the avifauna (Image 3).

Over extraction of provisioning, resources have intensified the human pressure, which has diminished the suitability of those lakes as the abode of the birds. As a large part of the ArparaBeel dries up in summer, every exposed and accessible part of the wetland is used for cultivation and grazing purposes. Similarly, a significant part of the submerged bank Chariganga has now been reclaimed and is used by the locals for cropping. Even, a remarkable portion of these two wetlands has been transformed into agricultural and pastoral land perpetually and the water areas have gradually been shrunk. For example, the water cover area of Chariganga has been reduced from 1.45 km^2 in 2010 to 1.05 km^2 in 2020, whereas the areal coverage of Arpara Beel has been reduced from 0.69 km^2 to 0.52 km^2 in 2020 due to anthropogenic interventions.

Such human-induced artificial alteration of the transitional areas has damaged the ecological niche of

Image 1. A & B showing habitat status of Chariganga, filled with water hyacinth and weeds, helps birds to settle, whereas C & D showing habitat status of Arpara Beel, used as pasture land and agricultural filed. © Authors.

the water birds, especially of the waders. It has brought profound adverse effects on the population and species diversity of the bird community. Once, Arpara Beel served the local people with various ecosystem services. Human intervention to grab that service led to serious damage to the wetland. As a result Arpara Beel now does not produce many resources for human beings except agricultural land and pastoral ground. Moreover, it has lost its quality as a habitat of avifauna thus the species richness of waterbirds is less in comparison to Chariganga Beel. In a similar way jute retting, wetland agriculture, the transformation of parts of Chariganga as pasture land, acting as garbage disposal center, pollution from pesticides coming from surrounded crop fields,etc are major threats to Chariganga Wetland. Local people have opined that the abundance of birds has gradually declined over time in the case of Chariganga also. The numbers of diverse bird species seen in winter are also reduced in number for enhanced human intervention, compared to the earlier phases of evolution of the concerned wetland. Though species richness is higher at Chariganga, it is now under tremendous pressure of human intervention which should be controlled otherwise Chariganga wetland will be a lost habitat for water birds.

CONCLUSION

The present study highlights the importance of the two selected wetlands as a habitat of residents as well as migratory birds species. But, fragmentation of the habitat by human encroachment and pressures has threatened the existence of the local birds. Recent agricultural extension, as well as arbitrary extraction of wetland resources, is instrumental to the tremendous degradation of those wetlands, which has posed a conspicuous impact upon the size, richness, and distribution of the birds' species. Predominantly, the bank areas have now been altered into the zone of

Image 2. A & B *Boro* cultivation at Arpara Beel. © Authors.

Image 3. Human encroachment and habitat alteration at both the wetlands in the dry period: A & B Arpara Beel; C & D Chariganga Beel. © Authors.

human-birds conflict. Thus the ecological setup of such areas has been disrupted which has directly been consequent upon the avian species. The importance of the resident birds in maintaining local ecological equilibrium should not be denied rather appreciated. Thus their habitat needs to be conserved essentially with a sustainable management plan that would benefit both the birds and the other stakeholders of the wetlands.

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COMMUNICATION

Phenotypic plasticity in *Barilius vagra* (Hamilton, 1822) (Teleostei: Danionidae) from two geographically distinct river basins of Indian Himalaya

Sumit Kumar [1], Sharali Sharma [2] & Deepak Singh [3]

[1–3] Freshwater Biodiversity Laboratory, Department of Zoology, H.N.B. Garhwal University, Srinagar (Garhwal), Uttarakhand 246174, India.
[1] sumitsharmaraina2109@gmail.com, [2] sharmashanali@gmail.com, [3] bhandaridrdeepak5@gmail.com (corresponding author)

Abstract: Truss-based morphometric analysis was used to examine phenotypic plasticity of *Barilius vagra* (Hamilton, 1822) inhabiting the tributaries of the Alaknanda (Ganga River basin) and Chenab (Indus River basin), two geographically distinct river basins in the Indian Himalaya. Fourteen landmarks were connected to generate a truss network of 90 parameters on the body of fish. Eighty morphometric traits out of ninety morphometric measurements explained statistically significant difference among six sampling locations of *Barilius vagra* from streams in the Alaknanda and Chenab basins. Discriminant function analysis revealed 82% of *Barilius vagra* specimens originally classified into their own groups. 95% of the variance was explained by 13 principal components. Morphometric characters (1–6, 1–13, 2–5, 2–6, 2–14, 3–6, 4–6, 4–14, 6–12, 7–8, 7–9, 10–11, and 13–14) contributed greatly in differentiation of *B. vagra* populations from different river basins. The Alaknanda basin reflected some mixing within populations, which may be due to common environmental conditions and fish migration in these streams. This study will be helpful in framing site-specific conservation and management strategies, such as net mesh size selection, avoiding overexploitation, stock augmentation and food availability for different fish populations.

Keywords: Danionidae, DFA, differentiation, morphometry, truss network.

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Author details: Dr. Sumit Kumar—presently working as wildlife biologist (fish) in a research project at Wildlife Institute of India, Dehradun. Dr. Sharali Sharma—specialization in fishery science and presently working as Assistant Professor in Zoology at the Chandigarh University, Chandigarh, Punjab. Dr. Deepak Singh—working as an Associate Professor at the HNB Garhwal University, Srinagar (Garhwal).

Author contributions: SK—collected and analysed the data for the present study. SS—helped during sampling of fishes and contributed in writing the manuscript. DS—supervised during the whole study, checked the manuscript and helped in data analysis and interpretation.

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INTRODUCTION

Phenotypic plasticity is the ability of an organism to change especially in response to varying environmental conditions (Sahoo et al. 2020). Long term geographic isolation and limited migration causes phenotypic plasticity among the population within a species (Cadrin 2005). The Alaknanda and Chenab rivers drained from the Indian Himalaya are geographically isolated and rich in fish fauna.

Fishes show higher degree of variation within and between populations than other vertebrates, and they are more susceptible to environmentally induced morphological variation (Wimberger 1992). It has been suggested that the morphological characters of fish are determined by environment, genetic and interaction between them (Poulet et al. 2004). During the early development stages the individual's phenotype is more amenable to environment influence (Pinheiro et al. 2005). The phenotypic variability may not necessarily reflect population differentiation at genetic level (Ihssen et al. 1981). A sufficient degree of isolation may result in notable phenotypic and genetic differentiation among fish populations within a species, as a basis for separation and management of distinct populations (Turanet al. 2004).

Among the various tools used for stock assessment and phenotypic plasticity, morphometry is one of the frequently used and cost-effective tools. Traditional multivariate morphometrics, accounting for variation in size and shape have successfully discriminated between many stocks (Turan 1999). As the traditional morphometric measurements have biased coverage and metric selection over the body structure of fishes under experimentation, this method might not be useful for discriminate species when there is morphological plasticity (Takács et al. 2016). However, with the time this traditional method has been enhanced by image processing technique which is more effective in description of shape and stock identification (Mir et al. 2013).

Advance tool kits such as truss network system and geometric morphometrics is the best alternative used to study phenotypic plasticity within and between species (Turan 1999). Truss morphometric approach is an effective method for capturing information about the shape of an organism (Cavalcanti et al. 1999). It has been used to identify stocks of many fish species from marine and fresh waters (Sajina et al. 2011; Garcia-Roudriguez et al. 2010; Sen et al. 2011; Khan et al. 2012; Miyan et al. 2015, Dwivedi et al. 2019). Different stocks identified on the basis of environmentally induced morphometric variations play a significant role in the fisheries management (Begg et al. 1999). Insufficient knowledge on the population structure hinders the rate of production and reduces yields (Cadrin 2005). Good knowledge and right information of fish stocks will help us in the proper management and conservation of endangered species and stock enhancement of cultivable species.

Bariline fishes belonging to family Danionidae are characterized by a compressed body, blue-black bars or spots on the body and dorsal fin inserted behind the middle of the body (Rahman, 1989). Thirty-two bariline species are reported globally out of which 23 species so far reported from India (Singh et al. 2016). The species of genus *Barilius* including *Barilius vagra* (Hamilton, 1822) are commonly called hill trouts. These minnows inhabit both shallow lentic and lotic waters of Himalayan region (Sahoo et al. 2009). The hill stream fishes are important part of food as well as source of income to the fishermen of the Himalayan region (Kumar & Singh 2019). There are a few studies available on the population structure of *Barilius bendelisis* (Mir et al. 2015; Saxsena et al. 2015; Kumar & Singh 2019). However, there is paucity of published information on the population structure of *Barilius vagra* from Indian waters. Therefore, the present study was carried out with the objective to examine the phenotypic plasticity among the different populations of *B. vagra* from two distinct river basins of Indian Himalaya.

MATERIALS AND METHODS

Sampling and Measurements

Total 257 *Barilius vagra* specimens were sampled from Alaknanda River basin (132 specimens) and Chenab River basin (125 specimens) of Indian Himalaya using different fishing gears (cast nets and gill nets) from March 2015 to April 2017. The GPS coordinates; altitude and number of samples from each site of two river basins are presented in Table 1. The specimens of *Barilius vagra* were collected before the breeding season and after the spawning period (April to June) to avoid a bias towards size difference. The fish specimens were identified by using identification keys of Mirza (1991), Talwar & Jhingran (1991), and Kullander et al. (1999). After image capture, each fish was dissected for sex determination by macroscopic examination of the gonads. The gender was used as the class variable in ANOVA to test for significance difference in morphometric characters, if any, between male and female of *B. vagra*.

The truss network system described by Strauss & Bookstein (1982) was used to extract the 90 morphometric measurements of fish. Fish specimens were placed on water resistant graph paper as background and a digital camera of (Nikon D3400) was used to take the photographs (Figure 1) from same height and angle. Some specimens were submitted to the animal museum of the Department of Zoology of H.N.B. Garhwal University, Uttarakhand and others were fixed in 10% formalin solution for preservation.

The truss protocol used for the hill trout in the present study was based on 14 landmarks and the truss network constructed by interconnecting them to form a total of 90 truss measurements (Figure 1). The extraction of truss distances from the digital images of specimens was conducted using linear combination of three softwares, tpsUtil, tpsDig2 v2.1 (Rohlf 2006) and Paleontological Statistics (PAST) (Hammer et al. 2001).

Data analysis

Size dependent variations in truss measurements were removed, using the equation given by Elliott et al. (1995) as "$M_{adj} = M (L_s/L_0)^b$" Here M_{adj}, is size adjusted measurement, M is original measurement of length, L_0 is standard length of fish, L_s the overall mean standard length, and *b* slope of the regression of log M on log L_0 which is estimated for each character from the observed.

Univariate analysis of variance (ANOVA) was applied to 90 morphometric characters to evaluate the significance of difference among the mean values of the individual morphological character among different six populations of *B. vagra*. The characters expressing significant differences were subjected to the discriminant function analysis (DFA) and principal component analysis (PCA). The principal component analysis helps in morphometeric data reduction (Veasey et al. 2001), in decreasing redundance among the variables (Samaee et al. 2006) and in extracting a number of independent variables for population differentiation (Samaee et al. 2009). The standardized coefficients are used to compare variables measured on different scales. Coefficients with large absolute values correspond to variables with greater discriminating ability.

The DFA was used to calculate the percentage of correctly classified (PCC) fish. The Wilks' lambda test of DFA was used to compare the differences between six populations, each three of which were collected from two geographically distinct river basins of Indian Himalaya. Statistical analysis for morphometric data were performed using the SPSS (ver. 16.1) and Microsoft Excel 2007.

List of extracted 90 truss generated morphometric measurements of *Barilius vagra*.

	Landmark No.	Particulars of Truss distance
1	1–2	Tip of snout to the anterior border of eye
2	1–3	Tip of the snout to the posterior border of eye
3	1–4	Tip of snout to the posterior border of operculum
4	1–5	Tip of snout to end of frontal bone
5	1–6	Tip of snout to pectoral fin origin
6	1–7	Tip of snout to dorsal fin origin
7	1–8	Tip of snout to pelvic fin origin
8	1–9	Tip of snout to dorsal fin termination
9	1–10	Tip of snout to origin of anal fin
10	1–11	Tip of snout to termination of anal fin
11	1–12	Tip of snout to dorsal side of caudal peduncle
12	1–13	Tip of snout to ventral side of caudal peduncle
13	1–14	Tip of snout to termination of lateral line
14	2–3	Anterior border of eye to posterior border of eye
15	2–4	Anterior border of eye to posterior border of operculum
16	2–5	Anterior border of eye to end of frontal bone
17	2–6	Anterior border of eye to pectoral fin origin
18	2–7	Anterior border of eye to dorsal fin origin
19	2–8	Anterior border of eye to pelvic fin origin
20	2–9	Anterior border of eye to dorsal fin termination.
21	2–10	Anterior border of eye to origin of anal fin
22	2–11	Anterior border of eye to termination of anal fin
23	2–12	Anterior border of eye to dorsal side of caudal peduncle
24	2–13	Anterior border of eye to ventral side of caudal peduncle
25	2–14	Anterior border of eye to termination of lateral line
26	3–4	Posterior border of eye to posterior border of operculum
27	3–5	Posterior border of eye to end of frontal bone
28	3–6	Posterior border of eye to pectoral fin origin
29	3–7	Posterior border of eye to dorsal fin origin
30	3–8	Posterior border of eye to pelvic fin origin
31	3–9	Posterior border of eye to dorsal fin termination
32	3–10	Posterior border of eye to origin of anal fin
33	3–11	Posterior border of eye to termination of anal fin
34	3–12	Posterior border of eye to dorsal side of caudal peduncle
35	3–13	Posterior border of eye to ventral side of caudal peduncle
36	3–14	Posterior border of eye to termination of lateral line
37	4–5	Posterior border of operculum to end of frontal bone
38	4–6	Posterior border of operculum to pectoral fin origin
39	4–7	Posterior border of operculum to dorsal fin origin
40	4–8	Posterior border of operculum to pelvic fin origin
41	4–9	Posterior border of operculum to dorsal fin termination
42	4–10	Posterior border of operculum to origin of anal fin
43	4–11	Posterior border of operculum to termination of anal fin
44	4–12	Posterior border of operculum to dorsal side of caudal peduncle.

	Landmark No.	Particulars of Truss distance
45	4–13	Posterior border of operculum to ventral side of caudal peduncle
46	4–14	Posterior border of operculum to termination of lateral line
47	5–6	End of frontal bone to pectoral fin origin
48	5–7	End of frontal bone to dorsal fin origin
49	5–8	End of frontal bone to pelvic fin origin
50	5–9	End of frontal bone to dorsal fin termination
51	5–10	End of frontal bone to origin of anal fin
52	5–11	End of frontal bone to termination of anal fin
53	5–12	End of frontal bone to dorsal side of caudal peduncle
54	5–13	End of frontal bone to ventral side of caudal peduncle
55	5–14	End of frontal bone to termination of lateral line
56	6–7	Pectoral fin origin to dorsal fin origin
57	6–8	Pectoral fin origin to pelvic fin origin
58	6–9	Pectoral fin origin to dorsal fin termination
59	6–10	Pectoral fin origin to origin of anal fin
60	6–11	Pectoral fin origin to termination of anal fin
61	6–12	Pectoral fin origin to dorsal side of caudal peduncle
62	6–13	Pectoral fin origin to ventral side of caudal peduncle
63	6–14	Pectoral fin origin to termination of lateral line
64	7–8	Dorsal fin origin to pelvic fin origin
65	7–9	Dorsal fin origin to dorsal fin termination
66	7–10	Dorsal fin origin to origin of anal fin
67	7–11	Dorsal fin origin to termination of anal fin
68	7–12	Dorsal fin origin to dorsal side of caudal peduncle
69	7–13	Dorsal fin origin to ventral side of caudal peduncle
70	7–14	Dorsal fin origin to termination of lateral line
71	8–9	Pelvic fin origin to dorsal fin termination
72	8–10	Pelvic fin origin to origin of anal fin
73	8–11	Pelvic fin origin to termination of anal fin
74	8–12	Pelvic fin origin to dorsal side of caudal peduncle
75	8–13	Pelvic fin origin to ventral side of caudal peduncle
76	8–14	Pelvic fin origin to origin of anal fin
77	9–10	Dorsal fin termination to origin of anal fin
78	9–11	Dorsal fin termination to termination of anal fin
79	9–12	Dorsal fin termination to dorsal side of caudal peduncle
80	9–13	Dorsal fin termination to ventral side of caudal peduncle
81	9–14	Dorsal fin termination to termination of lateral line
82	10–11	Origin of anal fin to termination of anal fin
83	10–12	Origin of anal fin to dorsal side of caudal peduncle
84	10–13	Origin of anal fin to ventral side of caudal peduncle
85	10–14	Origin of anal fin to termination of lateral line
86	11–12	Termination of anal fin to dorsal side of caudal peduncle
87	11–13	Termination of anal fin to ventral side of caudal peduncle
88	11–14	Termination of anal fin to termination of lateral line
89	12–13	Dorsal side of caudal peduncle to ventral side of caudal peduncle
90	13–14	Ventral side of caudal peduncle to termination of lateral line

Table 1. GPS coordinates of sites from Alaknanda and Chenab River basins.

Sampling site	Sample size	Latitude (°N)	Longitude (°E)	Altitude (m)
Dugadda	42	30.26	78.72	740
Khankhara	46	30.23	78.93	668
Khandah	44	30.19	78.78	718
Dudhar	40	32.92	75.03	486
Jhajar	46	32.87	74.99	555
Jhuni	39	32.89	75.95	754

RESULTS

The morphometric characters between two sexes of *B. vagra* did not differ significantly (p >0.05), hence the data for both sexes were pooled for all subsequent analysis. Univariate analysis of variance (ANOVA) extracted eighty morphometyric measurements having significant differences (p <0.05) and 10 measurements (1–7, 2–4, 3–4, 3–7, 4–5, 5–7, 7–12, 7–13, 8–9, and 9–11) did not show significant differences among six populations of *B. vagra*. Principal component analysis (PCA) of these significant measurements extracted 13 principal components having eigenvalues greater than one (Figure 2) explaining cumulative variance of 94.79%. The first principal component (PC1) accounted for 21.55% of the variation followed by 18.62%, 13.86%, 8.01%, and 6.52% variance, respectively by second, third, fourth, and fifth principal component (Table 2). Forward stepwise discriminant analysis of the significant variables produced five discriminant functions (DFs). The first, second, third, fourth and fifth discriminant functions explained 68.4%, 18.4%, 6.8%, 5.1%, and 1.3% of variance, respectively (Table 3). Plotting DF1 and DF2 showed clear specimen differentiation of stocks from different tributaries, Dudhar, Jhajjar, and Jhuni streams of Chenab River basin. However; slight intermingling in the population of *Barilius vagra* from three different tributaries, Dugadda, Khandah, and Khankhra of Alaknanda river basin was also noticed (Figure 3).

Thirteen truss morphometric measurements 1–6, 1–13, 2–5, 2–6, 2–14, 3–6, 4–6, 4–14, 6–12, 7–8, 7–9, 10–11, and 13–14 contributed largely in the discriminant function analysis of *B. vagra* (Table 4). A total of 81.7% of specimens of *Barilius vagra* were classified into their original groups. Maximum 87.0% and minimum 76.2% of the specimens were found in their own groups of Khankhra and Dugadda streams, respectively from the Alaknanda river basin (Table 5). Some mixing in the

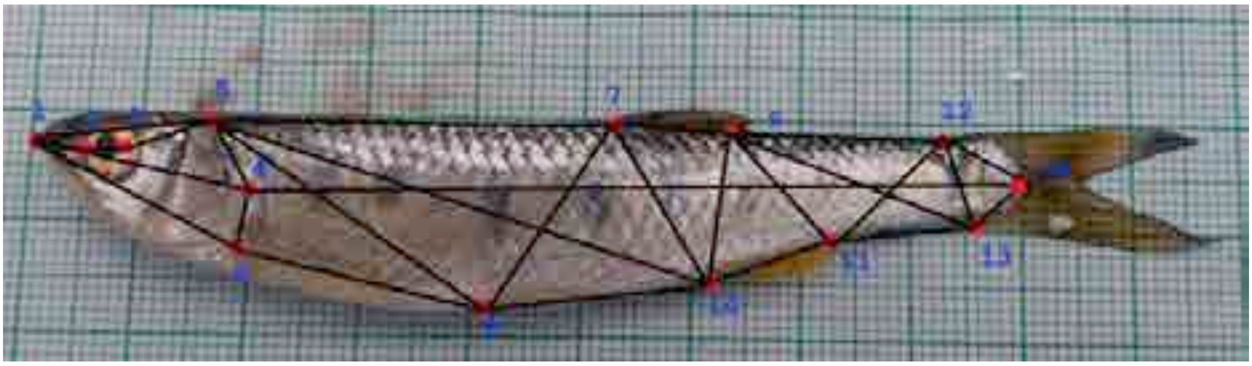

Image 1. *Barilius vagra* showing 14 morphometric landmarks and truss network: 1—Tip of snout | 2—end of eye towards mouth | 3—end of eye towards tail | 4—end of operculum | 5—forehead (end of frontal bone) | 6—dorsal origin of pectoral fin | 7—origin of dorsal fin | 8—origin of pelvic fin | 9—termination of dorsal fin | 10—origin of anal fin | 11—termination of anal fin | 12—dorsal side of caudal peduncle | 13—ventral side of caudal peduncle | 14—end of lateral line.

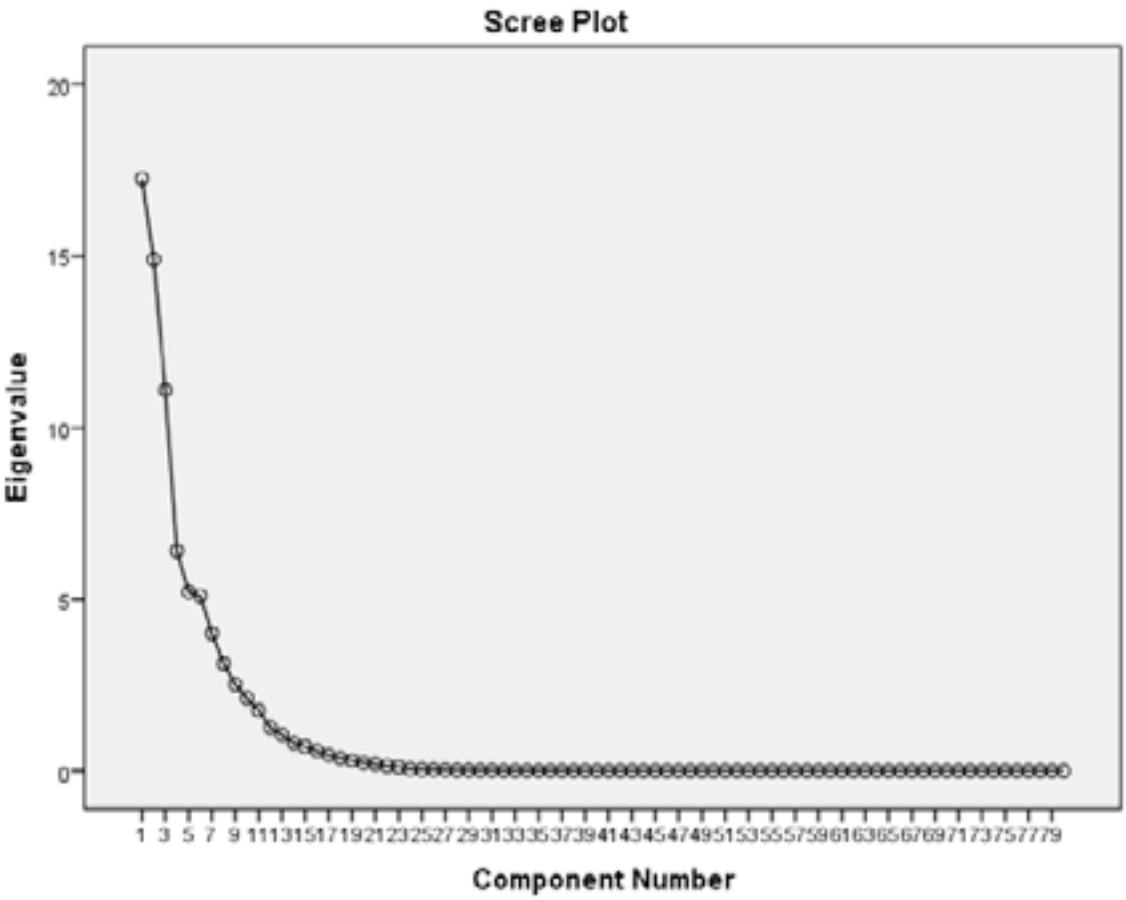

Figure 1. Principal component analysis plot showing maximum variance explained by 13 significant truss morphometric measurements of *Barilius vagra* collected from tributaries of Alaknanda and Chenab rivers.

populations of Alaknanda river basin was also found. Wilks' Lambda test reflected highly significant variations among the six populations of *B. vagra* from different tributaries of Alaknanda and Chenab River basins (Table 6).

DISCUSSION

Morphological differentiation can enable individuals to survive with existing environmental variability (Senay et al. 2015). Hossain et al. (2010) reported that

Table 2. Eigenvalues, percentage of variance and percentage of cumulative variance for the 13 PCs in case of morphometric measurements for *Barilius vagra*.

Component	Eigenvalues		
	Total	% of Variance	Cumulative %
PC 1	17.244	21.555	21.555
PC 2	14.895	18.618	40.173
PC 3	11.090	13.862	54.035
PC 4	6.407	8.009	62.045
PC 5	5.213	6.516	68.561
PC 6	5.106	6.383	74.944
PC 7	4.011	5.014	79.958
PC 8	3.127	3.909	83.867
PC 9	2.523	3.154	87.021
PC 10	2.125	2.656	89.677
PC11	1.765	2.206	91.884
PC 12	1.268	1.585	93.469
PC 13	1.056	1.320	94.789

Table 3. Eigenvalues and total variance explained by five discriminant functions.

Eigenvalues				
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
DF 1	5.878[a]	68.4	68.4	0.924
DF 2	1.582[a]	18.4	86.8	0.783
DF 3	0.584[a]	6.8	93.6	0.607
DF 4	0.438[a]	5.1	98.7	0.552
DF 5	0.109[a]	1.3	100.0	0.313

[a] First 5 canonical discriminant functions were used in the analysis.

Table 4. Discriminant function coefficients expressed by different morphometric measurements of *Barilius vagra* collected from tributaries of Alaknanda and Chenab rivers. (Bold digits indicates largest absolute correlation between each variable and any discriminant function)

Standardized canonical discriminant function coefficients					
Variables	Function				
	DF 1	DF 2	DF 3	DF 4	DF 5
VAR 1-6	0.550	**1.044**	-0.003	0.556	-0.896
VAR 1-13	-0.310	-0.046	**0.652**	-0.447	0.112
VAR 2-5	0.033	-0.026	0.197	**0.702**	0.418
VAR 2-6	1.895	-0.705	0.779	-1.366	**2.319**
VAR 2-14	0.040	**1.232**	-0.664	-1.299	-0.139
VAR 3-6	-1.515	-0.409	-0.730	1.021	**-1.842**
VAR 4-6	0.183	0.594	-0.098	0.578	**0.606**
VAR 4-14	1.195	-0.482	1.176	**1.388**	0.386
VAR 6-12	**-0.798**	-0.342	-0.640	-0.080	0.299
VAR 7-8	0.237	-0.063	-0.438	-0.151	**-0.457**
VAR 7-9	-0.201	**0.453**	0.316	0.177	-0.152
VAR 10-11	-0.148	0.035	**0.374**	-0.337	-0.084
VAR 13-14	**-0.649**	0.141	0.304	-0.526	0.048

phenotypic plasticity is very high in fishes. A sufficient degree of isolation may result in phenotypic and genetic differentiation among fish populations within a species (Turan et al. 2004). Franssen et al. (2013) also suggested that the selective pressure of the environmental conditions leading to genetic-environmental interactions influence the pattern of phenotypic variation at intraspecific level. The results of the present study showed significant phenotypic heterogeneity among the populations of *B. vagra* from two geographically distinct river basins. High level of morphometric differentiation was reported within the Chenab River basin as compared to the Alaknanda river basin as shown by the DFA plot. Chenab River is largely fragmented as compared to the Alaknanda river basin, might be one of the reasons for the cause.

Discriminant function analysis (DFA) could be a useful method to distinguish different stocks of the same species (Karakousis et al. 1991). In the present study, 81.7% of specimens were classified into their original groups by DFA, showing high variation in the stocks of Alaknanda and Chenab River basins. Eighty truss measurements in the whole body from head to tail were found to have significant differences ($p < 0.05$) among the six populations of both the river basins. 13 morphometric measurements (1–6, 1–13, 2–5, 2–6, 2–14, 3–6, 4–6, 4–14, 6–12, 7–8, 7–9, 10–11, and 13–14) extracted from DFA largely contributed in the discrimination of six populations. These all variations in the morphometric measurements of fishes were attributed to the environmental conditions of those particular streams and the fishes adapted to the existing environmental conditions by altering their morphology. It was interesting to note that most of these parameters were linked to the head, eye diameter and fin (Dorsal and anal) of the fish body. Rajput et al. (2013) while studying the eco-morphology of *Schizothorax richardsonii* reported strong correlation between the environmental variables and morphometric parameters like the fin morphology and body shape. Sajina et al. (2011) studied the stock structure of *Megalepis cordyla* from the east (Bay of Bengal) and west coast (Arabian Sea) of the Indian

Table 5. Number and percentage of correctly classified specimens of *Barilius vagra* into their original populations from Alaknanda (1, 2, 3) and Chenab (4, 5, 6) river basins.

		Pridicted Group Membership						
Variables		Alaknanda River			Chenab River			Total
		Dugadda	Khankhra	Khandah	Dudhar	Jhajjar	Jhuni	
Original Count/Percentage	1.Dugadda	32	5	5	0	0	0	42
	2.Khankhra	2	40	4	0	0	0	46
	3.Khandah	8	1	34	0	1	0	44
	4.Dudhar	0	0	0	32	8	0	40
	5.Jhajjar	0	0	1	2	39	4	46
	6.Jhuni	0	0	0	1	5	33	39
	1.Dugadda	76.2	11.9	11.9	0.0	0.0	0.0	100.0
	2.Khankhra	4.3	87.0	8.7	0.0	0.0	0.0	100.0
	3.Khandah	18.2	2.3	77.3	0.0	2.3	0.0	100.0
	4.Dudhar	0.0	0.0	0.0	80.0	20.0	0.0	100.0
	5.Jhajjar	0.0	0.0	2.2	4.3	84.8	8.7	100.0
	6.Jhuni	0.0	0.0	0.0	2.6	12.8	84.6	100.0
81.7% of original grouped cases correctly classified.								

Table 6. Results of Wilks' lambda (function 1 through 5) for verifying differences among the stocks of *Barilius vagra*.

Wilks' Lambda				
Test of Function(s)	Wilks' Lambda	Chi-square	df	Significance
1 through 5	0.022	937.579	65	0.000
2 through 5	0.153	462.231	48	0.000
3 through 5	0.396	228.375	33	0.000
4 through 5	0.627	114.932	20	0.000
5	0.902	25.411	9	0.003

peninsula using truss morphometric analysis and found significant heterogeneity among the stocks, attributed it to the uncommon hydrological conditions of habitats. Mir et al. (2013) investigated phenotypic variation in *Schizothorax richardsonii* from four rivers Jhelum, Lidder, Alaknanda, and Mandakini by using DFA and PCA and reported morphological discrimination among the stocks due to environmental factors.

Intermingling was noticed in three populations of Ganga River basin, which may be due to some common environmental conditions, migration and similar genetic origin at earlier period. Dwivedi et al. (2019) observed low level of morphometric differentiation among wild populations of *Cirrhinus mrigala* from ten different tributaries of Ganges and attributed it to the migration of individuals within the basin and common ancestry in the prehistoric period. In the present investigation Wilks λ test of discriminant function analysis indicated significant differences in morphometric characters of six populations of *B. vagra* from two river basins, similar findings were reported by (Mir et al. 2013) in case of *Schizothorax richardsonii*.

Truss system can be successfully used to investigate stock separation within a species, as reported for other species in freshwater and marine environments. Among the 13 measurements which contributed to the five discriminant functions, four measurements (2–6, 3–6, 4–6, and 7–8) dominantly contributed to fifth discriminant function explaining variance in six populations of *B. vagra*. Mahfuj et al. (2019) while studying the meristic and morphometrics variations of *Macrognathus pancalus* using truss network system from the freshwaters of Bangladesh explained that out of fifteen truss measurements, five measurements contributed to the 1st DF, six measurements contributed to the 2nd DF and remaining four measurements to the 3rd DF. Kenthao and Jearranaiprepame (2018) also conducted similar kind of study in *Yclocheilichthys apogon* from three different rivers Pong, Chi, and Mun of northeastern Thailand. The first three principal components explained 49.29% of variance and first three discriminant functions explained 72% of variation among the samples. However, in the present study, PCA explained 94.79% of variance by using 13 principal components.

In this study, truss system revealed clear separation of *B. vagra* populations from two distinct river basins which will help in site-specific conservation and management strategies such as implementation of appropriate mesh

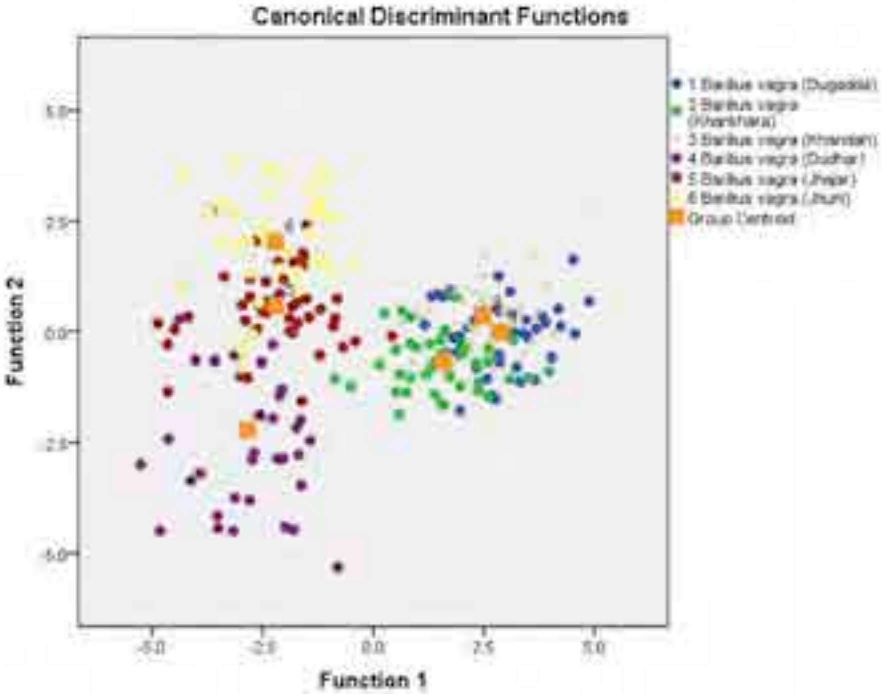

Figure 2. Discriminant analysis plot of *Barilius vagra* showing isolation of populations of Alaknanda and Chenab river basins.

sizes for fish harvesting, avoiding over-exploitation, augmentation of fish stock by culture, and making available sufficient food to fishes for their proper growth in different drainages of the Alaknanda and Chenab rivers. This will be instrumental in sustaining this resource for future use.

CONCLUSION

Truss protocol revealed phenotypic plasticity among six different populations of Alakanda and Chenab River drainages of Indian Himalaya. A clear separation of *B. vagra* populations between two geographically distinct river basins of Indian Himalaya was also found suggesting a need for separate conservation and management strategies to sustain the stock for future use.

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COMMUNICATION

Taxonomic notes, a new species, and a key to Indian species of the click beetle genus *Cryptalaus* Ôhira, 1967 (Coleoptera: Elateridae: Agrypninae)

Harshad Parekar [1] & **Amol Patwardhan** [2]

[1,2] Department of Zoology, K.J. Somaiya College of Science and Commerce, Vidyavihar, Mumbai, Maharashtra 400077, India.
[1] hparekar07@gmail.com (corresponding author), [2] amolppatwardhan@gmail.com

Abstract: *Cryptalaus alveolatus* sp. nov. is described and illustrated from India. The species has unique morphological characters: conspicuous longitudinal median ridge on pronotum, elytral interstria II more depressed than interstriae I and III. The Indian fauna of the genus *Cryptalaus* Ôhira, 1967 is updated and represented by seven species: *C. alveolatus* sp. nov., *C. assamensis* (Schwarz, 1902) comb. nov., *C. eryx* (Candèze, 1874), *C. lynceus* (Candèze, 1874), *C. nodulosus* (Waterhouse, 1877) comb. nov., *C. sculptus* (Westwood, 1848) and *C. sordidus* (Westwood, 1848). Genitalia and terminalia of male and female *C. sordidus* are also illustrated. A key to the Indian species of *Cryptalaus* is given.

Keywords: Click beetle, *Cryptalaus alveolatus* sp. nov., Hemirhipini, Indian fauna, new species, taxonomy.

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Author details: Harshad Parekar (HP)—currently pursuing PhD in the taxonomy and ecology of beetles and is keenly interested in studying click beetles from the Indian subcontinent. Alongside research, he is also a passionate science writer and believes that science communication is a great way to popularize research among the masses. Amol Patwardhan (AP)—an Assistant Professor from the Department of Zoology at K.J. Somaiya College of Science & Commerce, Vidyavihar. He has a keen interest in the taxonomy of click beetles of the Western Ghats and has discovered around a dozen new species of the elaterid beetles.

Author contributions: HP prepared taxonomic description and placement of the new species, studied different species from museums, prepared genitalia and terminalia, wrote the manuscript. AP conceptualized and guided the work, helped in manuscript preparation and improvement.

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INTRODUCTION

Cryptalaus Ôhira, 1967 was established as a subgenus of *Alaus* Eschscholtz, 1829 to include species with the presence of mesometaventral junction. Eventually, it was elevated to generic level and *Paracalais* Neboiss, 1967 was synonymized with it by Ôhira (1990). Cate (2007) reported 15 species from the Palaearctic region, five of which, namely, *C. cenchris* (Candèze, 1857), *C. eryx* (Candèze, 1874), *C. lynceus* (Candèze, 1874), *C. sculptus* (Westwood, 1848) and *C. sordidus* (Westwood, 1848), were from the North Indian region. Only two, *C. lynceus* (Candèze, 1874) and *C. sculptus* (Westwood, 1848), are represented from India by the type locality. Chandra et al. (2018) catalogued two more species, *C. berus* (Candèze, 1865) and *C. griseofasciatus* (Schwarz, 1902), from the Indian Himalayan region. The present knowledge on *Cryptalaus* species from the Indian region is scarce because it is based mainly on the above recent checklist or catalogue. Therefore, this study aims to evaluate and validate the actual presence of *Cryptalaus* species from the Indian subcontinent, describe a new species, and provide an identification key to the Indian species of this genus.

MATERIALS AND METHODS

The study is based on the materials examined from the following collections:

BNHS—Bombay Natural History Society, Mumbai, India

FRI—Forest Research Institute, Dehradun, India

ZKJSSC—Zoology Department, K.J. Somaiya College, Mumbai, India

This study was carried out by examining the adult morphology of *Cryptalaus* species. The definition of *Cryptalaus* follows Ôhira (1967, 1990) and Johnson (2001). Morphological terminology used for the study follows Calder (1996), Casari (2008), and Costa et al. (2010). The limits of the Oriental and Australian regions are based on Johnson (2001).

Materials from BNHS and ZKJSSC were examined under a Dewinter Zoomstar II stereomicroscope, while materials from FRI were observed under an E. Leitz Wetzlar microscope. As there are very few specimens of *C. assamensis*, *C. eryx*, *C. nodulosus*, and *C. sculptus* representing Indian region, it was not possible to prepare genitalia for the examination. Photographs of the new species and *C. sordidus* were taken using Nikon D3200, Nikon D5300, and Nikon AF105 macro lens with Kenko extension tubes. Photographs of the type(s) and non-type specimens provided by various museums were also used in the study to confirm descriptions and keys from the original and subsequent publications as well as to correlate with the materials examined from the abovementioned collections.

Body length was measured from the anterior edge of frons to the apices of elytra. Body width was measured near half of its length, usually before the middle of elytra. Pronotum length was measured at midline and width at the half. The elytral length was measured from anterior margin of an elytron to its apex and width at the half. Aedeagus was measured along the midline from the apex of the median lobe to the apical margin of the basal piece. For genitalia preparation, the abdomen was severed from the body and kept overnight in cold 5% KOH for a male and 10% KOH for a female. The male and female genitalia and terminalia were then removed, washed with water followed by a short treatment in 90% alcohol. Terminalia and male genitalia were preserved in alcohol, while female genitalia were stored in glycerol.

Under each species taxon, we provide literature (citing Indian localities) with relevant information on the taxon, type locality, information on type material with its depository, Indian material examined, distribution within India, measurements (given in range), diagnostic characters and remarks, wherever applicable. Under the 'Distribution in India' section, actual localities of the specimens physically examined are provided and the localities given in the literature, for which specimens were not available, are mentioned in parenthesis. The data labels are quoted verbatim with a single slash (/) separating each data label under the specimen. Within the data label section, additional information and current geographic names are provided in square brackets.

Types of the newly designated species were marked with red labels denoting their type status (holotype or paratype), gender, name of the species, and the authors.

The acronyms used for museums with the type specimens are as follows:

NHM—Natural History Museum, London, The United Kingdom

OUMNH—Oxford University Museum of Natural History, Oxford, The United Kingdom

RBINS—Royal Belgian Institute of Natural Sciences, Brussels, Belgium

SDEI—Senckenberg Deutsches Entomologisches Institut, Müncheberg, Germany

RESULTS

Genus *Cryptalaus* Ôhira, 1967

Cryptalaus Ôhira, 1967: 97. Type species: *Alaus putridus* Candèze, 1857 sensu Ôhira, 1967 (= *Alaus larvatus* Candèze, 1874; the designated type species was a misidentification and corrected to *Alaus larvatus* by Ôhira, 1976: 32 and amended it in Ôhira, 1990: 21)

Paracalais Neboiss, 1967: 261. Type species: *Alaus suboculatus* Candèze, 1857. (For more details on synonymy with *Cryptalaus* see Ôhira, 1990: 21 and Kundrata et al. 2019: 104)

Diagnosis: Frons carinate over antennal insertions; concave or with shallow triangular depression. Antennae serrate; antennomere I longest; II subglobular, shortest; III triangular with spiniform apex. Pronotum with anterior edge smooth or with two teeth-like projections in dorsal view; disc convex with or without raised longitudinal median region. Prosternal process grooved medially between procoxae. Mesocoxal cavity open to both mesepimeron and mesanepisternum. Sides of mesoventral cavity parallel, horizontal in lateral view; mesometaventral junction straight; metaventral discrimen furrowed near base. Scutellar shield declivous in one slanting plane or folded in two planes: anterior vertical and posterior horizontal. Elytral base with interstria III costate or tuberculate; apices rounded or truncate to emarginate with combinations of sutural and lateroapical spines. Abdominal sternite V posteriorly rounded in male; truncate in female with numerous spatulate setae. Aedeagus with median lobe longer than parameres; parameres articulated with median lobe and fused at base; each paramere with lateral subapical hook, setose apex; basal piece wide. Bursa copulatrix with horseshoe shaped sclerotized toothed structures at entrance of colleterial glands, with two lightly sclerotized spermathecae and single, long tubular sac-like extension.

Distribution: Oriental Region: China, India, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, South Korea, Sri Lanka, Taiwan, Thailand, and Vietnam. Australian Region: Australia, Fiji, Samoa, and Vanuatu.

Cryptalaus alveolatus sp. nov. (Images 1–21)

urn:lsid:zoobank.org:act:58809F44-36EE-4C11-8A8E-36EE88349464

Type locality: India: Supegaon, Raigad District, Maharashtra.

Type material: Holotype, female, India: "Supegaon, Raigad District, Maharashtra, 16.VIII.2016, leg. A. Patwardhan"/ "Reg. No. ZKJS 10" (ZKJSSC).

Paratypes: 7 females, **India:** 1 female, "Supegaon, Raigad District, Maharashtra, 07.X.2019, leg. S. Abhyankar"/ "Reg. No. ZKJS 10B" (ZKJSSC); 1 female, "Kanha, Madhya Pradesh"/ "Reg. No. ZKJS 10A" [without further data] (ZKJSSC); 3 females, "Gersoppa, on cut tree, 29.IX.[19]07" [Gersoppa, Karnataka; label data in pencil; without collector data; rewritten on new BNHS label; Reg. No. BNHS 260, BNHS 261, BNHS 263] (BNHS); 1 female, "Gersoppa, on cut tree, 09.XI.[19]06" [Gersoppa, Karnataka; label data in pencil; without collector data; rewritten on new BNHS label; Reg. No. BNHS 262] (BNHS); 1 female, "LOC. Kanger Valley NP, Chhattisgarh, June 17th 2017" [on front side] "coll. Saunak Pal" [on back side; Reg. No. BNHS 264] (BNHS).

Non-type material: 7 females, **India:** 1 female [Acc. No. 13572], "Tithimatti, S Coorg, VIII.1939" [without collector data; now Thithimathi in Kodagu, Karnataka] (FRI); 1 female [Acc. No. 13572], "Tithimatti, S Coorg, B. M. Bhatia, 10.X.1940" [now Thithimathi in Kodagu, Karnataka] (FRI); 1 female [Acc. No. 13572], "Kirwatti, E Kanara, Bombay, B.M. Bhatia, 14.VI.1930"/ "R.R.D. 42, B.C.R. 178, Cage 654" [on front side] "457" [on back side]/ "*Alaus* pris *eryx* Cand. FLEUTIAUX det." [Kirwatti, Uttar Kannad District, Karnataka; misidentified] (FRI); 1 female [Acc. No. 9959], "N. Sihawa, R. Raipur, C.P., N.C. Chatterjee, 8.VII.[19]93"/ "R.R.D. 85, B.C.R. 257, Cage 256"/ "ex. *Bombax malabaricum*"/ "*Alaus* near *elaps* Fleutiaux det." [North Sihawa, Chhattisgarh Plain, Chhattisgarh; misidentified] (FRI); 1 female [with illegible data] (FRI); 1 female [Acc. No. 13572], "Manor R., N. Thana, Bombay, C.F.C. Beeson, 22.vi.1930"/ "R.R.D. 32, B.C.R. 27, Cage 311"/ "ex. Unknown climber"/ "*Alaus* pris *eryx* Cand., J.C.M. Gardner det." [Manor, Palghar District, Maharashtra; misidentified] (FRI); 1 female [Acc. No. 13572], "Mandvi, West Thana, Bombay, B.M. Bhatia, 15.VII.1930"/ "R.R.D. 38, B.C.R. 135, Cage 502"/ "ex. *Mangifera indica*"/ "*Alaus* pris *eryx* J.C.M. Gardner det." [Mandvi, Maharashtra; misidentified] (FRI).

Distribution in India: Maharashtra, Madhya Pradesh, Karnataka, Chhattisgarh.

Measurements: (Holotype in parenthesis). Body length: 15–27 (26) mm. Body width: 4–8 (6.8) mm. Pronotum length including posterior angles: 5–10 (8.7) mm. Pronotum width including posterior angles: 4–7 (7) mm. Elytral length: 9–17 (15.6) mm. Elytral width: 4–8 (6.8) mm.

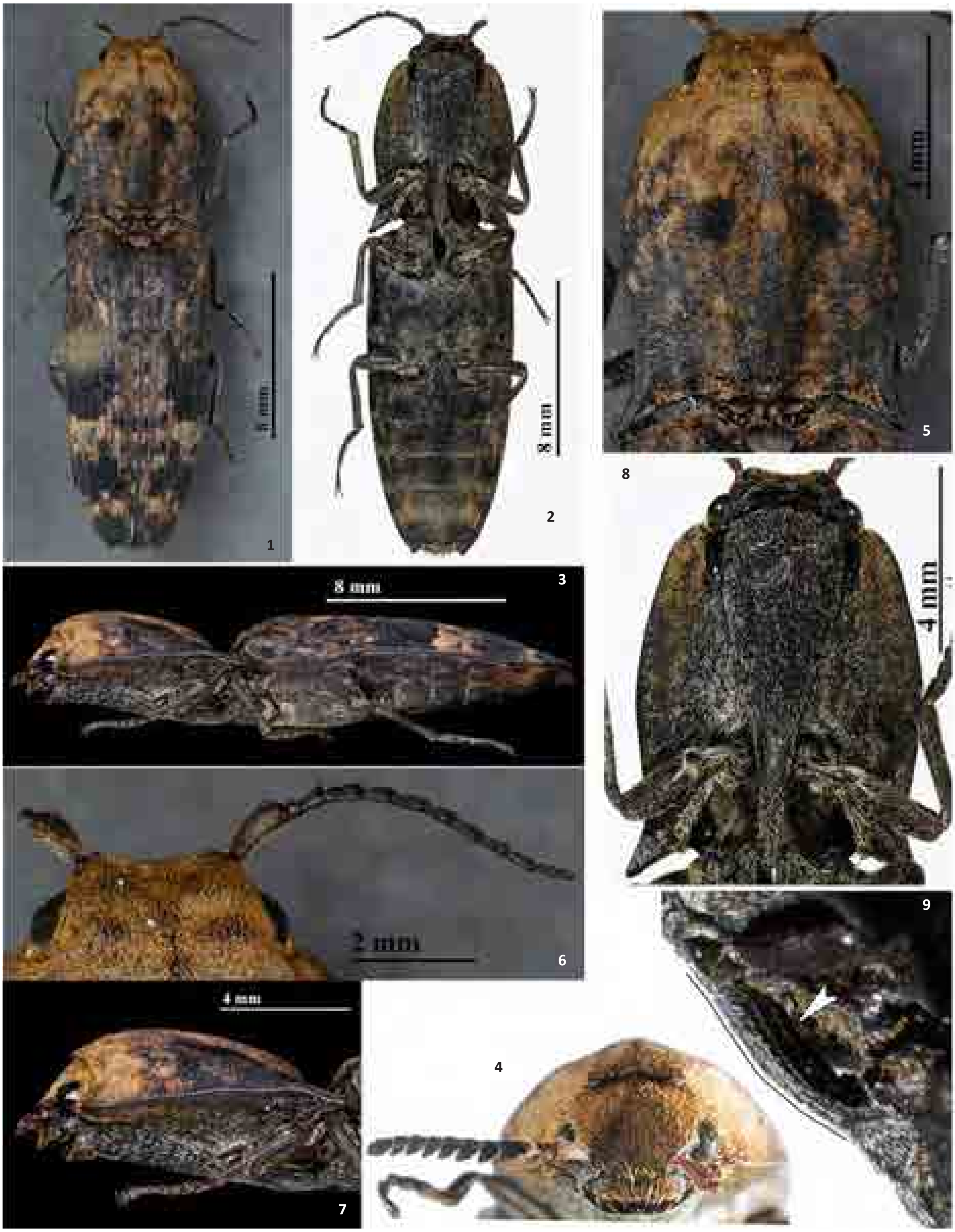
Diagnostic characters: *Cryptalaus alveolatus* sp. nov. distinguished from its congeners by the combination of following unique characters: length ratio of antennomeres II–IV is about 1.0 : 2.0 : 3.3, pronotum with prominent longitudinal median ridge in its posterior 3/4 (Images 5, 7), median basal tubercle of pronotum slightly raised and rounded (Image 5), scutellar shield folded in two planes, anterior 2/3 in vertical plane, while posterior 1/3 in horizontal (Image 10), elytral interstriae flat except interstria III which is raised throughout about 4/5 of elytral length (Image 11) and interstria II more depressed than I and III (Image 12), elytral apices emarginate with both sutural and lateroapical spine (Image 13), bursa copulatrix with darkly sclerotized spots (Images 18, 19) and single, tubular sac-like structure arising apically near base of one spermatheca (Images 18, 19), colleterial gland with tiny spinules-like sclerotized structures (Image 18).

This species resembles *C. lynceus* (Candèze, 1874), which is known only from North India, in general appearance and characters: pronotum longer than wide, anterior edge of pronotum with two teeth-like projections, disc of pronotum with longitudinal median region raised. However, the new species differs from it by the following combination of characters: body pitch-black, anterior 1/3 of pronotum with yellow-brown scales, while posterior 2/3 with brown-black, large elytral patch of black pubescence around eight interstriae wide in its mid-length, sides of pronotum sinuous, pronotum with conspicuous longitudinal median ridge, elytral interstria II more depressed than interstriae I and III, elytral apices emarginate with prominent sutural and lateroapical spines.

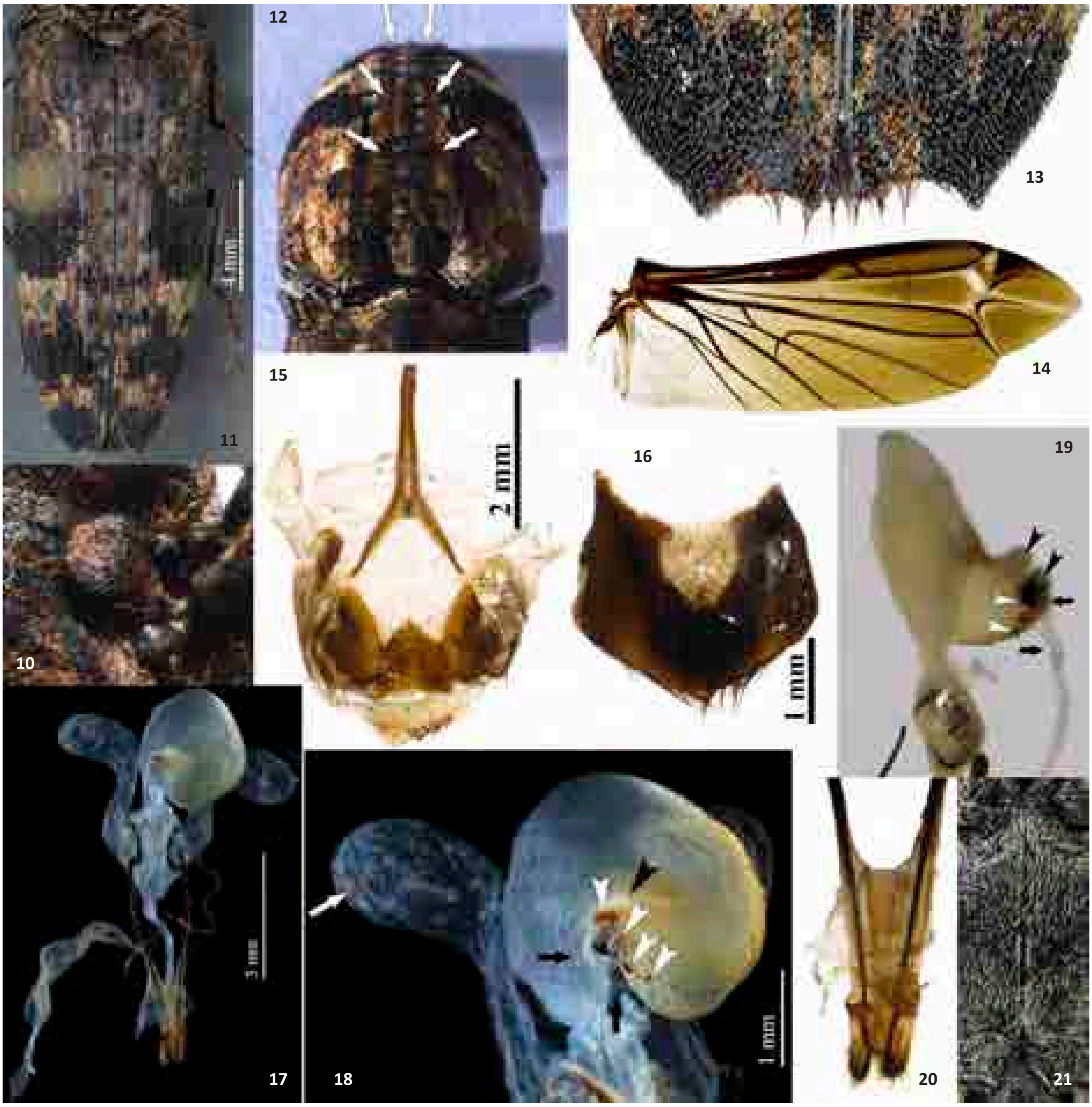
Description: Holotype, female (ZKJS 10): Body elongate (Image 1) 26 mm long, 6.8 mm wide, pitch-black, with antennomeres I–III and maxillary palpi red-brown; dorsum densely covered with white, black to several tonalities of brown, decumbent scale-like setae; head, anterior 1/3 of pronotum with yellow-brown scales gradually fading to brown-black scales in posterior 2/3 of pronotum, with two pitch-black discal spots medially; elytral interstria I with alternate black, white to light brown bands, two white to light brown blotches in posterior half of elytra sandwiched between three black blotches covering interstriae around III–X; ventrally (Image 2) with sparse white setae medially, laterally more yellow-brown to black; abdominal ventrite V with transverse band of yellow-brown scales.

Head: Short (Image 4), slightly wider than long (length/width 0.76), including eyes 0.5 times as wide as pronotum; frons (Image 4) carinate over antennal insertion, with shallow triangular depression medially; punctures dense. Labrum transverse, narrow, around 6.5 times as wide as long, sparsely punctate, covered with yellow, long setae. Maxillary palpi with apical palpomere securiform. Antennae (Images 1, 4, 6) short, slightly reaching about half of pronotal length in dorsal view, serrate from antennomere IV. Length ratio of antennomeres II–IV is about 1.0 : 2.0 : 3.3. Antennomere II about 1.5 times as wide as long; antennomere III about 1.1 times as wide as long; antennomere IV about 1.1 times as long as wide; antennomere XI as long as antennomere IV, 1.4 times as long as wide.

Thorax: Pronotum (Image 5) 1.17 times longer than wide, and 1.24 times longer than wide including posterior angles. Anterior edge (Image 6) sinuous, raised medioanteriorly forming two teeth-like projections; anterior angles acute, slightly produced anteriad; sides sinuate, gradually narrowed anteriorly, and smoothly sloping towards posterior angles; posterior angles long, pointed, divergent, with carinae slightly reaching beyond base. Disc of pronotum (Images 5, 7) notably with raised longitudinal median ridge in its posterior 3/4 (visible in both dorsal and lateral view), with median basal tubercle slightly raised and rounded. Punctures dense, round to oval, shallow. Hypomeron (Image 8) with anterior angles acute; punctures dense, intervals between punctures on average smaller than diameter of one puncture. Prosternum (Images 7, 8) in front of procoxae about 4.9 times longer, 2.6 times wider at base of chin piece, 1.6 times wider before procoxae than diameter of procoxa; chin piece around 3.0 times wider than long with anterior edge arcuate, around 20 degrees below prosternal plane in lateral view; surface convex in ventral view, punctures less denser, slightly larger than on hypomeron, each puncture on average separated by about 0.5–1.0 times its diameter; prosternal process (Images 8, 9) about 3.0 times longer than diameter of procoxa, inclined considerably around 10 degrees behind procoxae in lateral view, underside with notable dent in middle. Mesoventrite (Image 2) 1.5 times wider than long. Metaventrite (Image 2) 1.34 times wider than long; metaventral discrimen (Image 21) touching anterior edge of metaventrite, deeply furrowed in about its posterior 1/3, almost touching posterior edge. Metacoxal plate about 5.2 times as wide as narrowest part, anterior edge oblique, posterior edge subparallel to anterior edge. Scutellar shield (Images 10–12) distinctly folded in two planes, anterior 2/3 in vertical plane, posterior 1/3 in horizontal plane; anterior edge slightly emarginate in middle; sides sloping in vertical plane, notably rounded near fold, again sloping in posterior plane; posterior edge with slight notch concealed under pubescence. Elytra (Images 11–13) almost twice as long as pronotum, 2.3 times as long as its combined width, together as wide as pronotum;



Images 1–9. *Cryptalaus alveolatus* sp. nov., female holotype (ZKJS 10): 1—habitus, dorsal view | 2—habitus, ventral view | 3—habitus, lateral view | 4—head, antenna, anterodorsal view | 5—pronotum, dorsal view | 6—pronotal anterior edge, head and antenna, dorsal view | 7—pronotum and prosternum, lateral view | 8—hypomeron and prosternum, ventral view | 9—prosternal spine, lateral view, white arrowhead: dent on underside, black line: inclination of prosternal spine behind procoxae with conspicuous bents. 4, 9—not to scale. © 1–3, 5–8—M. Vankawala | 4, 9—A. Patwardhan.



Images 10–21. *Cryptalaus alveolatus* sp. nov.: 10, 11, 13, 21—female holotype (ZKJS 10) | 12, 15–20—female paratype (ZKJS 10B) | 14—female paratype (BNHS 264) | 10—scutellar shield, dorsolateral view | 11—elytra and scutellar shield, dorsal view | 12—elytra and scutellar shield, anterodorsal view, white arrows: depressed elytral interstria II than interstriae I and III | 13—apex of elytra | 14—right hind wing | 15—abdominal sternite VIII | 16—abdominal tergite VIII | 17—genitalia, ventral view | 18—details of bursa copulatrix, colleterial gland, ventral view, white arrow: tiny spinules-like structures within colleterial gland, black arrows: sac-like single tubular extension from bursa copulatrix, white arrowheads: darkly sclerotized spots on bursa copulatrix, black arrowhead: spermatheca | 19—details of bursa copulatrix, ventrolateral view, black arrows: sac-like single tubular extension from bursa copulatrix, white arrowheads: darkly sclerotized spots on bursa copulatrix, black arrowheads: two spermathecae | 20—apex of ovipositor, ventral view | 21—metaventral discrimen | 12–14, 19–21—not to scale. © 11, 13, 21—M. Vankawala | 10, 12, 14—A. Patwardhan | 15–20—H. Parekar.

sides sub-parallel to posterior half, then slightly tapering to apex, apex of each elytron distinctly emarginate with prominent sutural and lateroapical spine; striae with punctures usually separated by 1.0–3.0 times their diameter and laterally rarely by 5.0 times their diameter, distinctly larger than punctures on interstriae; interstriae flat except III, and IV raised near base, only interstria III raised throughout about 4/5 of elytron; interstria II (Image 12) more depressed than interstriae I, and III. Hind wing (Image 14: of paratype female, BNHS 264)

2.4 times as long as wide, apex narrowly rounded; radial cell short, about four times as long as wide; r3 extending about 0.2 times as long as radial cell.

Abdomen: Ventrite V (Image 2) anteriorly (measured near anterior edge) 2.19 times as wide as long. Tergite VIII (Image 16) 1.46 times as wide as long; anteriorly concave, sides subparallel, apically arcuate with short setae; sparsely covered with punctures; colorless median area vase shaped. Sternite VIII (Image 15) 1.76 times as wide as long; sclerotized area conspicuously forming letter W anteriorly, posterior margin incurved shallowly in middle; rarely covered with short setae; spiculum ventrale twice as long as sternite VIII, not touching tip of sclerotized area.

Genitalia: Female (Images 17–20: of paratype female, ZKJS 10B): Ovipositor 0.61 times length of abdomen (measured medially); coxites (Image 20) rarely covered with long, darkly sclerotized setae, apically covered with sparse, shorter, less sclerotized setae; paraprocts 5.8 times as long as coxites, 0.85 times length of ovipositor. Colleterial glands (Image 18) thrice as long as wide, with tiny spinules-like sclerotized structures inside (Image 18: shown with white arrow). Bursa copulatrix (Images 18, 19) coiled, two spermathecae on anteriormost section not sclerotized (Image 18, 19: shown with black arrowheads); single extension of long, tubular sac-like structure arising apically near base of one spermatheca (Images 18, 19: shown with black arrows); darkly sclerotized spots (Image 19: shown with white arrowheads) near, and from base of tubular extension.

Male unknown.

Etymology: The Latin word "alveolatus" means hollowed out like a trough. The specific epithet refers to depressed elytral interstria II (than interstriae I and III), which appears to be trough-shaped (see Image 12).

Cryptalaus assamensis (Schwarz, 1902) comb. nov. (Images 22, 23)

Alaus assamensis Schwarz, 1902: 204 (original description, type locality: Assam); Schenkling, 1925: 45 (catalogue, locality: Assam); Gaedike, 1985: 19 (catalogue of type specimens in SDEI, 1 Syntype).

Type locality: India: Assam.

Type material: Syntype, 1 female, **India:** "Assam"/ "coll. Schwarz"/ "Syntypus" [red label]/ "*assamensis* Schw." (SDEI).

Indian material examined: 1 female, "Jeypore Res. Lakhimpur, Assam., N.C. Chatterjee, 13.V.1938." (FRI).

Distribution in India: Assam.

Measurements: Syntype. Length: 28 mm. Width: 8.5 mm.; FRI specimen. Length: 26.5 mm. Width: 8 mm.

Diagnostic characters: Female: Body (Image 22) pitch-black with antennomeres I–III, trochanters red-brown; dorsum densely covered with grey to yellow decumbent scales intermingled with black spots; pronotum with two eye-like spots of black pubescence elongated oval, deviated towards central axis; elytral interstriae VII–VIII with elongate black patch near half of elytral length. Antennae short, slightly reaching half of pronotal length. Length ratio of antennomeres II–IV is about 1.0 : 1.6–2.0 : 3.0–3.6. Pronotum 1.18–1.19 times longer than wide and 1.28–1.30 times longer than wide including posterior angles, anterior edge with two teeth-like projections, anterior angles broad in dorsal view, sides narrowly convex to subparallel, posterior angles long, narrow, pointed and strongly divergent with carinae slightly reaching beyond base, disc with slightly raised median longitudinal surface glabrous, punctures denser laterally than on median longitudinal surface, with weakly developed transverse median carina near base. Scutellar shield almost as long as wide. Elytra 1.88–2.03 times as long as pronotum, 2.21–2.24 times as long as its combined width, apex emarginate with slightly produced sutural and lateroapical spine.

Male unknown.

Cryptalaus eryx (Candèze, 1874) (Images 24, 25)

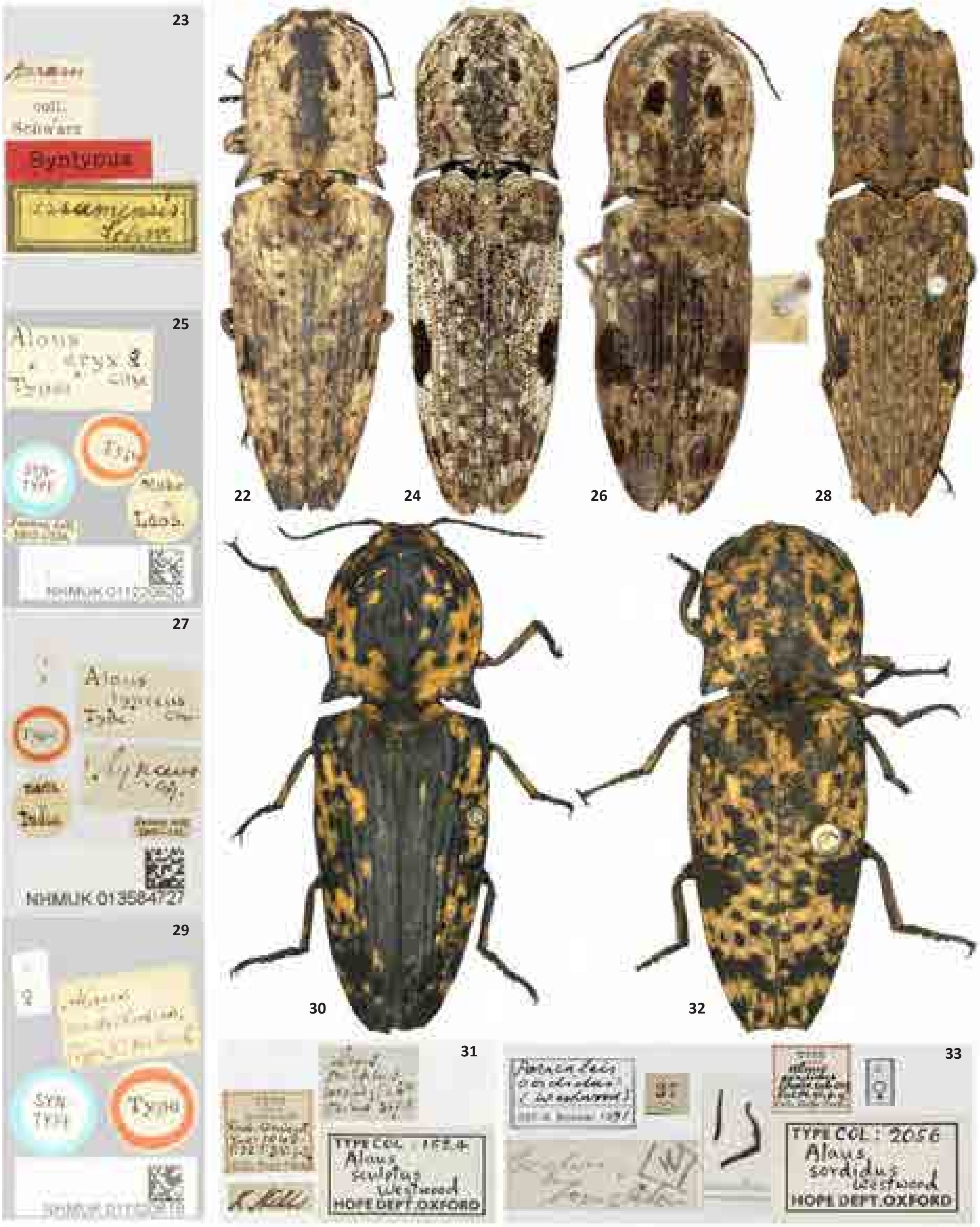
Alaus eryx Candèze, 1874: 140 (original description, type locality: Laos), 119–121 (key to *Alaus* species, Group 2); Fleutiaux, 1927: 102–104 (key to *Alaus* species), 105 (distributional note, locality: Darjeeling).

Cryptalaus eryx (Candèze, 1874); Cate, 2007: 107 (catalogue, locality: Sikkim, Darjeeling); Chandra et al. 2018: 499 (catalogue, locality: West Bengal, Sikkim).

Type locality: Laos: exact location not known.

Type material: Syntypes, 4 females, **Laos:** 1 female, "Muhot, Laos"/ "Janson coll. 1903–130."/ "*Alaus eryx* [female symbol], Cdze., Type."/ "SYNTYPE" [within blue circular border]/ "Type" [within orange circular border]/ "NHMUK 011220620" (NHM); 1 female, "Muhot, Laos"/ "Janson coll. 1903–130."/ "*Alaus eryx* [female symbol], Cdze"/ "SYNTYPE" [within blue circular border]/ "NHMUK 011220621" (NHM); 1 female, "Muhot, Laos"/ "Janson coll. 1903–130."/ "*Alaus eryx* [female symbol], Cdze"/ "SYNTYPE" [2 different labels; within blue circular border]/ "NHMUK 011220622" (NHM); 1 female, "Muhot, Laos"/ "Janson coll. 1903–130."/ "*Alaus eryx* [female symbol], Cdze"/ "SYNTYPE" [within blue circular border]/ "NHMUK 011220623" (NHM).

Indian material examined: 3 males. 1 male [Acc. No. 15243], "Samsingh 1800, Kalimpong, Bengal, XI.[19]33,



Images 22–33. *Cryptalaus* spp.: 22, 23—*Cryptalaus assamensis* (Schwarz, 1902) comb. nov., female syntype © S. Blank, SDEI | 22—habitus, dorsal view | 23—data labels | 24, 25—*Cryptalaus eryx* (Candèze, 1874), female syntype © K. Matsumoto, NHM | 24—habitus, dorsal view | 25—data labels | 26, 27—*Cryptalaus lynceus* (Candèze, 1874), female syntype © K. Matsumoto, NHM | 26—habitus, dorsal view | 27—data labels | 28, 29—*Cryptalaus nodulosus* (Waterhouse, 1877) comb. nov., female syntype © K. Matsumoto, NHM | 28—habitus, dorsal view | 29—data labels | 30, 31—*Cryptalaus sculptus* (Westwood, 1848), male syntype © K. Child, OUMNH | 30—habitus, dorsal view | 31—data labels | 32, 33—*Cryptalaus sordidus* (Westwood, 1848), female syntype © K. Child, OUMNH | 32—habitus, dorsal view | 33—data labels | 22–33—not to scale.

Balwant Singh."/ "Ex rotten wood."/ "1130"/ "*Alaus eryx* Cand. FLEUTIAUX det." [Samsing, Kalimpong, West Bengal; specimen with elytra distorted] (FRI); 1 male, "Bagdogra Range, Kurseong, Bengal, N.C. Chatterjee, 8.V.1936"/ "ex unknown wood."/ "R.R.D. 905, B.C.R. 39, Cage 598" [Bagdogra, Kurseong, Darjeeling District, West Bengal] (FRI); 1 male, "Assam, N.C. Chatterjee, 24.IV.1939" (FRI).

Non-Indian material examined: 1 female [Acc. No. 5069], **Myanmar:** "Okkyi, Schwegu, Burma, 2.VI.1919, C.F.C. Beeson" [Shwegu, Kachin District, Myanmar] (FRI).

Distribution in India: West Bengal, Assam, (Sikkim).

Measurements: Length: 23–28 mm. Width: 7–8.5 mm.

Diagnostic characters: Female: Body (Image 24) red-brown with pronotal longitudinal median region, hypomeron and prosternum, maxillary palpi pitch-black; dorsum densely covered with white to light brown decumbent scales intermingled with black spots and patches; pronotum with two eye-like spots of black pubescence oval; two interstriae wide semi-circular ring-like black patch on elytral interstriae VII–IX at near half of elytral length, ring-like patch anteriorly never touching interstriae IX–X, posteriorly touching interstriae X rarely. Antennae short, slightly reaching half of pronotal length. Length ratio of antennomeres II–IV is about 1.0 : 1.6–2.3 : 2.0–2.6. Pronotum 1.12–1.18 times longer than wide and 1.21–1.28 times longer than wide including posterior angles, anterior edge with two teeth-like projections not raised, anterior angles acute in dorsal view, sides evenly convex and narrowly sinuous before posterior angles, posterior angles short, narrow, pointed and divergent with carinae just reaching beyond base, disc with longitudinal median carina obliterating in prominent transverse median carina near base. Scutellar shield 1.2–1.5 times as long as wide, subpentagonal. Elytra 1.90–2.35 times as long as pronotum, 2.10–2.35 times as long as its combined width, interstriae flat, apex narrowly emarginate with slightly produced sutural spine.

Male similar to female in shape, size and appearance. Antennae reaching well beyond half of pronotal length, not reaching base of posterior angles. Length ratio of antennomeres II–IV is about 1.00 : 1.67–1.80 : 2.5–2.8.

Cryptalaus lynceus (Candèze, 1874) (Images 26, 27)

Alaus lynceus Candèze, 1874: 139 (original description, type locality: Inde boréale = North India), 119–121 (key to *Alaus* species, Group 2); Candèze, 1891: 33 (catalogue, locality: Hindoustan sept. = North India); Schenkling, 1925: 46 (catalogue, locality: N. Hindostan = North India).

Cryptalaus lynceus (Candèze, 1874); Cate, 2007: 107 (catalogue, locality: north India); Chandra et al. 2018: 499 (catalogue, locality: Himalaya: West Bengal, Sikkim, Himachal Pradesh).

Type locality: North India: exact location not known.

Type material: Syntype, 1 female, **north India:** "[female symbol]"/ "Type" [within orange circular border]/ "north India" [sic]/ "Janson coll. 1903–130"/ "*Alaus lynceus* Cdze. Type" [on front side] "*lynceus* cz" [on back side]/ "NHMUK013584727" (NHM).

Distribution in India: North India, (Himalaya: West Bengal, Sikkim, Himachal Pradesh).

Measurements: Length: 17 mm. Width: 5.5 mm. [measurements from original description: Candèze, 1874: 139]

Diagnostic characters: Female: Body (Image 26) dark brown; dorsum densely covered with grey and dark brown decumbent scales mixed with black spots and patches; pronotum with two eye-like spots of dark pubescence large and rounded; elytral large patch of dark pubescence about five interstriae wide. Pronotum longer than wide, anterior edge with two teeth-like projections, sides evenly convex and narrowly sinuous before posterior angles, posterior angles short, narrow, pointed and divergent, disc with longitudinal median region raised. Scutellar shield oblong, uniformly declivous. Elytra less than twice as long as pronotum, apex rounded.

Male unknown.

Remark: There is only one specimen of this species in NHM collection and is marked with label "Type". We have followed recommendation 73F, article 73.2 and 73.2.1 of ICZN for considering the specimen as "Syntype".

Cryptalaus nodulosus (Waterhouse, 1877) comb. nov. (Images 28, 29)

Alaus nodulosus Waterhouse, 1877: 4 (original description, type locality: Andaman Island); Schenkling, 1925: 47 (catalogue, locality: Andamanen = Andaman Island).

Type locality: India: Andaman Island.

Type material: Syntype, 1 female, **India:** "[female symbol]"/ "*Alaus nodulosus* (Type) C. Waterh."/ "SYNTYPE" [within blue circular border]/ "Type" [within orange circular border]/ "NHMUK011220618" (NHM).

Indian material examined: 1 female [Acc. No. 13573], **India:** "Andaman Island, C.F.C. Beeson, 6.IX.193[0]"/ "R.R.D. 88, B.C.R. 38, Cage 715"/ "ex. unknown climber"/ "*Alaus nodulosus* Waterh. FLEUTIAUX det." (FRI).

Distribution in India: Andaman Island.

Measurements: Length: 23–33 mm. Width: 6.8–10 mm. [measurements from original description: Waterhouse, 1877: 4; FRI specimen. Length: 26 mm. Width: 7.5 mm.]

Diagnostic characters: Female: Body (Image 28) pitch-black with antennae red-brown; dorsum densely covered with yellow-brown decumbent scales mixed with black spots forming patterns; pronotum with two eye-like spots of black pubescence small and oval; elytral interstria IV with elongate paler band near base with black spots on either end, elytral interstriae VI–X with black patch near half of elytral length partially encircling brown pubescence. Antennae short, slightly reaching half of pronotal length. Length ratio of antennomeres II–IV is about 1.0 : 1.8–2.0 : 2.8–3.0. Pronotum 1.15 times longer than wide and 1.24 times longer than wide including posterior angles, anterior edge with two teeth-like projections raised, pointed and strongly produced anteriorly, anterior angles conspicuously broad in dorsal view, sides almost subparallel, posterior angles short, pointed and slightly divergent with weak carinae not reaching near base, disc with uniformly and widely raised longitudinal median surface terminating posteriorly with prominent transverse median carina, punctures uniformly dense. Scutellar shield slightly longer than wide, subpentagonal. Elytra 2.19 times as long as pronotum, 2.40 times as long as its combined width, apex emarginate with strongly produced lateroapical spine.

Male unknown.

Remark: The locality label is missing from the syntype specimen. It is determined to be "Andaman Is. [sic]" from the original description. Waterhouse (1877: 4) mentioned both male and female, but did not mention actual number of specimens examined in the description. There is only one female syntype specimen in NHM collection (pers. comm. with Michael Geiser, NHM on 13.ix.2019). In the description, Waterhouse states "Elytris ad apicem emarginatis; abdominis segmento quinto apice truncate" for male and "Elytris ad apicem vix truncatis; abdominis segment quinto apice rotundato" for female. But it is found that female has the typical dimorphic characteristic of genus *Cryptalaus*: abdominal ventrite V truncate posteriorly with dense spatulate setae.

Cryptalaus sculptus (Westwood, 1848) (Images 30, 31)

Alaus sculptus Westwood, 1848: 72 (original description, type locality: Kasyah Hills = linguistically mutilated version of former Khasia Hills, Assam; now Khasi Hills in Meghalaya), plate XXXV (fig. 8); Candèze, 1857: 213–215 (key to *Alaus* species), 219 (species description, locality: Indes Orientales = East India); Candèze, 1874: 119–121 (key to *Alaus* species, Group 2), 127 (revision, locality: Hindoustan: Kasyah Hills); Candèze, 1891: 32 (catalogue, locality: Hindoustan sept. = North India; Sikkim); Stebbing, 1914: 225 (descriptive and bionomic note, locality: West Bengal; Assam; Balaghat, Central Province = Madhya Pradesh); Schenkling, 1925: 47 (catalogue, locality: Darjeeling; N. Hindostan = North India); Fleutiaux, 1927: 102–104 (key to *Alaus* species), 107 (distributional note, locality: Assam; Sikkim)

Cryptalaus sculptus (Westwood, 1848); Cate, 2007: 107 (catalogue, locality: Sikkim; Darjeeling; North India); Chandra et al. 2018: 499 (catalogue, locality: West Bengal; Sikkim).

Cryptalaus coomani (Fleutiaux, 1927); Cate, 2007: 107 (synonym).

Type locality: India: Khasi Hills, Meghalaya.

Type material: Syntype, 1 male, **India:** "TYPE, WESTWOOD, Cab. Orient Ent. 1848. P. 72. T.35. f.8., Coll. Hope Oxon." [within orange border]/ "K Hills"/ "*Alaus sculptus* Westw. Cab. Or. Ent 35 f.8"/ "TYPE COL: 1524, *Alaus sculptus* Westwood, HOPE DEPT.OXFORD" (OUMNH).

Non-type material: 1 female, **India:** "Coll. R. I. Sc. N. B., HINDOUSTAN, ex. coll. E. Candèze"/ " *Alaus sculptus* Westw. dét. E. Candèze"/ "Sculptus Hindost. West." [within square of yellow border]/ "[female symbol]"/ "*Paracalais sculptus* (Westwood), Det. R. Bouwer 1992" (RBINS).

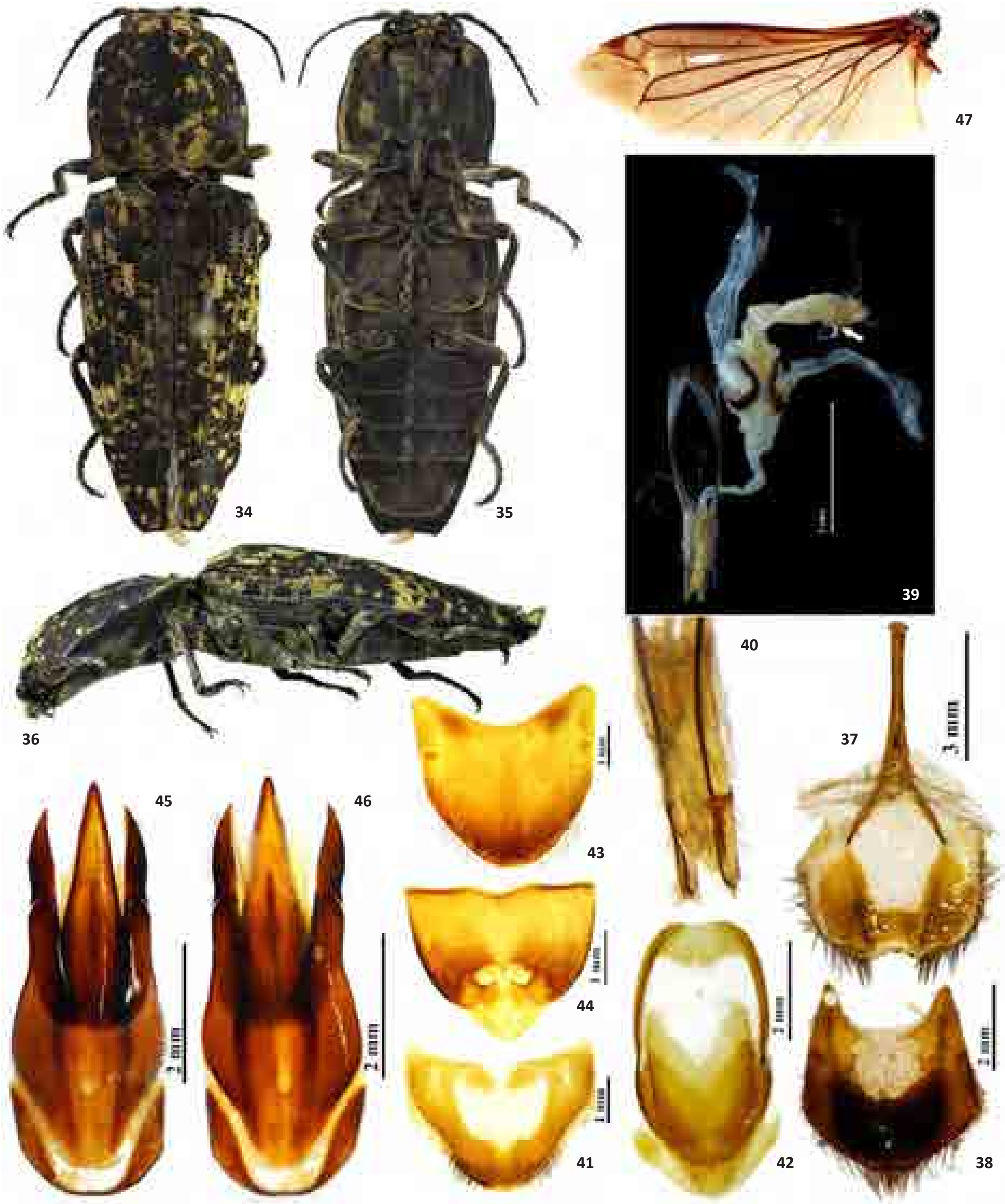
Indian material examined: 1 male [Acc. No. 5068], "Naga Hills 5,500' [feet]. Assam, O.C. Ollenbach, IV.1924"/ "*Alaus sculptus* Cand [sic], J.C.M. Gardner det." [Naga Hills are now part of Nagaland] (FRI).

Non-Indian material examined: 2 females [Acc. No. 5068], **China:** 1 female, "Su-Tsang [Ü-Tsang], 2000 m., East Yunnan"/ "*Alaus sculptus* Collection FLEUTIAUX" (FRI); 1 female, "Thibet" [Tibet]/ "*Alaus sculptus* Collection FLEUTIAUX" (FRI).

Distribution in India: Meghalaya, Nagaland, (West Bengal, Sikkim, Madhya Pradesh, Assam).

Measurements: Length: 28–32 mm. Width: 8–12 mm.

Diagnostic characters: Female: Body pitch-black; dorsum densely covered with white to yellow-grey decumbent scales mottled with black spots. Antennae short, slightly reaching half of pronotal length. Length ratio of antennomeres II–IV is about 1.0 : 2.0–2.3 :



Images 34–47. *Cryptalaus sordidus* (Westwood, 1848): 34–40, 47—female (ZKJS 66A) | 41–46—male (ZKJS 67A) | 34—habitus, dorsal view | 35—habitus, ventral view | 36—habitus, lateral view | 37—abdominal sternite VIII | 38—abdominal tergite VIII | 39—genitalia, dorsal view, white arrow: subapical origin of sac-like single tubular extension from bursa copulatrix | 40—apex of ovipositor, ventrolateral view | 41—abdominal sternite VIII | 42—abdominal sternite IX | 43—abdominal tergite VIII | 44—abdominal tergites IX–X | 45—genitalia, dorsal view | 46—genitalia, ventral view | 47—left hind wing. 34–36, 40, 47—not to scale | © 34–36—M. Vankawala | 47—A. Patwardhan | 37–46—H. Parekar.

2.5–2.7. Pronotum 0.98–1.10 times as long as wide and 1.02–1.16 times as long as wide including posterior angles, anterior edge with two teeth-like projections slightly produced, anterior angles conspicuously acute in dorsal view, sides strongly and evenly convex, posterior angles short, broad, pointed and moderately to strongly divergent with carinae just reaching base, disc with irregular wrinkly surface, median basal tubercle raised in transverse ridge and with small transverse tubercular ridge posteriorly near base just before median basal tubercle, punctures irregularly arranged. Prosternum with groove on prosternal process between procoxae extending anteriorly, not reaching half of prosternal length and posteriorly to about half of prosternal process, prosternal process curved distinctly in lateral view. Scutellar shield folded in two planes, anterior half folded in vertical plane and posterior half in horizontal plane. Elytra 1.80–2.07 times as long as pronotum, 1.83–2.02 times as long as its combined width, apex truncate with slightly produced sutural region without spine giving appearance as to be narrowly emarginate.

Male (Image 30) similar to female in shape and appearance. Antennae reaching well beyond half of pronotal length, not reaching base of posterior angles. Length ratio of antennomeres II–IV is about 1.00 : 1.8–2.2 : 2.5–2.8.

Remark: There is only one specimen of this species in OUMNH collection and is marked with label "TYPE". We have followed recommendation 73F, article 73.2 and 73.2.1 of ICZN for considering the specimen as "Syntype".

***Cryptalaus sordidus* (Westwood, 1848) (Images 32–47)**

Alaus sordidus Westwood, 1848: 72 (original description, type locality: Ceylon = Sri Lanka), plate XXXV (fig. 9); Candèze, 1857: 213–215 (key to *Alaus* species), 231 (species description, locality: Indes Orientales = East India); Candèze, 1874: 119–121 (key to *Alaus* species, Group 2), 129 (revision, locality: Ceylan [sic] = Sri Lanka); Candèze, 1891: 32 (catalogue, locality: Hindoustan; Assam); Schenkling, 1925: 47 (catalogue, locality: Hindostan; Nilgiri = Nilgiri Hills, Tamil Nadu; Assam); Fleutiaux, 1927: 102–104 (key to *Alaus* species), 106 (distributional note, locality: Hindoustan meridional = South India; Assam; Sikkim)

Cryptalaus sordidus (Westwood, 1848); Cate, 2007: 107 (catalogue, locality: Sikkim; Darjeeling; North India); Chandra et al. 2018: 499 (catalogue, locality: West Bengal; Sikkim).

Type locality: Sri Lanka: exact location not known.

Type material: Syntype, 1 female, **India:** "[female symbol]"/ "37"/ "Ceylon <W> Templeton" [written in pencil]/ "TYPE *Alaus sordidus* Westw. Cab. Ort. Ent. Pl. 35, f. 9., Coll. Hope Oxon." [within orange border]/ "TYPE COL: 2056, *Alaus sordidus* Westwood, HOPE DEPT.OXFORD"/ "*Paracalais sordidus* (Westwood), DET. R. Bouwer 1991" [single antenna and tibia-tarsal part of leg mounted on paper card] (OUMNH).

Indian material examined: 7 females [Reg. No. ZKJS 66A–66G] and 7 males [Reg. No. ZKJS 67A–67G], "Kovin, Changlang, Arunachal Pradesh, 21–25.VIII.2006, leg. A. Patwardhan, on light" (ZKJSSC); 1 male, "Nagsidh, Dehra Dun, U.P., C.F.C. Beeson, 25.VII.1931"/ "ex. *Kydia calycina*"/ "R.R.D. 213, B.C.R. 35, Cage 619"/ "*Alaus sordidus* Fleutiaux det." [Dehradun, Uttarakhand] (FRI); 1 male, "Khasis: 5000 ft., Shillong, 19.VI.1928, Fletcher coll."/ "*Alaus sordidus* Fleutiaux det." [Khasi Hills, Shillong, Meghalaya] (FRI); 1 female, "Thano R., Dehra Dun, U.P., C.F.C. Beeson, 15.VIII.[19]23"/ "ex. *Shorea robusta*"/ "R.R.D. 95, B.C.R. 1, Cage I"/ "*Alaus sordidus* S.N. Chatterjee det." [Dehradun, Uttarakhand] (FRI); 1 female, "Thano R., Dehra Dun, U.P., 22.VII.1921, N.C. Chatterjee"/ "ex. *Shorea robusta*"/ "R.R.D. 849, B.C.R. 197, Cage V"/ "*Alaus sordidus* J.C.M. Gardner det." [Dehradun, Uttarakhand] (FRI); 1 female, "Bagdogra Range, Kurseong, Bengal, C.F.C. Beeson, 17.VII.1935"/ "*Alaus sordidus* G.D. Pant det." [Bagdogra, Kurseong, Darjeeling District, West Bengal] (FRI); 1 female, "Palhri, Saharanpur, U.P., C.F.C. Beeson, 30.VIII.1918"/ "Predaceous on *Plocaederus obesus* Gah."/ "R.R.D. 357a, B.C.R. 195, Cage 121, log 32" [Saharanpur, Uttar Pradesh] (FRI).

Non-Indian material examined: 1 male [Acc. No. 4398], "Mawagankanda, Ratnapura 500 [ft.], Ceylon S.A.B."/ "F.R.I. coll., Gauri Dutt., 15.III.1936"/ "ex. *Artocarpus nobilis*"/ "R.R.D. 839, B.C.R. 408, Cage 622" [Ratnapura, Sri Lanka] (FRI).

Distribution in India: Arunachal Pradesh, West Bengal, Uttarakhand, Meghalaya, Uttar Pradesh, (Sikkim, Assam, Tamil Nadu).

Measurements: Length: 22–38 mm. Width: 7–13 mm.

Diagnostic characters: Female: Body (Image 32: female syntype; Images 34–36; specimen with distorted scutellar shield, ZKJS 66A) medially pitch-black to red-brown laterally; dorsum densely covered with yellow-brown scales mixed with several dark brown to black spots. Antennae short, slightly reaching half of pronotal length. Length ratio of antennomeres II–IV is about 1.0: 1.7–2.1 : 2.9–3.2. Pronotum 1.05–1.15 times as long as wide and 1.17–1.23 times as long as wide including posterior angles, anterior edge smooth without any tooth-like projections, anterior angles acute in dorsal view, sides sinuous to evenly convex, posterior angles short, broad, pointed and narrowly divergent with carinae about to reach base, disc uniformly convex with prominent transverse median carina posteriorly near base, median basal tubercle raised, punctures dense. Scutellar shield as long as wide, or slightly longer than wide, subpentagonal. Elytra 2.05–2.24 times as long as pronotum, 2.11–2.25 times as long as its combined width, apex truncate with distinct lateroapical spine.

Male similar to female in shape and appearance. Antennae reaching well beyond half of pronotal length, not reaching base of posterior angles. Length ratio of antennomeres II–IV is about 1.0 : 1.6–2.0 : 3.3–3.6.

Additional description: Hind wing—(Image 47, ZKJS 66A) 2.7 times as long as wide, apex slightly pointed; radial cell long, about five times as long as wide; r3 extending about 0.3 times as long as radial cell. Abdomen—Female (ZKJS 66A)**:** Tergite VIII (Image 38) 1.17 times as wide as long; anterior edge strongly concave, sides anteriorly narrower than posterior end, posterior edge strongly arcuate, medially slightly emarginate; rows of short setae arising from mediolateral region to posterior edge, gradually with row of much longer setae on posterior edge; sparsely covered with punctures; colorless median area distinctly shaped with inner lateral margins wavy and posterior margin arcuate. Sternite VIII (Image 37) 1.34 times as wide as long; sclerotized area horseshoe shaped with anterior margin subtrapezoidal, posterior margin deeply incurved in middle; rows of numerous short to long setae on mediolateral edge; spiculum ventrale almost twice as long as sternite VIII, touching tip of sclerotized area. Male (ZKJS 67A)**:** Tergite VIII (Image 43) U-shaped, about 1.22 times as wide as long, anterior edge concave; medially and apicolaterally punctate with bristle-like setae. Sternite VIII (Image 41) subtriangular, about 1.47 times as wide as long, colorless median area with sparse punctures, posterior margin with dense pubescence of varying length, apex widely rounded without any setae. Tergite IX and X (Image 44) connected with membrane; tergite IX twice as wide as long, anterior margin almost linear, slightly emarginate medially, sides curving towards apex, posterior margin deeply incurved forming wide inverted V; tergite X small, V-shaped. Sternite IX (Image 42) elongate, twice as long as wide, apically rounded with sparse pubescence in middle. Genitalia—Female (Image 39, ZKJS 66A): Ovipositor 0.70 times length of abdomen (measured medially); coxites (Image 40) finely punctured, covered with long, lightly sclerotized setae, apically covered with densely arranged shorter setae at the tip; paraprocts 6.3 times as long as coxites, 0.86 times length of ovipositor. Colleterial glands five times as long as wide. Bursa copulatrix twisted but not coiled, two spermathecae on anteriormost section lightly sclerotized; single extension of long, tubular sac-like structure arising sub-apically on bursa copulatrix. Male (Images 45, 46, ZKJS 67A): Aedeagus more than twice as long as wide; median lobe gradually narrowed towards apex, apex narrowly rounded; basal struts moderately short, about 0.33 times as long as aedeagus. Parameres abruptly constricted behind subapical hook with small setae near constriction; apical lobe of paramere with pointed apex, outer margin slightly rounded medially with more setae on dorsal side than on ventral, sinuate just before subapical hook; subapical hook sharp.

Remark: There are 25 specimens of *C. sordidus* from India in FRI collection [all with Acc. No. 4398]. Only six specimens spanning different Indian states have been studied and mentioned under 'Indian material examined' section. There is only one specimen of this species in OUMNH collection and is marked with label "TYPE". We have followed recommendation 73F, article 73.2 and 73.2.1 of ICZN for considering the specimen from OUMNH as "Syntype". The female syntype specimen (Image 32) has a remarkable deformity as stated by Westwood (1848: 72): "The specimen figured is a singular monstrosity; the middle leg on the right side having the coxa and trochanter of the normal form, followed by three femora conjoined together at the base, each with its perfect tibia, and with one imperfect and two perfect tarsi".

Ecology of Indian *Cryptalaus* species

Four Indian species are represented only from females: *C. alveolatus*, *C. assamensis*, *C. lynceus*, and *C. nodulosus*. Except for *C. alveolatus* all the above species are known from a limited number of specimens. *Cryptalaus* larvae are predaceous on immature wood-boring longhorn beetles. Stebbing (1914) reports larvae of *C. sculptus* as predaceous on Sal tree, *Shorea robusta*, and cerambycid, *Hoplocerambyx spinicornis* (Newman). According to the data label under a specimen at FRI, (the larva of) *C. sordidus* is predaceous on *Neoplocaederus obesus* (Gahan) (= *Plocaederus obesus*). For brief insights on ecology of some *Cryptalaus* species and bionomics of *C. sordidus* see Beeson (1941: 297, 298). Besides *C. sordidus*, very little knowledge is available about the larval stages and biology of other Indian *Cryptalaus* species.

Key to known Indian species of *Cryptalaus* Ôhira, 1967

1. Pronotum with transverse median carina near base 2
– Pronotum without transverse median carina near base 5

2. Anterior edge of pronotum smooth without any medioanterior projections .... ***C. sordidus* (Westwood, 1848)**
– Anterior edge of pronotum sinuous with two teeth-like projections medioanteriorly 3

3. Sides of pronotum evenly convex, anterior angles of pronotum acute in dorsal view; elytral interstriae flat .... ***C. eryx* (Candèze, 1874)**
– Sides of pronotum irregularly convex to subparallel, anterior angles of pronotum broad in dorsal view…4

4. Pronotum 1.18–1.19 times as long as wide, two eye-like spots of black pubescence oval, deviated towards central axis, median longitudinal region glabrous with a carina; elytra 1.88–2.03 times as long as pronotum, apex of elytra emarginate .... ***C. assamensis* (Schwarz, 1902) comb. nov.**
– Pronotum 1.15 times as long as wide, two eye-like spots of black pubescence round, two teeth-like projections on anterior edge raised and pointed; elytra 2.19 times as long as pronotum, apex of elytra emarginate with lateroapical region conspicuously produced with spine .... ***C. nodulosus* (Waterhouse, 1877) comb. nov.**

5. Scutellar shield strongly declivous and folded in two planes, anterior vertical and posterior horizontal; elytral apex truncate or emarginate 6
– Scutellar shield declivous in single slanting plane; elytral apex rounded .... ***C. lynceus* (Candèze, 1874)**

6. Pronotum with sides sinuate to narrowly convex, posterior angles elongate, with conspicuous longitudinal median ridge, median basal tubercle raised and rounded; elytral apex emarginate with sutural and lateroapical spine .... ***C. alveolatus* sp. nov.**
– Pronotum with sides strongly convex, posterior angles broad, disc with irregular surface and without longitudinal median ridge, median basal tubercle raised in transverse ridge; elytra with apex truncate to slightly emarginate due to produced sutural region .... ***C. sculptus* (Westwood, 1848)**

DISCUSSION

The species of the genus *Cryptalaus* Ôhira are widespread in the Oriental and Australian regions. In India, however, the presence of the genus was mainly from the northern part. The recent checklists by Cate (2007) and Chandra et al. (2018) were the only source of knowledge for Indian *Cryptalaus*. A few species from these checklists such as *Cryptalaus berus*, *C. cenchris, C. eryx*, *C. griseofasciatus*, and *C. sordidus* were described originally from Japan, Oriental India (Eastern India; Laos, Myanmar), Laos, Borneo, and Sri Lanka, respectively. In this study, only the presence of *C. eryx* and *C. sordidus* from the Indian subcontinent is confirmed and a new species, inhabiting the Western Ghats and central India, is discovered. During the examination of *Cryptalaus* species, a single specimen each for species *Alaus assamensis* and *Alaus nodulosus* was discovered from the museum collection and transferred to *Cryptalaus*. This study confirms the following seven *Cryptalaus* species from India: *C. alveolatus* sp. nov., *C. assamensis* comb. nov., *C. eryx*, *C. lynceus*, *C. nodulosus* comb. nov., *C. sculptus*, *C. sordidus*.

The present study also finds that the characters like the length ratio between antennomeres II–IV, anterior angles of pronotum and hypomeron vary significantly between the species. Thus, these characters, along with others, can be used for distinguishing the congeners. Future studies on *Cryptalaus* species based on ecological, molecular, and additional morphological data are essential to better our understanding of all congeners.

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COMMUNICATION

Niche overlap of benthic macrofauna in a tropical estuary: diurnal variation

Mário Herculano de Oliveira [1], Lidiane Gomes de Lima [2], Caroline Stefani da Silva Lima [3], Jéssica de Oliveira Lima Gomes [4], Franciely Ferreira Paiva [5], Graciele de Barros [6], Carlinda Railly Medeiros [7] & Joseline Molozzi [8]

[1–6] Programa de Pós-Graduação em Ecologia e Conservação, Universidade Estadual da Paraíba, Paraíba, Brazil.
[7] Programa de Pós-graduação em Ecologia, Universidade Federal do Pará, Pará, Brazil.
[8] Departamento de Ciências Biológicas e da Saúde; Programa de Pós-graduação em Ecologia e Conservação, Universidade Estadual da Paraíba, 58429-500, Campina Grande, Paraíba, Brazil.
[1] mariohecules@hotmail.com (corresponding author), [2] lidianelimauepb@gmail.com, [3] carollinnestefani@hotmail.com, [4] lima.jessica.bio@gmail.com, [5] franciely0903@gmail.com, [6] gracibarross@gmail.com, [7] carlindarailly@gmail.com, [8] jmolozzi@gmail.com

Abstract: The complexity of estuaries allows for the establishment of diverse communities composed of species with different survival strategies. The vertical migration of animals in the sediment is linked to competition, escape from predators and adaptations to diurnal physio-chemical changes related to variations in water levels. The present study aimed to evaluate niche overlap and amplitude, as well as the composition and structure, of communities of polychaetes and molluscs between sediment aliquots during the day and at night. Data sampling was performed in the Tubarão River estuary. The highest individual occurrence was registered during the diurnal period. Communities of polychaetes varied significantly between sediment aliquots during the day and at night, while molluscs did not show diurnal variation. Niche overlap results for polychaetes showed higher values between aliquots during the night, while molluscs showed greater overlap during the day. This indicates that polychaetes and molluscs have different mechanisms of coexistence. This may be related to different attributes of species allowing for the division of resources among individuals. Examination of niche overlap provides insights into coexistence of mechanisms within benthic macroinvertebrate communities.

Keywords: Coexistence, hypersaline estuary, vertical migration, Mollusca, Polychaeta.

Editor: Anonymity requested.

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INTRODUCTION

Estuaries are considered highly productive, complex and heterogeneous ecosystems that allow the establishment of diverse organisms that depend on these habitats for feeding, reproduction, colonization, and protection against predators (Elliot & MCluscky 2002; Kennish 2002; Kaiser et al. 2005; Vasconcelos et al. 2007; Potter et al. 2010). Estuarine dynamics are influenced by seasonal, monthly & daily variations, and consequently the concentrations of organic matter, nutrients, and water level can oscillate during these periods (Dyer 1979). These variations come from chemical, physical and biological alterations, causing changes at spatial and temporal scales in the functioning of biological communities (Officer & Lynch 1981; Day et al. 2012; Medeiros et al. 2016).

Among the communities that inhabit estuarine ecosystems, benthic macroinvertebrates, mainly represented by Polychaeta and Mollusca, have important roles in the decomposition of organic matter, nutrient cycles, and energy fluxes (Nunes et al. 2008; Wildsmith et al. 2011; Tweedley et al. 2012). Benthic macroinvertebrates can migrate vertically within the sediment according to spatial and temporal scales, reacting to the variations of environmental conditions (Cardoso et al. 2010). Thus, vertical migration of organisms in the sediment can occur in function of their tolerance to limiting factors (e.g., light availability), life strategy (e.g., protection against predators) or feeding habits (Cardoso et al. 2010). This locomotive ability is related to the presence of determined functional traits of each species (e.g., related to feeding category, larvae development and body size) (Esselink & Zwarts 1989; Cruz-Motta 2005; Persson & Svensson 2006).

It has been observed in the sand/mudflats of estuaries, that the vertical locomotion of invertebrates is influenced according to light availability or tide cycle (Yannicelli et al. 2001). In this case, the pattern of vertical migration in relation to tide cycles, determines the density of macrofauna in the sediment as a form to escape adverse conditions. That is, during low tide, organisms can migrate to protect themselves from predators, while during higher tides, organisms, when moving vertically, can maximize foraging opportunities (Cardoso et al. 2010). Diurnal changes also generate vertical migration, regulated according to light availability, that alter the visibility, and consequently influence organisms' survival in the presence of predators (Estlander et al. 2017). In addition, vertical migrations can also be enhanced when the organisms of a community share the same functional categories, this can result in greater niche overlap causing the development of strategies which, consequently, results in the use of different resources and organism coexistence (Silva-Camacho et al. 2017).

Hypervolume niche concept was stated by Hutchinson (1957) who considered a niche as multidimensional space in which species might be established in accordance with their demands relative to abiotic factors and resources. Abiotic factors limit species distribution through their physiological tolerance and space and food as resources limited through competition among species when they are scarce (Kraft et al. 2015). Some strategies developed by species viewing coexistence are: the species may use their resources differently in spatial and temporal scales (Devictor et al. 2010) or functional traits of species (Violle 2007) which allow them to explore a wider range or to specialize in a narrow range of resources (Devictor et al. 2010). In this way, these strategies are not only important to understand the mechanism underlying community assembly processes but also to understand how the complexity of species interactions influence their occurrence and their environment defining ecosystem functioning (Dehling & Stouffer 2018).

Researchers have used different parameters related to species' niches, such as amplitude and niche overlap, associated with other parameters of functional traits that can aid in the understanding of species coexistence. However, the understanding of how benthic macrofauna species utilize their habitat resources in relation to vertical distribution, according to light availability (diurnal variation), has been neglected. Understanding the pattern of vertical distribution of species in the sediments of tropical estuaries and coexistence strategies of benthic macrofauna, is a key factor in describing the importance of these organisms in the maintenance of ecosystem functions. As such, the aim of this study was to evaluate amplitude and niche overlap, as well as the composition and structure of polychaete and mollusc communities between sediment aliquots during day and night periods. The questions that directed this study were: i) are there differences in the composition and taxonomic structure of polychaete and mollusc communities when comparing sediment aliquots analyzed during the day and night? and ii) does niche overlap and the overlap of polychaete and mollusc functional trophic groups occur, when comparing the sediment aliquots during day and night?

MATERIAL AND METHODS

Study area

The Tubarão River is located in the semiarid coast of the state of Rio Grande do Norte, northeastern Brazil (-5.09361111, -36.53916667) (Figure 1), inserted on the limits of the Sustainable Development Reserve of Ponta do Tubarão, a protected area with sustainable use administered by the state government. The Tubarão River is an estuarine system which extends a distance of 10 km, presents preserved mangrove vegetation and its surroundings have a variety of ecosystems such as marshes, Caatinga vegetation and dunes (Dias et al. 2007). Based on the precipitation standards, the climate of the region is characterized by higher evaporation rates and a lower pluviometric index with the rainy season occurring between February and May and the dry season occurring between June and January (INMET 2017). Additionally, the freshwater input comes from subterranean waters and from the lower precipitation of the region (Queiroz & Dias 2014, Medeiros et al. 2016). The average rainfall between January and June is 161 mm (INMET 2010, 2017).

This study was performed throughout the estuary, where we defined three zones: upstream, intermediate and downstream. The sampling was carried out covering all the variation of the environmental variables of the estuarine ecosystem, from the continental drainage to the sea (Figure 1). The upstream zone presents lower profundity and higher evaporation rates with salinity varying between 30 and 50 and the predominant substrate is sandy and muddy. The intermediate zone presents salinity between 32 and 45, with muddy substrates. The downstream zone is located near the sea, with salinity between 35 and 45, and the predominant substrate is sandy with an abundance of gravel (Sales et al. 2016).

Sampling procedures

Samples were collected in May 2017, during the rainy season. In each zone (upstream, intermediate, and downstream) three sampling points were determined,

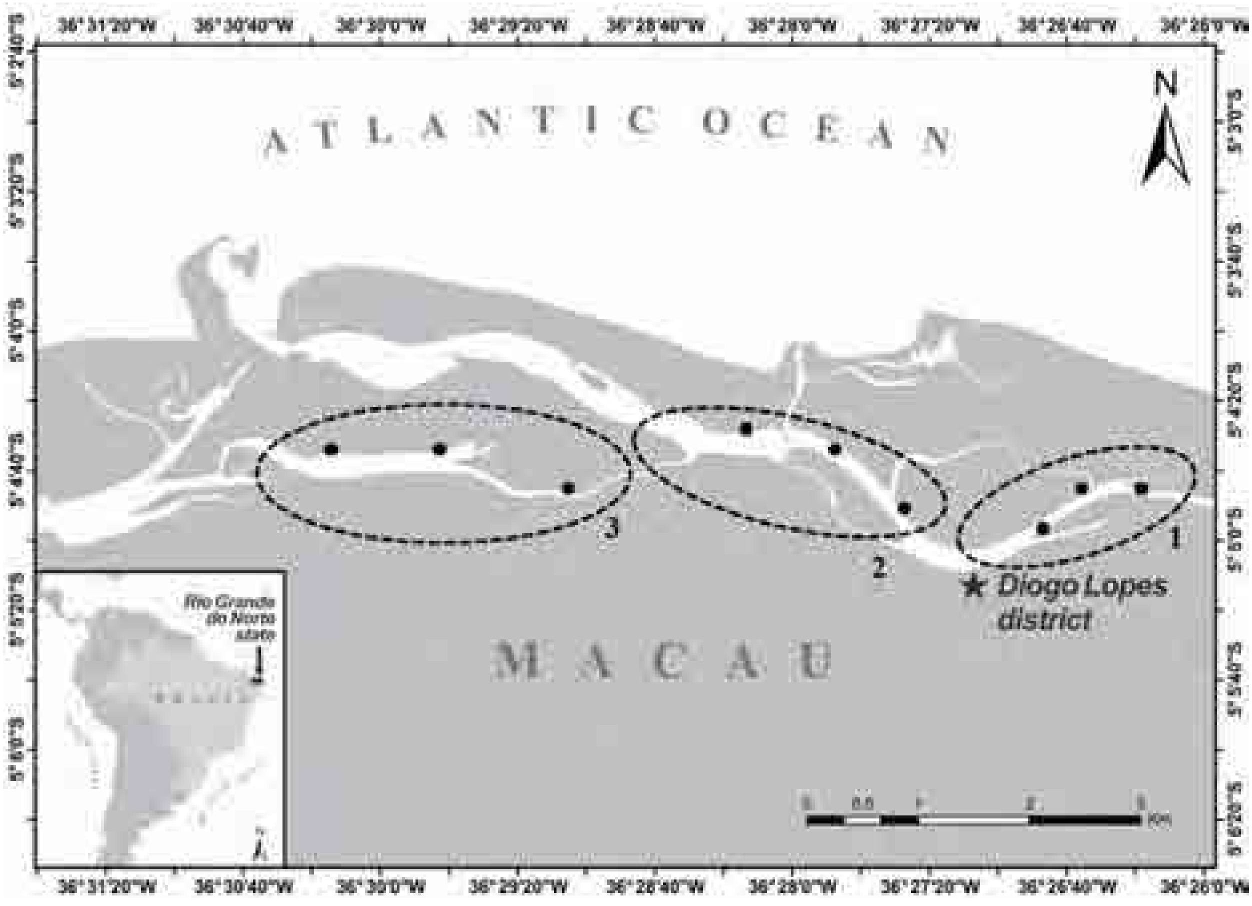

Figure 1. Tubarão River estuary, Rio Grande do Norte, highlighting the sampling zones of benthic macrofauna: (1) Greater, (2) Intermediate, (3) Downstream, and ( ) Sampling point.

totaling nine points across the estuary. The benthic macrofauna was sampled once during the day and at night, utilizing a PVC cylindrical core (16.67 cm²). The core was buried in the substrate (profundity 10 cm) and posteriorly the sediment was partitioned in two aliquots: A1 (0 to 5 cm) and A2 (5 to 10 cm). The interval between diurnal and nocturnal sampling was 12 hours. The benthic macroinvertebrates were sampled in the intertidal region, always during low tide. The samples were washed in a 500 micro mesh sieve for the separation of benthic macrofauna. Organisms were preserved in 70% alcohol.

Laboratory procedures

In the laboratory, the organisms were separated and identified to the lowest possible taxonomic level with specialized keys for Polychaeta (Amaral & Nonato 1996; Amaral et al. 2006), and a specialized bibliography for Mollusca (Rios 2009; Tunnel Jr. et al. 2010). In addition, the Conquiliologistas site of Brazil was consulted (www.conchasbrasil.org.br) and the nomenclature followed the database Malacolog 4.1.1 (Rosenberg 2009).

Measurement of niche breadth and overlap

Niche breadth and overlap analyses were performed to quantify how many species and functional guilds partitioned the spaces as resource between aliquots. The Morisita simplified index (Krebs 1989) was calculated to analyze the niche overlap of the functional trophic groups of polychaetes and molluscs between day and night aliquots based on abundance data. The index value varies from zero to one: when the index is zero or close to zero, the overlap is low or absent, while when equal to or close to one, the niche overlap is high or total. To analyze the taxonomic niche breadth and functional trophic amplitude of polychaetes and molluscs groups, the Shannon-Wiener (H') diversity index was used based on abundance data (Shannon & Weaver 1949), which corresponds to the niche breadth, considered high when close to one. These analyses were carried out in the "spaa" package, in the statistical software program R 1.9.0 (R Development Core Team 2017).

Composition and taxonomic structure

For the analysis of the composition and taxonomic structure of polychaetes and molluscs communities, species richness was analyzed using the Shannon-Wiener (H') index and Pielou (J') equitability. Species richness reflects the number of different species in an area, while the Shannon-Wiener index considers the richness and species equitability, both abundant and rare (Shannon & Weaver 1949). The Pielou (J') equitability index reflects the uniformity and species' distribution (Pielou 1966).

Functional trophic guilds

Macrofauna benthic taxa were classified within functional trophic guilds according to the food resources consumed, based not only on the type of resource, but also on the morphological and behavioral mechanisms of acquisition, following Fauchald & Jumars (1979) and Muniz & Pires (1999) for polychaetes and Linden et al. (2017), Mikkelsen & Bieler (2008) and Rosenberg et al. (2009) for molluscs (Table 1). Five guilds were considered for polychaetes: Carnivore (Car), Deposit feeder: digger (DC) e Deposit feeder: surface (DS), Filter feeder (Fil), Omnivore (Omn), while six guilds were considered for molluscs: Carnivore, Filter feeder, Herbivore (Her), Omnivore, Scavenger (Sce), and Suspension feeder (Sus). Functional trophic guilds were chosen as they reflect the distribution of resources in the ecosystem, the mechanism of adaptation and coexistence of species, in addition to influencing ecosystem processes, such as energy flow and nutrient cycle (Pearson & Rosenberg 1978; Dolbeth et al. 2015).

Data analyzes

To test the differences in the taxonomic composition and trophic guilds of polychaetes and molluscs between the sediment aliquots during the day and night, a Permutational Multivariate Analysis of Variance (PERMANOVA) (with 9999 permutations, $p \leq 0.05$) was performed, considering a factor (aliquots) with two fixed levels (A1 and A2) for day and night. For this, the abundance data was transformed into square

Table 1. Functional trophic guilds of polychaetes and molluscs and their importance in demonstrating the relationships of organisms with the ecosystem.

	Functional trophic guilds	Rationale
Polychaeta	Carnivore	Reflects the distribution of resources in the ecosystem and the adaptation of the species to the habitat. As well as influencing ecosystem processes such asenergy flux and nutrient cycling (Pearson & Rosenberg 1978; Dolbeth et al. 2015).
	Deposit feeder: digger	
	Deposit feeder: surface	
	Filter feeder	
	Omnivore	
Mollusca	Carnivore	
	Filter feeder	
	Herbivore	
	Omnivore	
	Scavenger	
	Suspension feeder	

root values and a Bray-Curtis matrix was utilized as a dissimilarity measurement. To verify differences in the taxonomic structure of the polychaetes and molluscs between sediment aliquots during the day and night, analyzes of univariate significance were applied to species richness, Shannon-Wiener index, and Pielou equitability, considering a factor (aliquots) with two fixed levels (A1 and A2) for day and night (PERMANOVA; 9999 permutations; p ≤0.05). For this analysis the coefficient of euclidean distance was utilized as a measure of dissimilarity. All the analyzes were performed using the statistical software PRIMER-6 + PERMANOVA (Anderson et al. 2008).

RESULTS

Composition and taxonomic structure of polychaete and mollusc communities

A total of 1,329 individuals were captured and distributed across 19 and 21 polychaete and mollusc taxa, respectively (Supplementary material: T1; Figure 2). The highest individual occurrences (705) were registered during the diurnal period, accounting for 53% of the total abundance. During the day, aliquot A1 obtained the highest abundance of polychaetes, Cirratulidae (25%), Capitellidae (12%), and the bivalve *Anomalocardia flexuosa* (11%), while the polychaetes Orbiniidae (20%), Ampharetidae (15%), and the bivalve *A. flexuosa* (10%) had the highest abundances in aliquot A2 (Figure 2). During the night, 624 individuals were captured with higher abundances registered in aliquot A1 for the polychaetes Cirratulidae (28%), Spionidae (8%), and the bivalve *A. flexuosa* (8%). In aliquot A2, the polychaetes Cirratulidae (25%) and bivalves *A. flexuosa* (17%) & *Phacoides pectinatus* (15%) were most abundant (Figure 2).

PERMANOVA results show that the polychaetes group varied significantly between the sediment aliquots during the day (Pseudo-$F_{1,37}$= 2.3226; p= 0.027), as well as during the night (Pseudo-$F_{1,41}$= 2.8135; p= 0.007). The molluscs did not present variation between the day and night sediment aliquots, (day: Pseudo-$F_{1,31}$= 1.4734; p= 0.21; night: Pseudo-$F_{1,37}$= 1.9075; p= 0.079). The species richness, Shannon-Wiener index, and Pielou equitability varied significantly between sediment aliquots during the day and night for polychaetes and molluscs (Table 2).

Overlap and breadth of polychaetes and molluscs taxonomic niches

Overlap results showed higher values between the aliquots for polychaetes during the night and molluscs during the day (Table 3). For polychaetes niche breadth, the taxa Orbiniidae, Ampharetidae, Pilargidae, and Onuphidae were found to exhibit higher values when comparing day aliquots, while Ampharetidae, Pilargidae, Onuphidae, Dorvilleidae, and Nereididae demonstrated higher values at night (Table 3). The molluscs, Veneridae sp., *A. succinea*, and *Macoma* sp.1, exhibited higher niche breadths during the day and *P. pectinatus*, *B. varium*, *C. cariabaea*, *S. fragilis* at night (Table 3).

Overlap and breadth of functional trophic guilds

The functional trophic guilds of polychaetes that obtained higher proportions were Deposit feeder: digger, Deposit feeder: surface, Carnivore and Filter feeder, while for molluscs, the abundant guilds were Filter feeder, Suspension feeder, and Scavenger (Figure 3). For the polychaetes community, the guilds Deposit feeder: digger (42%), Carnivore (24%), and Deposit feeder: surface (21%) were most abundant in aliquot A1, while Deposit feeder: digger (44%), Deposit feeder: surface (33%) and filter feeder (11%) were most abundant in aliquot A2 during the day. During the night, Deposit feeder: digger (50%), Carnivore (18%), Deposit feeder: surface (15%) and filter feeder (14%) presented higher abundance proportions in aliquot A1, and Deposit feeder: digger (49%), Carnivore (27%), Deposit feeder: surface (18%) in aliquot A2. Significant differences in the abundance of trophic guilds were observed only between day and night periods for Molluscs (Pseudo-$F_{1,68}$ = 4.05; p= 0.0513) and between aliquots for polychaetes (Pseudo-$F_{1,76}$= 2.98; p= 0.0368).

The functional trophic groups of polychaetes, Carnivore, Deposit feeder: surface and Omnivore exhibited higher breadth during the night while Filter feeder were more representative during the day (Table 4). For the molluscs, the only functional trophic group with higher amplitude was Suspension feeder for both day and night periods (Table 4).

DISCUSSION

The macrobenthic community of the Tubarão River varied quantitatively and qualitatively between day and night periods, exhibiting a pattern of vertical distribution in the sediment, possibly determined by ecological preferences and as a result of the interactions between species throughout the estuary which was corroborated with Hutchinson's niche concept (Hutchinson 1957) who stated that a combination of abiotic and biotic factors

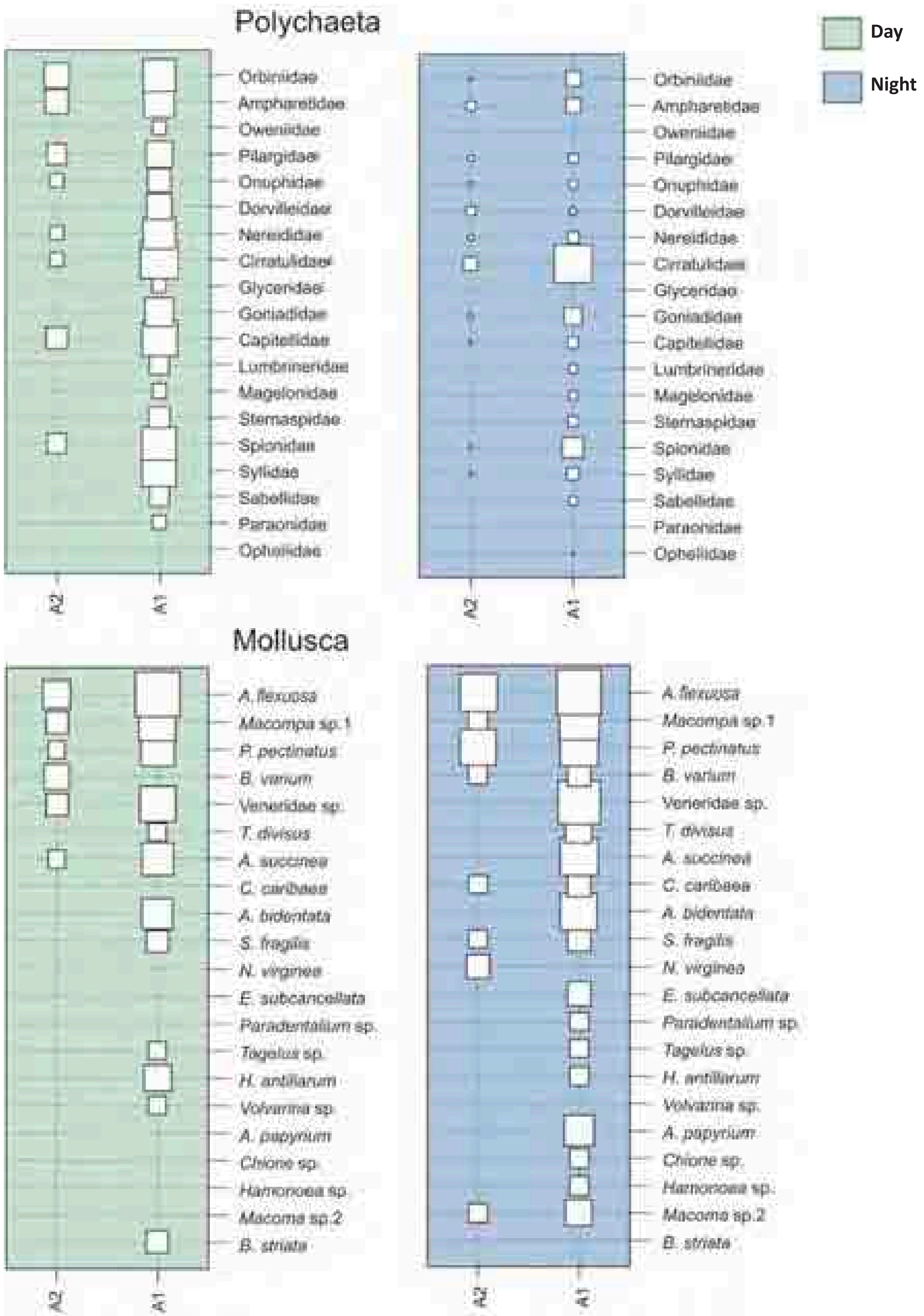

Figure 2. Abundance (%) of polychaetes and molluscs taxa in aliquots during the diurnal and nocturnal periods in the Tubarão River estuary, Macau-RN, northeastern Brazil. The box sizes are determined by the abundance of taxa.

Table 2. PERMANOVA values for the taxonomic diversity of polychaetes and molluscs between day and night sediment aliquots (A1 e A2), in the Tubarão River estuary, Macau-RN, northeastern Brazil.

Polychaeta										
	Day	(A1xA2)				**Night**	(A1xA2)			
	Df	SS	MS	Pseudo-F	P(perm)	Df	SS	MS	Pseudo-F	P(perm)
Richness	1	156.06	156.06	39.373	0.0001	1	110.01	110.01	32.225	0.0001
Shannon-Wiener	1	10.542	10.542	44.901	0.0001	1	8.0869	8.0869	28.991	0.0001
Pielou	1	4.2535	4.2535	38.865	0.0001	1	1.9306	1.9306	12.44	0.001
Mollusca										
	Day	(A1xA2)				**Night**	(A1xA2)			
	Df	SS	MS	Pseudo-F	P(perm)	Df	SS	MS	Pseudo-F	P(perm)
Richness	1	39.014	39.014	29.061	0.0001	1	66.125	66.125	15.651	0.0001
Shannon-Wiener	1	4.7689	4.7689	33.107	0.0001	1	3.9247	3.9247	16.981	0.0002
Pielou	1	2.6835	2.6835	22.399	0.0001	1	1.9569	1.9569	15.462	0.0004

Table 3. Results of the niche overlap of polychaetes and molluscs abundance between day and night periods in the Tubarão River estuary, Macau-RN, northeastern Brazil.

	Polychaeta	**Day**	**Night**
Niche overlap/ Taxonomic Niche breadth	A1 vs. A2	0.47	0.88
	Orbiniidae	0.47	0.17
	Ampharetidae	0.47	0.57
	Pilargidae	0.51	0.56
	Onuphidae	0.45	0.56
	Dorvilleidae	-	0.63
	Nereididae	0.11	0.48
	Cirratulidae	0.03	0.37
	Goniadidae	-	0.21
	Capitellidae	0.19	0.28
	Spionidae	0.20	0.10
	Syllidae	-	0.24
	Mollusca	**Day**	**Night**
Niche overlap/ Taxonomic Niche breadth	A1 vs. A2	0.81	0.61
	A. flexuosa	0.20	0.54
	*Macoma*sp.1	0.29	0.17
	P. pectinatus	0.27	0.68
	B. varium	-	0.63
	Veneridae sp.	0.33	-
	A. succinea	0.32	-
	C. cariabaea	-	0.63
	S. fragilis	-	0.63
	*Macoma*sp.2	-	0.56
	B. striata	-	-

influence species occurrences in given habitats relative to their preferences. These results are an important contribution to understanding how macrobenthic communities interact with each other and select their preferential habitats in tropical estuaries. Other studies (e.g., Poole & Stewart 1976) have demonstrated that variation in benthic macroinvertebrates communities exists in function of sediment profundity, which corroborates our results. A study conducted in an estuary of Portugal found that the vertical migration patterns of macroinvertebrates depend mainly on the size and feeding behavior of individuals (Cardoso et al. 2010).

Over short time-scales, individuals can move within sediments as a result of feeding behavior or to escape from predators (Goeij et al. 2001; Person & Svensson 2006). This may be the reason why the polychaete and mollusc presented functional and taxonomic differences between sediment aliquots. Vertical migration behavior can also be observed in other communities, such as zooplankton, which migrate from the water column to submerged macrophytes, avoiding open water predators (Sagrario & Balseiro 2010). Our results showed that polychaetes and molluscs had a greater abundance in aliquot A2 at night when compared to the day period. This result may be related to a survival strategy used by these taxonomic groups to escape from predators (e.g., fish) at night. In contrast, the considerable increase in nocturnal carnivorous polychaetes may be related to feeding behavior and food availability for these species at night. Other factors that can generate vertical migration are reproductive processes that occur mainly during

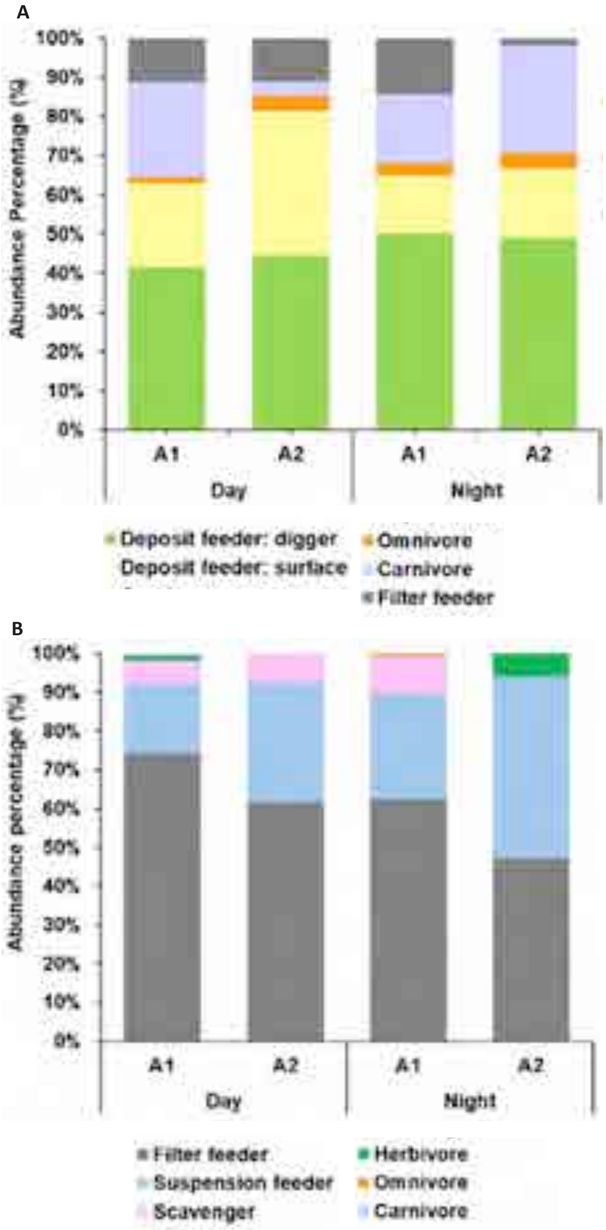

Figure 3. Percentage of functional trophic guilds during the day and night in the Tubarão River estuary, Macau-RN, northeastern Brazil. (A) functional trophic guilds of polychaetes, and (B) functional trophic guilds of molluscs.

Table 4. Overlap of polychaetes and molluscs functional trophic groups between day and night periods in the Tubarão River estuary, Macau-RN, northeastern Brazil.

Polychaeta		Day	Night
Functional overlap	Deposite feeder: digger	0.20	0.36
	Deposite feeder: surface	0.28	0.41
	Omnivore	0.34	0.41
	Carnivore	0.04	0.47
	Filter feeder	0.19	0.09
Mollusca		**Day**	**Night**
Functional overlap	Filter feeder	0.24	0.38
	Suspension feeder	0.38	0.56
	Scavenger	0.32	-

seasonal fluctuations (Cardoso et al. 2010), although this was not tested in this study.

The high niche overlap observed for the polychaete and mollusc indicates that there are coexistence mechanisms working in these communities, thus allowing the partitioning of resources between individuals. However, the mechanisms of coexistence that act on polychaetes and molluscs, act at opposing times. Different times for daily foraging are strategies used by individuals to reduce competition, allowing the partition and coexistence of food (Sánchez-Hernández et al. 2011). The different types of trophic guilds used by the species in this study may explain their coexistence. According to Kneitel & Chase (2004), alternative traits can enable the exploration of the same type of resource by different strategies, ensuring coexistence between species. This may explain the fact that in this study we found different types of trophic guilds, such as Filter feeder, Deposit feeder: digger, Deposit feeder: surface and Suspension feeder, that utilize the same type of resource, with different methods of capture.

The significant differences of the mollusc trophic guilds between the aliquots may be explained by the reduction in abundance of the three species that demonstrated the highest abundance during the day. The variation in the contribution of Suspension feeders occurred mainly by the elevation of *Phacoides pectinatus* density during the day. Some species of the Lucinidae family, such as *P. pectinatus* have specializations for surviving in environments with a lower oxygen content, under these conditions these species are likely to have symbiosis with sulfide oxidant bacteria (Taylor & Glover 2006), which allows for the displacement of individuals to areas of deep sediment.

It is possible that the higher abundance of *A. flexuosa* in both aliquots was due to the fact that the sampling period included the start of the rainy season, which is linked to the greatest reproductive activity of the specie (Boehs et al. 2008). This may also explain the high proportions of polychaete families, Capitellidae and Cirratulidae, according to Giangrande & Simonetta (1993) and Gibbs (1971). These authors showed that these species from both families increase their reproductive activity during the month of May.

CONCLUSION

In conclusion, the polychaetes and mollusks groups occupied different functional guilds and presented dynamics of vertical migration in the sediment during the diurnal period, which may be a strategy used by species to obtain food resources, reproduce and persist in the environment under adverse conditions (for example, escape predation). These results provide information on the mechanisms of coexistence of benthic macroinvertebrate communities and may support other studies aimed at the conservation of tropical estuaries.

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Supplementary Material 1. Composition, numerical abundance and functional trophic guilds of the taxa of Polychaeta and Mollusca captured at day and at night in the Tubarão River Estuary, Macau-RN, northeastern of Brazil. Functional trophic guilds: Car—Carnivore | Fil—Filter feeder | Her—Herbivore | DC—Depositer feeder: digger | DS—Deposite feeder: surface | Omn—Omnivore | Sce—Scavenger | Sus—Suspension feeder.

Benthic macroinvertebrate communities			
	Day (A1/A2)	Night (A1/A2)	Trophic functional guilds
Polychaeta			
Orbiniidae	36/8	23/1	DC
Ampharetidae	27/6	23/8	DS
Oweniidae	1/0	0/0	DC
Pilargidae	11/3	9/3	DC
Onuphidae	5/1	6/2	Omn
Dorvilleidae	9/0	4/8	Car
Nereididae	41/1	13/3	Car
Cirratulidae	165/1	149/21	DC
Glyceridae	1/0	0/0	Car
Goniadidae	16/0	33/3	Car
Capitellidae	77/4	11/1	DS
Lumbrineridae	2/0	6/1	Omn
Magelonidae	1/0	7/0	DS
Sternaspidae	4/0	12/0	DS
Spionidae	55/3	45/1	Fil
Syllidae	56/0	14/1	Car
Sabellidae	3/0	7/0	Fil
Paraonidae	1/0	0/0	DS
Opheliidae	0/0	1/0	DC
Polychaeta total abundance:	**538**	**416**	
Mollusca			
Anomalocardia flexuosa	75/4	45/14	Fil
*Macoma*sp.1	21/2	23/1	Fil
Phacoides pectinatus	12/0	16/14	Sus
Veneridae	17/2	37/0	Fil
Bittiolum varium	0/3	2/1	Sus
Tagelus divisus	1/0	3/0	Sus
Assiminea succinea	9/1	17/0	Sce
Caryocorbula caribaea	0/0	2/1	Fil
Acteocina bidentada	7/0	14/0	Sus
Sphenia fragilis	2/0	2/1	Sus
Neritina virginea	0/0	0/2	Her
Ervilia subcancellata	0/0	2/0	Fil
Paradentalium sp.	0/0	1/0	Omn
Tagelus sp.	1/0	1/0	Sus
Haminoea antillarum	4/0	1/0	Sus
Volvarina sp.	1/0	0/0	Car
Amygdalum papyrium	0/0	5/0	Sus
Chione sp.	0/0	1/0	Fil
Haminoea sp.	0/0	1/0	Sus
Macoma sp.2	0/0	3/1	Sus
Bulla striata	2/0	0/0	Her
Mollusca total abundance:	**164**	**211**	
Macroinvertebrate total abundance:	**702**	**627**	

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COMMUNICATION

Diversity of aquatic insects and biomonitoring of water quality in the upper Ganga River, a Ramsar site: a preliminary assessment

Kritish De [1], Arkojyoti Sarkar [2], Kritika Singh [3], Virendra Prasad Uniyal [4], Jeyaraj Antony Johnson [5] & Syed Ainul Hussain [6]

[1–6] Wildlife Institute of India, Chandrabani, Dehradun, Utarakhand 248001, India.
[1] Present address: Department of Life Sciences, Sri Sathya Sai University for Human Excellence, Navanihal, Okali Post, Kamalapur, Karnataka 585313, India.
[1] kritish.de@gmail.com (corresponding author), [2] arko.joti777@gmail.com, [3] kritika17singh@gmail.com, [4] uniyalvp@wii.gov.in, [5] jaj@wii.gov.in, [6] hussainsyedainul@wii.gov.in

Abstract: Monitoring of freshwater habitats through aquatic insects is widely used. A study was carried out in March, 2019 at 14 sites in the Upper Ganga River between Brijghat and Narora, a riverine Ramsar site in India, to document the diversity of three major aquatic predatory insect groups—Odonata, Coleoptera, and Hemiptera—and determine their biomonitoring potential. The study recorded three species of Coleoptera, four Hemiptera, 14 dragonflies, and eight damselflies. The Shannon diversity index (H') ranged from 2.465 to 2.782, Pielou's Evenness index (J') from 0.841 to 0.894, and Berger–Parker index of dominance (d) from 0.122 to 0.243. Families Libellulidae (Odonata), Coenagrionidae (Odonata) and Gerridae (Hemiptera) had high relative abundance and dominant status. The stream invertebrate grade number-average level (SIGNAL2) score (for family) ranged from 2.316 to 3.174, lying within quadrant 2 of the SIGNAL2 (family) quadrant diagram. This suggested that the water in the area is likely to have high levels of turbidity, salinity, or nutrients, caused naturally or by anthropogenic activities, and the water has low levels of most toxic chemicals.

Keywords: Coleoptera, Hemiptera, Odonata, SIGNAL2 (family) score.

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Author details: Kritish De worked as project fellow at the Wildlife Institute of India. Presently he is working as Assistant Professor at Sri Sathya Sai University for Human Excellence. His research interests are biodiversity and ecology. Arkojyoti Sarkar is working as project fellow. His research interests are biodiversity and ecology. Kritika Singh worked as project intern. Her research interest is monitoring of environmental health. Virendra Prasad Uniyal is working as Scientist G. His research interests are ecology and systematics of insects, bioindicators, biodiversity, and ecological monitoring. Jeyaraj Antony Johnson is working as Scientist E. His research interests are ecology and monitoring of aquatic ecosystems. Syed Ainul Hussain worked as Scientist G. His research interests are aquatic ecology and conservation biology.

Author contributions: KD—conceptualization, field work, formal analysis, writing original draft; AS—field work, writing original draft; KS—field work, writing original draft; VPU—supervision, review and editing the draft; JAJ—supervision, review and editing the draft; SAH—supervision, review and editing the draft, funding acquisition.

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NAMAMI GANGE

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

INTRODUCTION

Freshwater habitats occupy 1% of the earth's surface (Strayer & Dudgeon 2010), and in addition to supporting many species freshwater ecosystems provide goods and services of critical importance to human societies. Nevertheless, they are among the most heavily altered ecosystems, with proportional loss of biodiversity (Geist 2011), owing to human activities that have led to widespread habitat degradation, pollution, flow regulation, water extraction, fisheries overexploitation, and alien species introductions (Strayer & Dudgeon 2010). Alterations of natural flow regimes by manmade dams, land use changes, river impoundments and water abstraction often have profound impacts on lotic communities (Geist 2011). Aquatic insects are an indispensable part of food webs and of nutrient cycling in freshwater ecosystems, and they are essential components of the diets of fish, amphibians and many birds and mammals (Morse 2017). Their abundance and responses to changes in their environment make aquatic insects key indicators for monitoring the effects of human activity on water quality (Adu & Oyeniyi 2019), and they widely used for freshwater ecosystem monitoring (Souto et al. 2019).

In India, 42 wetlands of international importance (i.e., Ramsar sites) cover 1,081,438 ha according to the Ramsar Sites Information Service (https://rsis.ramsar.org/sites/default /files/rsiswp_search/exports/Ramsar-Sites-annotated-summary-India.pdf?1625598230). Among these wetlands, information on aquatic insect communities and their utility is scant. There are a few studies available on aquatic insect communities of Indian Ramsar sites such as eastern Kolkata wetlands in West Bengal (Sahaet al. 2007), Pong Dam in Himachal Pradesh (Babu et al. 2009), Loktak Lake in Manipur (Takhelmayum & Gupta 2011, 2015), Deepor beel in Assam (Sharma & Sharma 2013; Choudhury & Gupta 2017), and Nalsarovar Bird Sanctuary in Gujarat (Rathod & Parasharya 2018).

The use of insects as bioindicators is a low-cost strategy for preliminary assessments of the water quality of inland freshwater bodies, as it avoids the use of expensive analytical methods (Pal et al. 2012). The top predators among insects in aquatic ecosystems include aquatic Coleoptera, Hemiptera, and Odonata (Klecka & Boukal 2012). This study assessed diversity of these groups in the upper Ganga River, a Ramsar site; the goal of using them as indicators of water quality.

MATERIALS AND METHODS

The study was conducted in an 85-km stretch of the river Ganga from Brijghat to Narora in Uttar Pradesh (Figure 1). This section of the river was declared a Ramsar site in 2005 and is generally characterized by shallow water, although some deep water pools are present inhabited by conservative significant species such as Ganges River Dolphin, Gharial, crocodiles, turtles, otters, 82 species of fish and more than a hundred species of birds. The study was carried out during March 2019. The study area was stratified into 14 sampling sites with a distance of ~5 km between two sites and insect sampling was done at each site. At each study site, sampling was done between 0930 h and 1130 h along the left bank (because of accessibility to the river bank) of the main channel of the river Ganga.

To collect odonates, a 100 m × 20 m transect (subdivided into 20 segments of 5 m) (Juen & De Marco 2011) was placed at each sampling site parallel to and ~1 m beside the main river channel. Adult odonates present in each of these segments were captured using insect collection nets (mesh size 60 µm) and released after identification using published pictorial field guides (Andrew et al. 2008; Subramanian 2009; Nair 2011). For Coleoptera and Hemiptera, a circular net (mesh size 60 µm) was dragged in the open water for one minute and continued three times per site (Subramanian & Sivaramakrishnan 2007). All samples were preserved in 70% ethanol and brought to the laboratory for further analysis. They were later identified at species level using a stereo zoom microscope with the help of taxonomic literature (Bal & Basu 1994a,b; Biswas & Mukhopdhyay 1995; Biswas et al. 1995; Chandra & Jehamalar 2012).

The aquatic insect data were subjected to Shannon diversity index (H'), Pielou's evenness index (J'), and Berger–Parker index of dominance (d) index analysis. The dominant status of the insects was calculated according to Engelmann's scale (1978) in which if relative abundance of a species is up to 1%, it is considered as subrecedent; if between 1.1–3.1%, recedent; if between 3.2–10%, subdominant; if between 10.1–31.6 %, dominant, and if 31.7% or more then eudominant.

By evaluating comparative performance of several aquatic health indices, Cox et al. (2019) found that the stream invertebrate grade number-average level (SIGNAL2) is the most sensitive index, family richness percentage is the most robust index, family richness and family richness percentage are the best ranked indices for both measures of usability; but Australian River Assessment System (AUSRIVAS OE50), Ephemeroptera

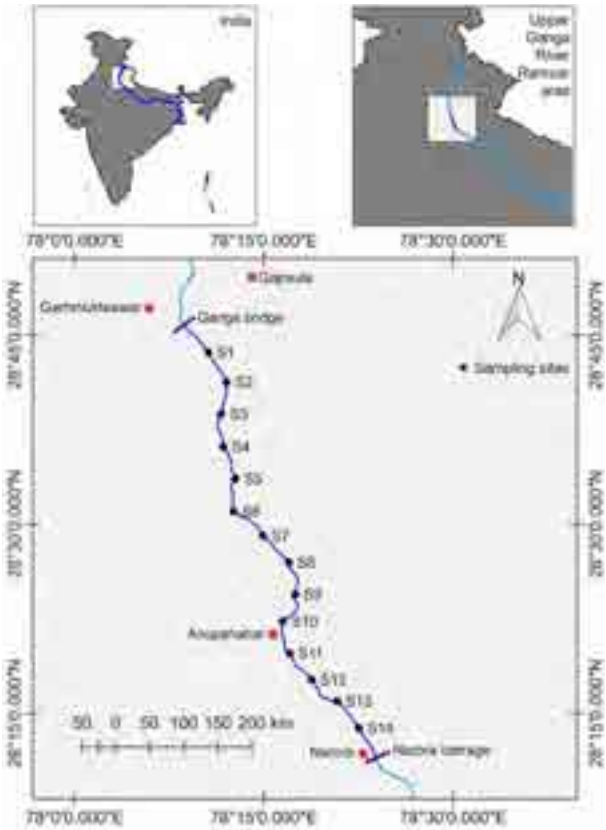

Figure 1. Location of sampling sites (S1–S14) in the Ganga River from Brijghat to Narora, Uttar Pradesh.

Plecoptera & Trichoptera index (EPT), and Bray-Curtis index (BCI) have poor performance to asses river health condition.

In this study, for the assessment of the bioindicator potential of the insects, SIGNAL2 (family) score was used which is a family-level water pollution index based on the known tolerances of aquatic macro-invertebrate families to various pollutants which has a gradient from 1 to 10 (ranging from a pollution tolerant to a pollution sensitive community) (Chessman et al. 1995). The SIGNAL2 (family) scores were plotted in a quadrant diagram (SIGNAL2 score in the y axis and the numbers of families in the x axis) which includes four quadrants. The first quadrant indicates favourable habitat and chemically dilute waters, the second quadrant indicates high salinity or nutrient levels (may be natural), the third quadrant indicates toxic pollution or harsh physical conditions and the fourth quadrant indicates urban, industrial or agricultural pollution, or downstream effects of dams (Chessman et al. 1995).

All the analyses were performed in the software Past 3 (Hammer et al. 2001) and R 3.5.3 (R Core Team 2019).

RESULTS

A total of 29 species of aquatic insects were recorded (Table 1), including three species of Coleoptera belonging to two families, four species of Hemiptera belonging to four families, and 22 species of Odonata belonging to three families. Among the odonates, 14 were dragonflies (Suborder Anisoptera) and eight were damselflies (Suborder Zygoptera). Nine species were recorded from all 14 sampling sites: *Gerriss pinolae* Lethierry & Severin, 1896; *Anisops campbelli* Brooks, 1951; *Brachythemis contaminata* Fabricius, 1793; *Diplacodes trivialis* Rambur, 1842; *Orthetrum sabina* Drury, 1770; *Trithemis aurora* Burmeister, 1839; *Ceriagrion coromandelianum* Fabricius, 1798; *Pseudagrion decorum* Rambur, 1842, and *Pseudagrion rubriceps* Selys, 1876.

The Shannon diversity index (H') ranged from 2.465 (at S8) to 2.782 (at S14) (mean= 2.579, SD= 0.086); Pielou's evenness index (J') was maximum at S7 (J'= 0.894), and Berger-Parker index of dominance (d) ranged from 0.122 (S7) to 0.243 (S11) (mean= 0.170, SD= 0.037). Variation of Shannon diversity index (H'), Pielou's evenness index (J'), and Berger-Parker index of dominance (d) are given in Figure 2.

For families, Gerridae (Hemiptera) was dominant in >92 % of sampling sites, and Notonectidae (Hemiptera) in >28 % of sites. Libellulidae (Odonata) was eudominant in >64 % of sampling sites and dominant in >35 % of sites, while Coenagrionidae (Odonata) was eudominant in >71 % of the sampling sites, and dominant in >28 % of sites. Dominance status in different sites is given in Table 2.

The family richness and the family richness percentage varies from 7 to 9 and 77.77 to 100 %, respectively. Highest family richness and family richness percentage was found at S10.

The SIGNAL2 (family) score ranges between 2.316 (S6) and 3.174 (S11) (mean= 2.579, SD= 0.086). The family richness, family richness percentage and SIGNAL2 (family) score showed an increasing trend in values from S1 to S14 (Figure 3).

The SIGNAL 2 quadrant diagram plots SIGNAL 2 scores (on y axis) against numbers of aquatic invertebrate families (on x axis). Each diagram has four quadrants which represent different status of water and habitat qualities (Chessman 2003). In the present study, the SIGNAL2 (family) score ranged from 2.316 to 3.174 (Figure 3) and fell within the quadrant 2 (Figure 4).

Table 1. List of Coleoptera, Hemiptera, and Odonata recorded from across the study area in different sites of Upper Ganga Ramsar site (+ represents presence and - represent absence).

Species	Sampling sites													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Order: Coleoptera														
Family: Dytiscidae (Predaceous Diving Beetle)														
1. *Cybister limbatus* (Fabricius, 1775)	+	-	-	-	+	+	+	+	-	+	+	+	+	-
2. *Eretes sticticus* (Linnaeus, 1767)	-	+	-	-	+	-	+	-	+	+	+	+	-	-
Family: Hydrophilidae (Water Scavenger Beetle)														
1. *Hydrophilus senegalensis* (Percheron 1835)	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Order: Hemiptera														
Family: Belostomatidae (Water Bug)														
1. *Diplonychus rusticus* (Fabricius, 1781)	-	+	+	+	-	+	-	+	-	+	+	+	-	-
Family: Gerridae (Water Striders)														
1. *Gerris spinolae* Lethierry & Severin, 1896	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Family: Nepidae (Water Scorpion)														
1. *Ranatra elongate* Fabricius, 1790	+	-	+	+	+	+	+	-	+	+	+	-	+	+
Family: Notonectidae (Backswimmers)														
1. *Anisops campbelli* Brooks, 1951	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Order: Odonata														
Suborder: Anisoptera (Dragonflies)														
Family: Gomphidae														
1. *Platygomphus dolabratus* Selys, 1854	-	-	-	-	-	-	-	-	-	-	+	-	-	+
2. *Ictinogomphus rapax* Rambur, 1842 (Indian Common Clubtail)	-	-	-	-	-	-	-	-	-	+	+	+	+	+
Family: Libellulidae Leach, 1815														
1. *Acisoma panorpoides* Rambur, 1842 (Trumpet Tail)	+	+	+	-	+	+	+	+	+	-	+	+	+	+
2. *Brachydiplax sobrina* Rambur, 1842 (Little Blue Marsh Hawk)	-	-	-	-	-	-	-	-	-	-	-	+	-	-
3. *Brachythemis contaminate* Fabricius, 1793 (Ditch Jewel)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4. *Crocothemis servilia* Drury, 1770 (Ruddy Marsh Skimmer)	+	-	-	+	+	+	+	+	+	+	+	-	+	+
5. *Diplacodes trivialis* Rambur, 1842 (Blue Ground Skimmer)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6. *Neurothemis tullia* (Drury, 1773) (Pied Paddy Skimmer)	-	-	-	-	-	-	-	-	-	-	-	-	-	+
7. *Orthetrum sabina* Drury, 1770 (Green Marsh Hawk)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8. *Pantala flavescens* Fabricius, 1798 (Wandering Glider)	+	-	+	+	+	+	+	-	+	+	-	-	-	+
9. *Rhyothemis variegate* Linnaeus, 1763 (Common Picturewing)	-	-	-	-	+	-	-	-	+	-	-	+	+	+
10. *Tramea basilaris* Palisot de Beauvois, 1805 (Red Marsh Trotter)	-	+	+	+	+	-	-	+	-	-	+	-	+	+
11. *Trithemis aurora* Burmeister, 1839 (Crimson Marsh Glider)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
12. *Urothemis signata* Rambur, 1842 (Greater Crimson Glider)	-	+	-	+	+	+	+	+	+	-	-	-	+	+
Suborder: Zygoptera (Damselflies)														
Family: Coenagrionidae														
1. *Agriocnemis lacteola*Selys, 1877 (Milky Dartlet)	+	+	-	-	+	+	+	+	+	+	+	+	+	+
2. *Agriocnemis pygmaea* Rambur, 1842 (Pygmy Dartlet)	+	-	+	-	-	+	-	+	+	+	+	-	-	+
3. *Amphiallagma parvum*Selys, 1876 (Azure Dartlet)	+	+	+	+	+	-	+	-	-	-	-	-	+	+
4. *Ceriagrion coromandelianum* Fabricius, 1798 (Coromandel Marsh Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5. *Ischnura nursei* Morton, 1907 (Pixie Dartlet)	-	-	-	+	-	+	-	-	+	+	-	-	-	+
6. *Ischnura rubilio*Selys, 1876 (Western Golden Dartlet)	+	+	+	+	-	+	+	-	+	+	+	+	-	+
7. *Pseudagrion decorum* Rambur, 1842 (Three Lined Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8. *Pseudagrion rubriceps* Selys, 1876 (Saffron Faced Blue Dart)	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 2. Relative abundance (RA) and dominance status (DS) of different families of aquatic insects in different sampling sites (S1 to S14) of the upper Ganga River, a Ramsar site according to Engelmann's scale (1978)

		Dytiscidae	Hydrophilidae	Belostomatidae	Gerridae	Nepidae	Notonectidae	Gomphidae	Libellulidae	Coenagrionidae
S1	RA	1.515	1.515		21.212	1.515	9.848		34.091	30.303
	DS	Recedent	Recedent		Dominant	Recedent	Subdominant		Eudominant	Dominant
S2	RA	1.724	1.724	1.724	12.069		0.862		44.828	37.069
	DS	Recedent	Recedent	Recedent	Dominant		Subrecedent		Eudominant	Eudominant
S3	RA		2.069	1.379	18.621	0.69	12.414		30.345	34.483
	DS		Recedent	Recedent	Dominant	Subrecedent	Dominant		Dominant	Eudominant
S4	RA		0.758	1.515	19.697	3.03	9.091		30.303	35.606
	DS		Subrecedent	Recedent	Dominant	Recedent	Subdominant		Dominant	Eudominant
S5	RA	2.564	1.709		16.239	0.855	7.692		45.299	25.641
	DS	Recedent	Recedent		Dominant	Subrecedent	Subdominant		Eudominant	Dominant
S6	RA	0.735	2.206	0.735	15.441	0.735	12.5		33.088	34.559
	DS	Subrecedent	Recedent	Subrecedent	Dominant	Subrecedent	Dominant		Eudominant	Eudominant
S7	RA	3.053	1.527		11.45	2.29	7.634		39.695	34.351
	DS	Recedent	Recedent		Dominant	Recedent	Subdominant		Eudominant	Eudominant
S8	RA	1.923	1.923	0.962	14.423		0.962		40.385	39.423
	DS	Recedent	Recedent	Subrecedent	Dominant		Subrecedent		Eudominant	Eudominant
S9	RA	0.73	1.46		15.328	2.19	12.409		43.066	24.818
	DS	Subrecedent	Recedent			Recedent	Dominant		Eudominant	Dominant
S10	RA	3.008	0.752	0.752	16.541	2.256	10.526	0.752	27.82	37.594
	DS	Recedent	Subrecedent	Subrecedent	Dominant	Recedent	Dominant	Subrecedent	Dominant	Eudominant
S11	RA	1.429		1.429	24.286	1.429	2.857	5	30	33.571
	DS	Recedent		Recedent	Dominant	Recedent	Recedent	Subdominant	Dominant	Eudominant
S12	RA	2.308	1.538	1.538	23.846	0	9.231	1.538	35.385	24.615
	DS	Recedent	Recedent	Recedent	Dominant		Subdominant	Recedent	Eudominant	Dominant
S13	RA	1.835	2.752		14.679	2.752	0.917	0.917	39.45	36.697
	DS	Recedent	Recedent		Dominant	Recedent	Subrecedent	Subrecedent	Eudominant	Eudominant
S14	RA		1.527		13.74	3.053	9.924	3.053	29.771	38.931
	DS		Recedent		Dominant	Recedent	Subdominant	Recedent	Dominant	Eudominant

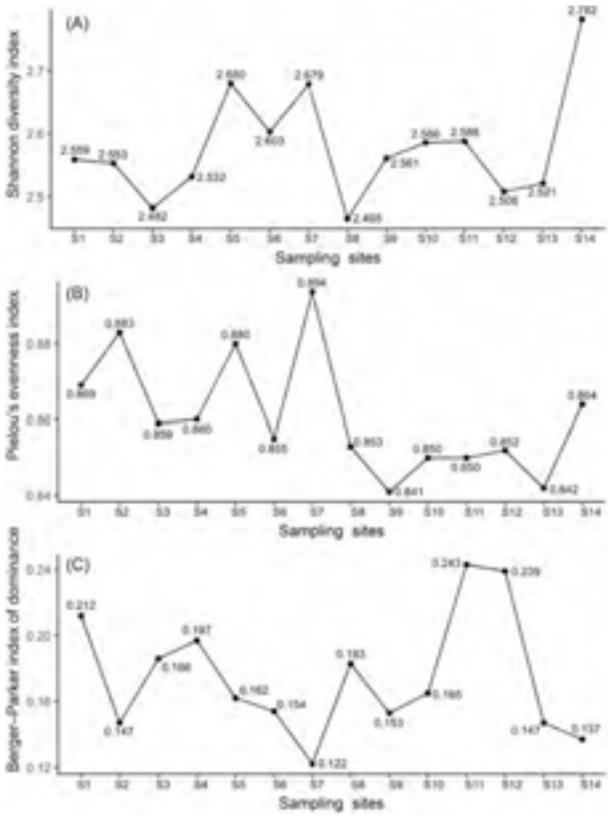

Figure 2. Variation of Shannon diversity index, Pielou's evenness index, and Berger-Parker index of dominance in different sites (S1–S14) of the upper Ganga River Ramsar site.

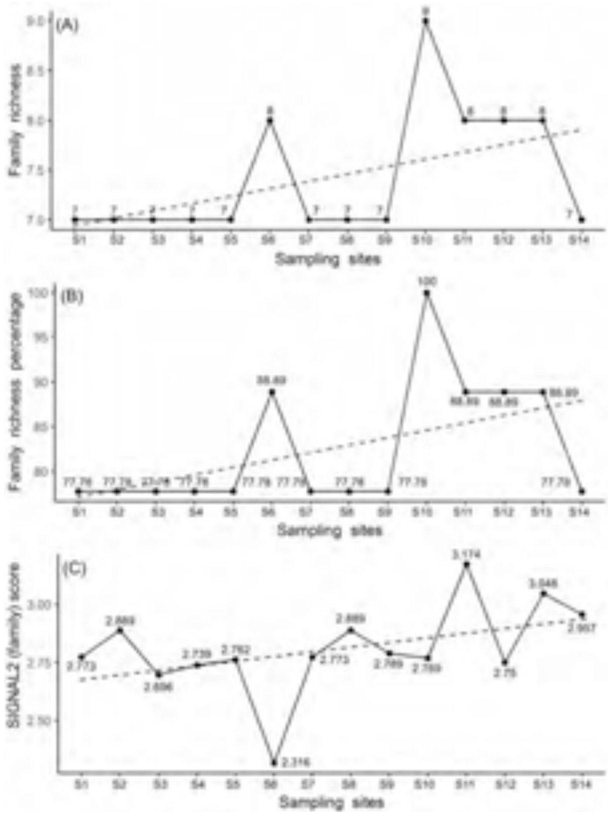

Figure 3. Variation of Family richness, Family richness percentage and SIGNAL2 (family) score in different sites (S1–S14) of the upper Ganga River Ramsar site. The linear trend lines are showing increase of values towards the Narora barrage (at S14).

DISCUSSION

Insects have the ability to move from unfavourable habitats to favourable ones. If a habitat becomes polluted or altered, tolerant species will thrive and sensitive ones will move to a more suitable habitat (Medina et al. 2007). Thus habitat alternation, either by natural process or by anthropogenic impacts, can shape invertebrate communities. Aquatic macroinvertebrates constitute important components of their ecosystems, and they exhibit differential tolerances to changes in environmental conditions (Adu & Oyeniyi 2019). In the present study, three species of Coleoptera from two families, four species of Hemiptera from four families, and 22 species of Odonata from three families were recorded. The coleopterans included predaceous diving beetles (family Dytiscidae) and water scavenger beetles (family Hydrophilidae). The hemipteran group included water bugs (family Belostomatidae), water striders (family Gerridae), water scorpions (family Nepidae) and backswimmers (family Notonectidae), and the odonates included dragonflies and damselflies.

In the present study Shannon diversity index (H'), Pielou's Evenness index (J') and Berger-Parker index of dominance (d) did not differ much between study sites, probably because of uniform geomorphological features of the area, as geomorphological heterogeneity plays a major role in determining species richness (Nichols et al. 1998). Libellulidae, Coenagrionidae, and Gerridae had high relative abundance and dominant status, probably because of their ability to tolerate a wide range of environmental factors (Spence 1983; Chang et al. 2014).

The SIGNAL 2 result suggested that the water of the study area was likely to have higher levels of turbidity, salinity or nutrients, which was perhaps caused either naturally, because of local geology and soil types, or as a result of human activities and physical conditions. Toxic chemicals were not present in large amounts (Chessman 2003).

The family richness, family richness percentage and SIGNAL2 (family) score showed an increase in values towards the Narora barrage, probably because of the increase in water quantity (as the barrage stores more water) which directly affects the physiochemical

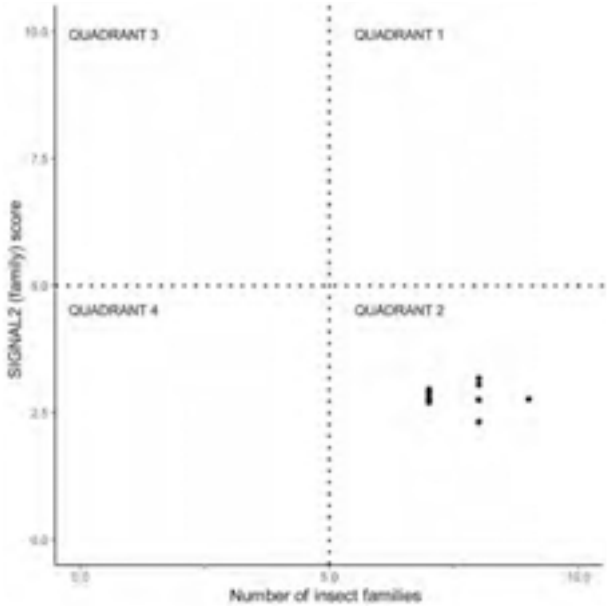

Figure 4. The quadrant diagram for the family version of SIGNAL 2 for the sampling sites.

properties of the water and habitat structures.

The upper Ganga Ramsar site is facing stress from anthropogenic pressure (Kuniyal 2013; Pandey & Sharma 2013). The study stretch between the Brijghat and Narora, the Ganga is characterized by the presence of agricultural lands and numerous ghats (steps leading down to the river) with religious and tourism importance on both the banks. Local people use the river bank and water for bathing, cremation and other religious activities. Activities like cattle grazing and fishing occur throughout the year. As a result, the river is exposed to various threats like waste discharge, sewage disposal, agricultural runoff, fishing, and river bank erosion.

While there is some regional information, knowledge remains limited concerning the natural ranges and ecology of species found in the Ganga (Nautiyal et al. 2014). Long-term seasonal monitoring of the physiochemical properties of the water, coupled with assessment of faunal and floral diversity as well as socio-economic factors influencing the conditions of the area is recommended in order to arrive at better management strategies.

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Patterns of forest cover loss in the terrestrial Key Biodiversity Areas in the Philippines: critical habitat conservation priorities

Bernard Peter O. Daipan

Department of Forest Biological Sciences, College of Forestry, Benguet State University, La Trinidad, Benguet 2601, Philippines.
bp.daipan@bsu.edu.ph

Abstract: The Philippines, home to over 20,000 endemic species of plants and animals, is facing a biodiversity crisis due to the constant decrease of forest cover. The Key Biodiversity Area (KBA) approach was developed to conserve species threatened with extinction using a site-based conservation strategy to select globally important sites using threshold-based criteria for species irreplaceability and vulnerability. This study investigates the applicability of remotely sensed data through geospatial analysis to quantify forest cover loss of the 101 terrestrial KBAs in the country between 2001 and 2019. Results showed that the study sites had 4.5 million hectares (ha) of forest in the year 2000. However, these sites have lost about 270,000 ha of forest in nearly two decades, marking a steady decline with an annual deforestation rate of 14,213 ha per year in these terrestrial KBAs. The majority of the study sites (58) had a high percentage of forest loss (>3.13%), and these should be prioritized for conservation. By the year 2030, it is forecast that a total of 331 thousand ha of forest will be lost unless there is a transformational change in the country's approach to dealing with deforestation. The results of this study provide relevant data and information in forest habitat in near real-time monitoring to assess the impact and effectiveness of forest governance and approaches within these critical habitats.

Keywords: Deforestation, forest habitat, geospatial technology, KBA.

Abbreviations: AZE—Alliance for Zero Extinction | DENR—Department of Environment and Natural Resources | GIS—Geographic Information System | IUCN—International Union for the Conservation of Nature | KBA—Key Biodiversity Area | UNEP—United Nations Environment Programme.

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Author details: Bernard Peter O. Daipan is currently the department chairperson of the Forest Biological Sciences (FBS) and research coordinator of the College of Forestry, Benguet State University in the Philippines. He previously worked with the Conservation and Development Division of the DENR–CAR for almost seven years before joining the academy. At present, the author is pursuing his PhD degree in Forestry Major in Forest Biological Sciences at the University of the Philippines Los Baños (UPLB).

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INTRODUCTION

Forests are home to over 80% of the earth's terrestrial biodiversity (Aerts & Honnay 2011), including almost half of all avian species (Hilton-Taylor et al. 2009). Forests provide many ecosystem services that include conservation of threatened and endemic species (Gibson et al. 2011). However, these forests have undergone remarkable pressure (Drummond & Loveland 2010) over the past decades, leading to a global biodiversity crisis (Driscoll et al. 2018) which is even worse than climate change (University of Copenhagen 2012). There is no doubt that habitat loss, caused by the conversion of forest to non-forest land uses such as agricultural and built-up areas, is the predominant threat to biodiversity (Foley et al. 2005; Estavillo et al. 2013). As a result, many endemic species have either become extinct or threatened with extinction (Brooks et al. 2002). In the Philippines, there are more than 20,000 endemic species of plants and animals (Mittermeier et al. 1998; Conservation International Philippines 2020) and the country is home to 20% of all known flora and fauna species (Ambal et al. 2012). This mega-diverse country has long been recognized as one of the top biodiversity hotspots in the world (Gaither & Rocha 2013) due to the constant exploitation and destruction of its forest resources. This habitat destruction can generate zoonotic diseases (UNEP 2020), such as COVID-19 that caused a worldwide pandemic (Cucinotta & Vanelli 2020). Biodiversity also protects humans against infectious disease (Wood et al. 2014; Levi et al. 2016)

To this end, the Key Biodiversity Area (KBA) approach was developed. This site-based conservation approach is considered one the most effective means to halt biodiversity loss on global and regional scales (Eken et al. 2004; UNEP-CBD 2010). The KBAs are promoted by the International Union for the Conservation of Nature (IUCN) to identify and delineate important sites for the global persistence of biodiversity as manageable units (IUCN 2016; Kulberg et al. 2019), using standard criteria based on the concepts of species irreplaceability and vulnerability (Langhammer et al. 2007; Melovski et al. 2012).

In the Philippines, the identification and delineation of KBAs was initiated by Conservation International Philippines (CIP), the Biodiversity Management Bureau (BMB), formerly Protected Areas and Wildlife Bureau (PAWB), of the Department of Environment and Natural Resources (DENR), and the Haribon Foundation supported by Critical Ecosystem Partnership Fund (CEPF) (CIP et al. 2006). It was started in the country to support the government and other stakeholders in prioritizing and mainstreaming conservation efforts and formulating site-based strategies that protect these vulnerable and irreplaceable species within their habitats (Edgar et al. 2008).

A total of 228 KBAs were identified and delineated in the Philippines, which cover over 106,000 km^2, around 35% of the total land area of the country. The ecosystem coverage of these KBAs includes the following: terrestrial only with 101 KBAs (51,249 km^2); marine only with 77 KBAs (19,601 km^2); and combinations of terrestrial and marine with 50 KBAs (35,702 km^2). These KBAs are home to over 855 species, 396 of these are globally threatened species, 398 are considered restricted-range species, and 61 are congregatory species of birds (CIP et al. 2006; Ambal et al. 2012; FPE, 2020).

Hence, there is an urgent need for effective conservation and management of the remaining forest habitats of these threatened species in the country. One of the essential management strategies is through near real-time monitoring of the temporal and spatial trend of forest cover loss in these KBAs to investigate which critical habitats are more vulnerable to future degradation (Leberger et al. 2019), to identify biodiversity threats, to develop appropriate management interventions such as forest protection and reforestation, and evaluate its effectiveness (Jones et al. 2013). With the advent of remote sensing technology over the last decade, it is now possible to monitor spatial and temporal patterns of forest cover losses on a global scale using high-resolution satellite imaging (Buchanan et al. 2011; Hansen et al. 2013; Turner et al. 2003). Using remotely sensed data for forest monitoring will effectively contribute to the conservation and management of these habitats. Also, it has the potential to assess the impact of site-based policy implementation (Leberger et al. 2019).

This study aimed to quantify the spatial and temporal forest cover loss of the terrestrial KBAs in the Philippines between 2000 and 2019 using high-resolution satellite imaging of forest loss produced by Hansen et al. (2013). Also, it aimed to aid in monitoring efforts and identify the most critical terrestrial KBAs with the highest loss of forest cover - including percent loss - that need immediate intervention. A conservation priority ranking was created based on the annual rate of deforestation, which will demonstrate the applicability of the results of this study in forest monitoring of these sites. Finally, forecasting of the future trend of forest cover loss in these critical habitats was performed as well.

MATERIAL AND METHODS

Study Area

This study was conducted in 101 identified terrestrial KBAs across the 17 regions of the Philippine archipelago with a total area of 51,298.34 km^2 (Image 1) from June to October 2020. The 50 KBAs, with combined terrestrial and marine areas, were not included in the study because there is a need to delineate first the boundaries between the terrestrial and marine realms of the KBA prior to the computation of percentage forest cover of the KBA. If the boundaries will not be delineated, the marine portion of the KBA will be treated as non-forested areas and this will result in a very low percentage of forest cover although the terrestrial portion has a high percentage of forest cover. Due to the unavailability of the delineated realms of the 50 KBAs, the study was only limited to 101 terrestrial KBAs.

The Philippines, with more than 7,000 islands, is geographically located in the western Pacific Ocean and part of the southeastern Asian region which is among the biodiversity hotspots in the world with the highest concentration of terrestrial vertebrate species on the planet. According to the Foundation for the Philippine Environment (FPE) (2020), these terrestrial KBAs in the country represent several types of forest ecosystems across different elevations, namely; sub-alpine forest, mossy forest, montane forest (upper and lower), pine forest, semi-deciduous forest (moist deciduous), lowland evergreen forest, forest over limestone (karst), forest over ultrabasic soil, forest over ultramafic rocks, beach forest, and mangrove forest.

Data

Terrestrial key biodiversity areas shapefile

To investigate the spatial and temporal forest cover loss within the study sites, the vector maps in shapefile (.shp) format of the KBAs were requested from the world database of Key Biodiversity Areas developed and maintained by BirdLife International (2020). After extracting the spatial data of terrestrial KBAs in Geographic Information System (GIS) software, the maps were compared with the web-based Philippine KBA maps using the Geoportal Philippines (2020). Based on the comparative assessment, 21 of the 101 terrestrial KBAs were observed to have notable inconsistencies in terms of area and its boundaries. Nonetheless, the 21 terrestrial KBA boundaries from the Geoportal Philippines along with the 80 terrestrial KBAs without discrepancies from Birdlife International were selected and used in the analysis of this study, which represents the best sites for biodiversity conservation.

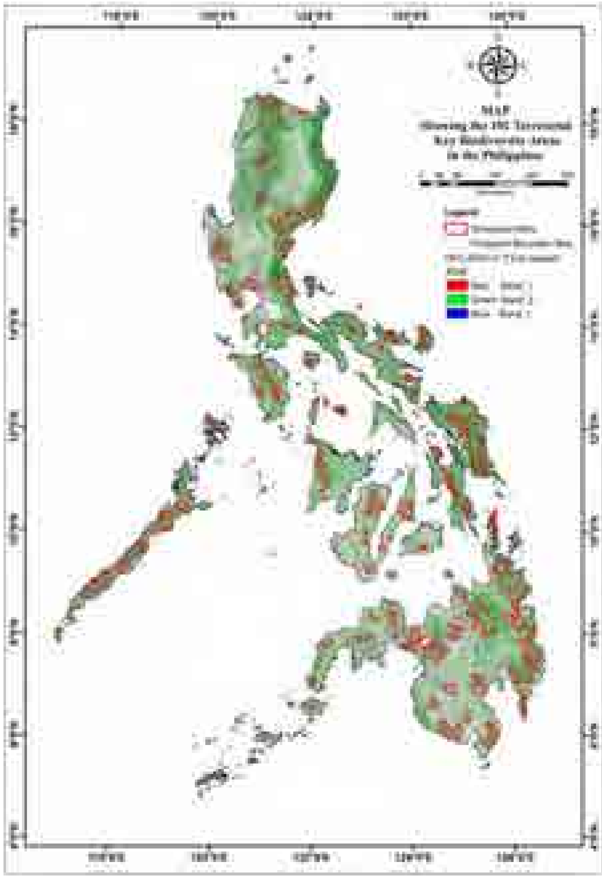

Image 1. Map showing the location of the 101 terrestrial Key Biodiversity Area study sites across the Philippine archipelago.

Hansen global forest change 2000–2019 version 1.7

The main dataset in quantifying the spatial and temporal loss in forest cover of the terrestrial KBAs in the Philippines, including the initial forest cover dataset for the year 2000, is the high-resolution global maps of 21st century forest cover change developed by Hansen et al. (2013). The product used in this study was version 1.7, which is the result of time-series analysis of Landsat data at a spatial resolution of one arc-second per pixel (30m x 30m) depicting forest extent and change such as loss (forest to non-forest) and gain (non-forest to forest state) during the period 2000 to 2019. These data are updated annually based on a high-end remote sensing technology and can be freely downloaded from the University of Maryland - Global Land Analysis and Discovery (UM-GLAD) website as raster data. The data can also be downloaded and visualized from the Google Earth Engine (GEE) data repository.

Geospatial processing and statistical analysis of forest cover loss

The software used to quantifying and process yearly forest cover loss of each terrestrial KBA was the Quantum Geographic Information System (QGIS) version 3.14 (pi). The KBA shapefiles were used in clipping the downloaded raster format of forest loss. After clipping, the raster datasets were converted to vector for an easier geostatistical calculation such as area determination. To facilitate the editing of the attribute data, the vector of forest cover loss was split into individual shapefiles following each KBA boundary. Finally, the area in hectares for annual forest loss per terrestrial KBA, between the periods 2001 and 2019, were calculated using the built-in calculate geometry tool. The general overview of the methodology is presented in Figure 1.

The total forest cover loss or the area change, percentage area change, and the annual rate of forest cover loss were computed using the following mathematical formulas by Hansen et al. (2013) which were also used in the study of Sulieman et al. (2017):

$$\Delta A = A2 - A1$$

where:

ΔA = forest cover loss or change in the area

A1 = beginning of the period (date 1)

A2 = end of the period (date 2)

$$PAC = \Delta A/TA \times 100$$

where:

PAC = percentage area change

TA = the total area of KBA

$$ARC = \Delta A/N$$

where:

ARC = Annual rate of change (ha/year)

N = the number of years between date one and date two of the study period

The percentage of forest cover loss was categorized from low to high which is adapted from the study of Leberger et al. (2019). The forecasting of the future trend of forest cover loss from 2020 to 2030 was performed using the forecasting function in MS Excel based on the existing historical forest loss values.

RESULTS

Spatial and temporal forest cover loss

The forest cover of the identified terrestrial KBAs in the Philippines was estimated at around 4.5 million ha in the year 2000, which represents 89% of the total terrestrial KBA area (Image 2). However, after almost two decades, the forest cover of these terrestrial KBAs, based on the GIS analysis of high-resolution remotely sensed data developed by Hansen et al. (2013), had decreased by around 270,000 ha, which is almost 6% of the total forest cover in the year 2000. It is estimated that the remaining forest cover within these terrestrial KBAs as of 2019 is around 81% with an area of 4.27 million ha. Moreover, the annual rate of forest cover loss for these priority areas for biodiversity conservation is computed at around 14,213 ha/year with an annual average deforestation rate of 6% (Image 3).

The scatter plot shows an increasing trend in the annual forest cover loss from 2001 to 2019. The period with the highest recorded rate of deforestation was between 2016 and 2017, but on a positive note, there has been a notable decrease of these losses in the last two consecutive years (2018 and 2019) (Figure 2).

The 10 terrestrial KBAs with the highest percentage of forest loss between 2000 and 2019, except for the KBAs with lake environments (Malasi Lake and Mungao Lake), are presented in Table 1. The percentage of forest loss was highest in Tawi-tawi Island, located in Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) with 27.88%. Based on the percentage frequency distribution presented in Table 2, the majority of the study sites (58)

Table 1. Top ten KBAs with the highest percent forest loss between 2001 and 2019.

Region	Terrestrial Key Biodiversity Areas	% Forest Cover Loss
BARMM	Tawi-tawi Island	27.88
XIII, XI	Bislig	25.75
IX	Mount Sugarloaf	19.24
IV-B	Mount Mantalingahan	17.14
IX	Lituban-Quipit Watershed	14.98
IV-B	Malpalon	13.01
IV-B	San Vicente-Roxas Forests	11.96
XI	Mount Agtuuganon and Mount Pasian	11.76
IV-B	Mount Calavite	11.49
IX	Mount Dapiak and Mount Paraya	11.11

Table 2. Percentage frequency distribution of forest loss in the study sites.

Classification	Percentage of forest loss	Frequency
Low	0–0.76	3
Moderate	0.77–3.13	40
High	>3.13	58
Total		101

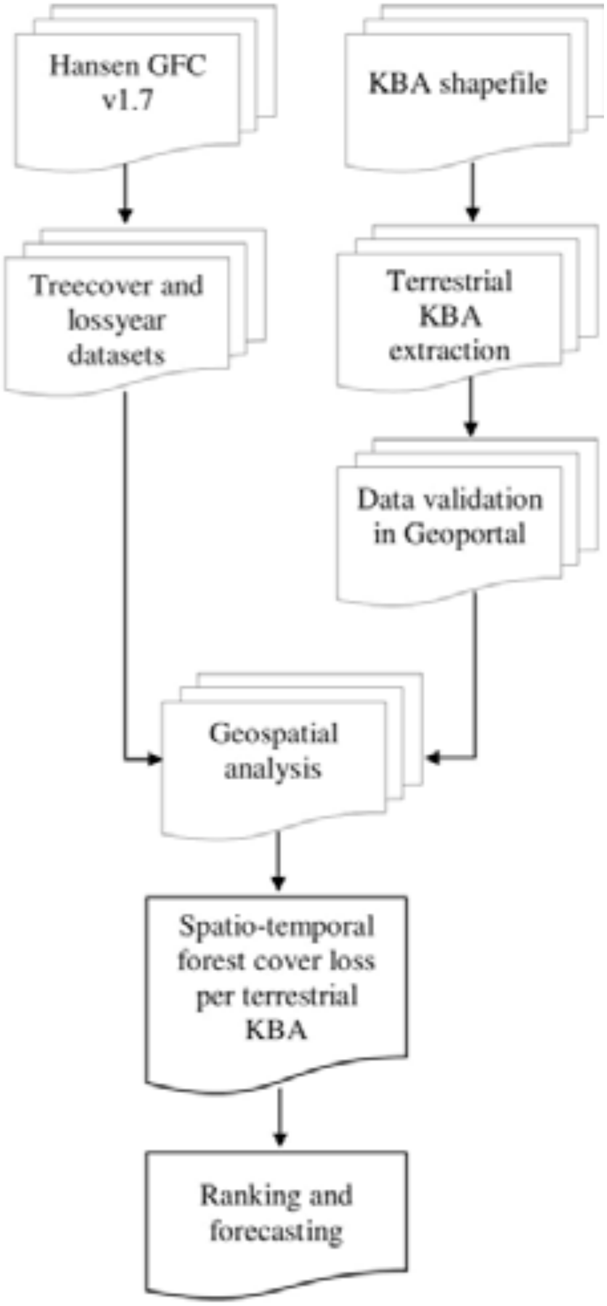

Figure 1. General overview of the methodology.

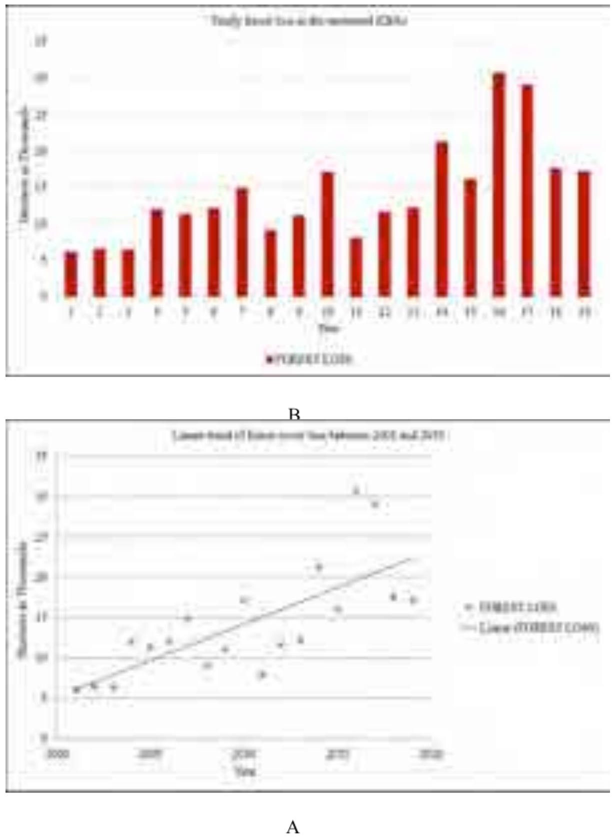

Figure 2. Forest cover loss in terrestrial key biodiversity areas: A—Annual loss | B—The linear trend of forest cover loss in nearly two decades.

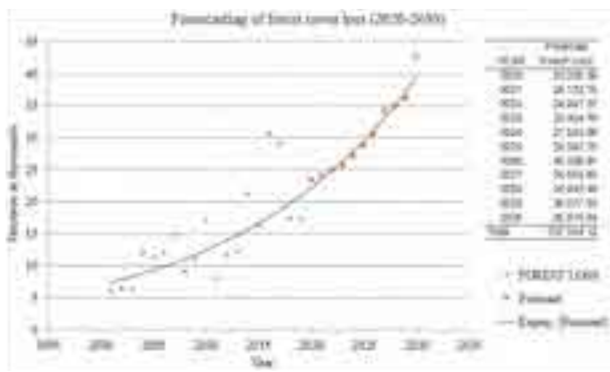

Figure 3. Forecast of forest cover loss in terrestrial key biodiversity areas.

had a high percentage of forest loss with more than 3.13%. On the other hand, only three (3) among the 101 terrestrial KBAs had low percentage of loss, these are Timpoong and Hibok-hibok Natural Monument in Region 10, Mounts Banahaw and San Cristobal Protected Landscape in Region 4A, and Mount Kitanglad in Region 10, with 0.31%, 0.27%, and 0.24%, respectively.

The KBA with the highest net loss of forest area in nearly two decades was Bislig, located in Region 13 covering some portion of Region 11, which was around 38.5 thousand ha (Table 3), while the Timpoong and Hibok-hibok Natural Monument had the lowest area of forest loss (except for KBAs with lake environment) with only 10.59 ha in two decades. Moreover, the Bislig KBA also had the highest annual rate of deforestation with a loss of 2,031 hectares per year (ha/year). This was followed by Mount Mantalingahan in Region 4B and Samar Island Natural Park in Region 8, with 1,266 ha/

Table 3. Top ten sites with the highest forest loss between 2001 and 2019.

Region	Terrestrial Key Biodiversity Areas	Forest cover loss (ha)
XIII, XI	Bislig	38,589.02
IV-B	Mount Mantalingahan	24,071.86
VIII	Samar Island Natural Park	14,037.57
CAR, II, I	Apayao Lowland Forest	12,384.94
XIII	Mount Diwata Range	10,146.78
XI	Mount Agtuuganon and Mount Pasian	9,989.77
XIII	Mount Hilong-hilong	9,842.84
II	Quirino Protected Landscape	9,610.57
IV-B	San Vicente-Roxas Forests	9,221.44
IV-B	Victoria and Anepahan Ranges	8,742.57

Table 4. Top ten sites with the highest annual rate of deforestation.

Region	Terrestrial Key Biodiversity Areas	Annual rate of forest cover loss (ha/year)
XIII, XI	Bislig	2,031.00
IV-B	Mount Mantalingahan	1,266.94
VIII	Samar Island Natural Park	738.82
CAR, II, I	Apayao Lowland Forest	651.84
XIII	Mount Diwata Range	534.04
XI	Mount Agtuuganon and Mount Pasian	525.78
XIII	Mount Hilong-hilong	518.04
II	Quirino Protected Landscape	505.82
IV-B	San Vicente-Roxas Forests	485.34
IV-B	Victoria and Anepahan Ranges	460.14

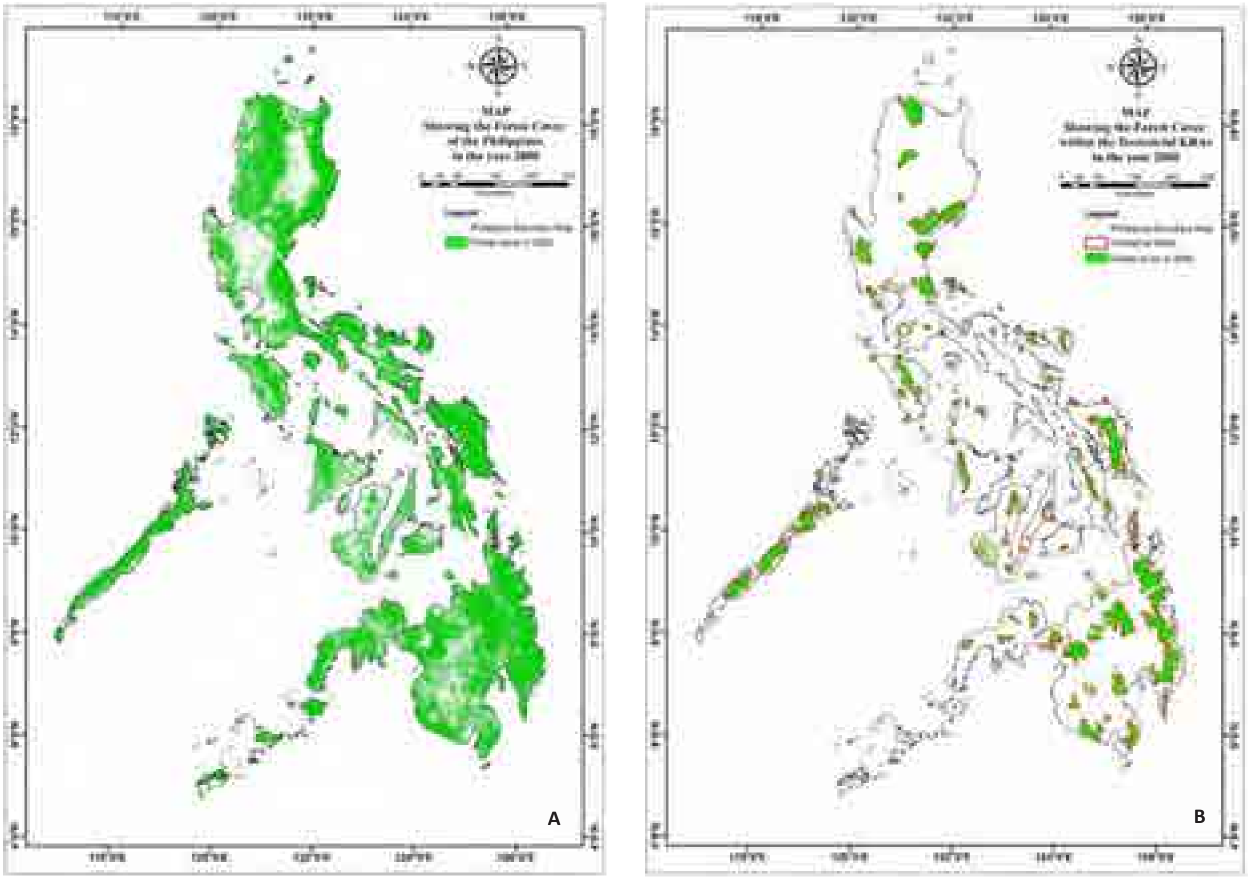

Image 2. Forest cover in the year 2000: A—Nationwide | B—Within terrestrial KBAs.

year and 738.82 ha/year forest loss, respectively (Table 4). The conservation priority ranking of the 101 terrestrial KBAs, ranked in terms of forest cover loss and the annual rate of deforestation, is presented in Appendix 1. This also includes relevant information such as the region and area of KBAs, forest cover and percent forest cover in the year 2000 and 2019, and percent forest cover loss.

DISCUSSION

Quantification of spatial and temporal forest cover loss using Hansen remotely sensed data

In the Philippines, the use of remote sensing for annual forest cover monitoring and loss detection in terrestrial KBAs, even on the national scale, is not yet fully developed compared to other tropical countries like Brazil (Instituto Nacional de Pesquisas Espaciais 2010) and India (Forest Survey of India 2019). Thus, remotely sensed satellite imagery, such as the dataset produced by Hansen et al. (2013), can contribute significantly to biodiversity monitoring (Tracewski et al. 2016). However, errors are inevitable for these datasets, for example, forest loss estimation in dry forests may be underestimated, as reported by Achard et al. (2014), but are working well enough in moist humid forest. Also, the accuracy assessment conducted by Mitchard et al. (2015) in Ghana showed a significant underestimation of forest change. Another limitation in the dataset is that it does not distinguish permanent deforestation from temporary forest disturbance like forest fires, forestry plantations, and shifting cultivation (Curtis et al. 2018). Nevertheless, the overall accuracy of forest cover loss of Hansen GFC dataset as shown in different studies is between 88% (Feng et al. 2016) to 93% (Hirschmugl et al. 2020) and it represents the best high-resolution, with 30m x 30m spatial resolution, global assessment of forest cover change that is freely accessible to the public (Hansen et al. 2010; Tracewski et al. 2016).

Critical habitat conservation priorities

The Tawi-tawi Island, identified in this study with the highest percent forest loss (27.88%) among the terrestrial KBAs, was also recognized as one of the Alliance for Zero Extinction (AZE) sites (AZE 2010) that holds two critically endangered (CR) species and one endangered (EN) species (IUCN 2008). The AZE sites are those that have threatened species constrained to just a single site globally (AZE 2010). Also, this KBA has 45 trigger species identified (Odevillas 2018). Trigger species are those that trigger either the irreplaceability criterion or vulnerability criterion within the KBAs (Langhammer et al. 2007), these could also be identified by combining both the endemism and rarity criteria (Yahi et al. 2012). Based on the findings of this study, 58 sites recorded a high percentage forest loss which suggests that these areas should be prioritized in terms of forest conservation and protection. It is also advisable that the strategies and good practices in forest conservation of the three (3) sites with the lowest percentage of forest loss should be adapted to other sites of this study.

The second site with the highest percent forest loss, which also had the highest annual deforestation rate, and with the largest area of forest cover loss within the study period is the Bislig KBA in Region 13 (Image 4). This terrestrial KBA has 33 trigger species and one (1) critically endangered species based on the data from the Haribon Foundation (2020) and red list of threatened species (IUCN 2008).

Mount Mantalingahan in Region 4B, with a total of 24,071.86 ha of forest cover loss between 2001 and 2019 and an annual deforestation rate of 1,266 ha/year, has one (1) endangered species, one (1) vulnerable species (Ambal et al. 2012), and 38 trigger species (Odevillas 2018). Although this KBA was already removed from the AZE list in 2010 after the *Palawanomys furvus* was reclassified as Data Deficient from Endangered (EN) species in 2008 (Ambal et al. 2012), the threat to biodiversity remains. This is mainly due to its high annual rate of forest cover loss as observed in this study.

The Samar Island National Park in Region 8, which ranked third in this study with the highest rate of forest cover loss, was also identified as a top priority site for protection due to its large number of trigger species with 180 species in total, and three (3) critically endangered species (Odevillas 2018). These findings suggest that the aforementioned terrestrial KBAs are more likely to experience species extinction in the coming decades without proper conservation and protection measures.

Status and trends of forest cover in the terrestrial key biodiversity areas in the Philippines

The identified terrestrial KBAs in the Philippines cover at least 17% of the estimated total land area of the country (30 million ha) and were declared as "critical habitats" under the Presidential Executive Order 578 in 2006. However, these sites alone are not enough for biodiversity conservation (FAO & UNEP 2020) especially in a country regarded as one of the top global biodiversity hotspots (Mittermeier et al. 1998). Therefore, an expansion of these habitats is necessary to increase conservation coverage of the threatened species (Kullberg et al. 2019). Also, there are only 27 protected terrestrial KBAs, 25 are partially protected, while the remaining 49 are unprotected or not covered with any legislative interventions (Ambal et al. 2012), which make these areas more vulnerable to anthropogenic deforestation that has a remarkable effect on forest cover (Margono et al. 2014). However, even a protected KBA is still vulnerable to land cover conversion for agro-industrial use, as observed in the buffer zones of Mount

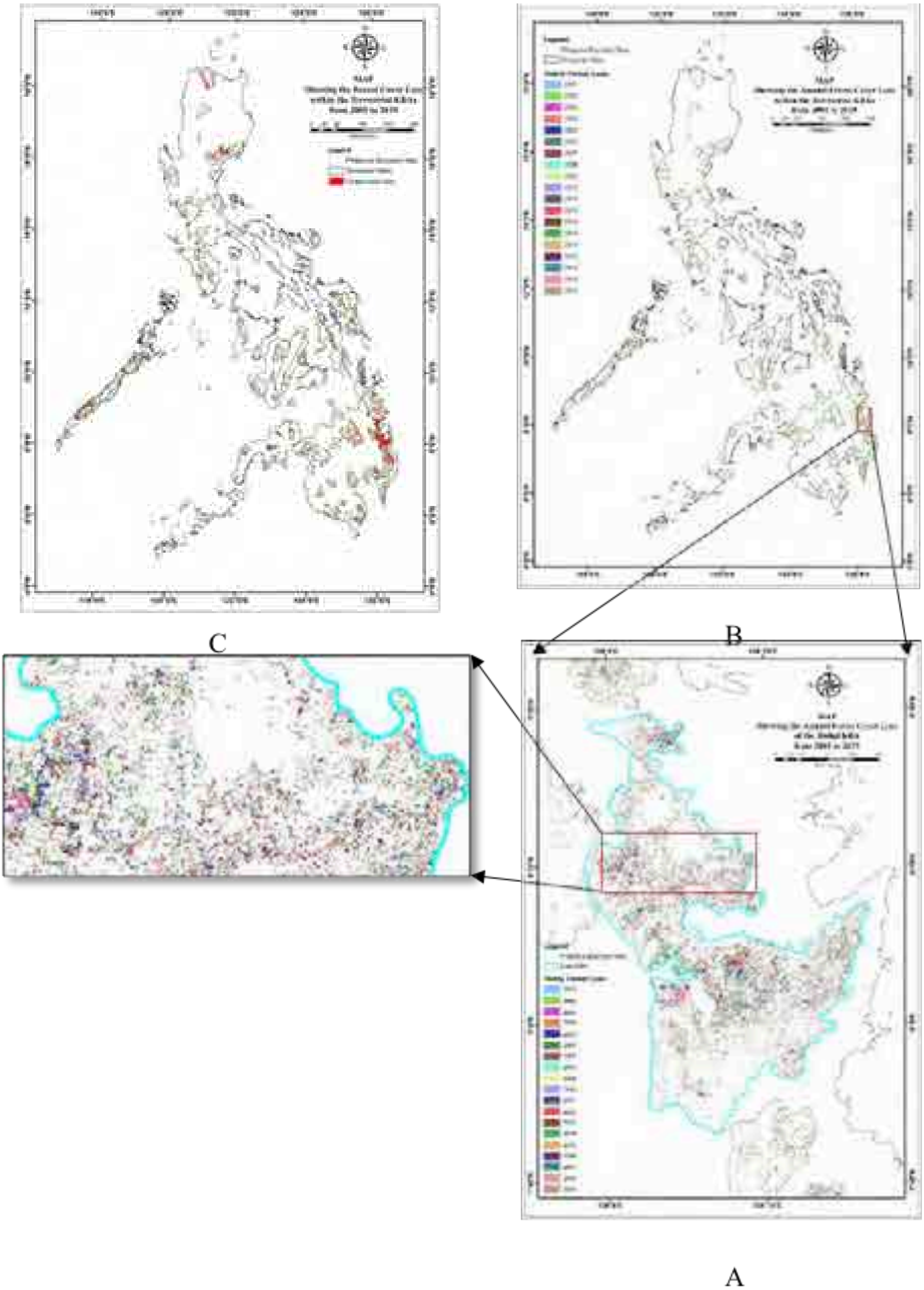

Image 3. Map showing the forest cover loss within the Philippines' terrestrial key biodiversity areas: A—The total forest loss from 2001 to 2019 | B—The annual forest loss from 2001 to 2019 | C—The annual forest loss of Bislig Key Biodiversity Area.

Image 4. The deforestation area in Bislig Key Biodiversity Area. © Francesco Veronesi.

Kalatungan (Azuelo & Puno 2018).

As reported by the DENR (2000) in its 2000 Philippine Forestry Statistics (PFS), the country's forest cover was around 5.4 million ha in the year 2000 (18% of the total land area), which implies that 83% of these forests were found in the terrestrial KBAs. Although forest cover increased in the country between 2000 and 2015, with an estimated area of seven million ha or a 22% increase (DENR 2019), a consistent decline in the forest cover of these terrestrial KBAs was detected in this study within the same period. The decline in forest cover in the country is also reported by Mongabay (2020) based on deforestation statistics stating that a total of 1,128,788 ha of forest was lost between 2001 and 2018. Globally, the rates of forest cover loss in Important Birds and Biodiversity Areas (IBAs) were highest in South America and southeastern Asia (Tracewski et al. 2016), which includes the Philippines. This indicates that the country's efforts in managing and protecting these critical habitats, as well as the existing environmental protection measures, are seriously inadequate (Oliver & Heaney 1996; Hammond 1997) due to the constant rate of deforestation and forest degradation within these areas, which are generally caused by logging, mining, and land conversion (from forest to non-forest) (Lillo et al. 2018). Although a promising finding was observed in the last two periods (2018 & 2019) due to the substantial decreased in the forest cover loss, there is still a need for annual forest cover loss monitoring to identify and evaluate the impact of policy and conservation interventions in the spatial and temporal forest cover loss in these areas (Broich et al. 2011).

Since the forest cover loss of the study sites exhibited an increasing trend, with a similar pattern of results obtained in the study of Leberger et al. (2019) on a global scale, it is predicted in this study that by the end of 2030 an area of approximately 331,000 ha of forest will be lost, equivalent to around 7.3% of the total forest cover in these sites (Figure 3). This immense decline in forest will leave these critical habitats with only 76% remaining cover, and in turn escalate the threat to the 25 Critically Endangered (CR), 40 Endangered (EN), and 117 Vulnerable (VU) species (Ambal et al. 2012) found in these sites. Unless there is a transformational change in the way the country manages and conserves its forests and biodiversity (FAO & UNEP 2020) through these terrestrial KBAs, extinction of species is imminent. For that reason, there is an undeniable need for near real-time monitoring of forest loss within these areas (Leberger et al. 2019), and ranking/prioritizing them for conservation based on vulnerability to degradation (Brooks et al. 2006).

CONCLUSION

The present study quantified the spatial and temporal pattern of forest cover loss in 101 terrestrial key biodiversity areas of the Philippines between the periods 2001 and 2019 using high-resolution satellite-based earth observation datasets. Remote sensing technology and geospatial analysis have a high potential for timely monitoring of the forest cover status of these habitats, an essential component of biodiversity conservation. The increasing trend of forest loss in the terrestrial KBAs, as observed in this study, with an annual deforestation rate of about 14,213 ha per year, clearly suggests that the efforts in the conservation of these critical habitats need recalibration. Thus a paradigm shift is necessary to manage these sites in an attempt to prevent the extinction of 182,000 species or at least improve their conservation status. There is also a need to expand the terrestrial KBAs in the country taking into consideration the threatened species of vascular plants since the identification and delineation of terrestrial KBAs was only based on some faunal taxonomic groups, such as amphibians, reptiles, birds, and mammals.

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Appendix 1. Conservation priority ranking of the 101 terrestrial key biodiversity areas based on the annual rate of forest cover loss.

Region	Terrestrial Key Biodiversity Areas	Area of KBA*	Forest cover in 2000*	% Forest cover in 2000	Remaining forest cover in 2019*	% forest cover in 2019	Forest cover loss*	% Forest cover loss	Annual rate of forest loss (ha/year)	Priority ranking
XIII, XI	Bislig	154.12	149.85	97	111.26	72	-38.59	-25.75	-2031.00	1
IV-B	Mount Mantalingahan	146.00	140.42	96	116.35	80	-24.07	-17.14	-1266.94	2
VIII	Samar Island Natural Park	333.00	330.24	99	316.20	95	-14.04	-4.25	-738.82	3
CAR, II, I	Apayao Lowland Forest	177.37	171.43	97	159.04	90	-12.38	-7.22	-651.84	4
XIII	Mount Diwata Range	93.80	92.08	98	81.94	87	-10.15	-11.02	-534.04	5
XI	Mount Agtuuganon and Mount Pasian	85.50	84.92	99	74.93	88	-9.99	-11.76	-525.78	6
XIII	Mount Hilong-hilong	240.24	237.66	99	227.81	95	-9.84	-4.14	-518.04	7
II	Quirino Protected Landscape	164.54	149.48	91	139.87	85	-9.61	-6.43	-505.82	8
IV-B	San Vicente-Roxas Forests	81.16	77.11	95	67.88	84	-9.22	-11.96	-485.34	9
IV-B	Victoria and Anepahan Ranges	164.79	163.46	99	154.72	94	-8.74	-5.35	-460.14	10
XIII, X	Mount Kaluayan-Mount Kinabalian Complex	180.98	180.99	100	172.26	95	-8.73	-4.82	-459.62	11
XI	Mount Kampalili-Puting Bato	169.91	166.94	98	158.89	94	-8.04	-4.82	-423.23	12
BARMM, XII	Mount Piagayungan and Butig Mountains	154.34	148.39	96	140.73	91	-7.66	-5.16	-403.09	13
IV-B	Cleopatras Needle	104.73	102.30	98	95.76	91	-6.55	-6.40	-344.64	14
IX	Mount Sugarloaf	34.42	32.73	95	26.43	77	-6.30	-19.24	-331.44	15
XI, XII	Mount Latian complex	95.08	87.45	92	82.40	87	-5.04	-5.77	-265.45	16
IX	Lituban Quipit Watershed	33.29	32.64	98	27.75	83	-4.89	-14.98	-257.23	17
XIII	Agusan Marsh Wildlife Sanctuary	54.77	49.20	90	44.94	82	-4.26	-8.66	-224.33	18
XII	Mount Busa-Kiamba	114.14	106.07	93	102.38	90	-3.68	-3.47	-193.74	19
VI, VII	Southwestern Negros	196.44	83.91	43	80.46	41	-3.45	-4.11	-181.36	20
III, I	Zambales mountains	139.68	118.49	85	115.05	82	-3.44	-2.91	-181.19	21
IV-A, III	Mounts Irid-Angilo and Binuang	115.21	114.08	99	110.71	96	-3.37	-2.95	-177.15	22
XI, XII	Mount Apo	99.08	85.68	86	82.48	83	-3.21	-3.74	-168.80	23
X	Mount Tago Range	83.42	68.33	82	65.22	78	-3.10	-4.54	-163.34	24
X, BARMM	Munai/Tambo	69.84	65.39	94	62.62	90	-2.77	-4.24	-145.95	25
VIII	Anonang-Lobi Range	58.05	56.98	98	54.34	94	-2.63	-4.62	-138.51	26
II, III	Casecnan Protected Landscape	90.72	82.07	90	79.96	88	-2.11	-2.57	-111.05	27
IV-B	Puerto Galera	37.31	32.33	87	30.54	82	-1.79	-5.54	-94.29	28
XII, BARMM	Mount Daguma	32.36	31.02	96	29.36	91	-1.65	-5.33	-87.09	29
IV-A	Polillo Islands	20.28	19.95	98	18.35	91	-1.60	-8.01	-84.11	30
IV-B	Iglit-Baco Mountains	56.30	47.19	84	45.61	81	-1.58	-3.35	-83.20	31
IV-B	Mount Calavite	18.15	13.50	74	11.94	66	-1.55	-11.49	-81.61	32
IV-B	Malpalon	14.09	11.86	84	10.32	73	-1.54	-13.01	-81.23	33
BARMM	Tawi-tawi Island	5.85	5.53	94	3.99	68	-1.54	-27.88	-81.11	34
IX	Mount Dapiak-Mount Paraya	14.67	13.57	92	12.06	82	-1.51	-11.11	-79.35	35
BARMM, XII	Liguasan marsh	39.42	18.10	46	16.65	42	-1.45	-8.01	-76.35	36
III	Aurora Memorial National Park	47.15	42.34	90	40.91	87	-1.42	-3.36	-74.83	37
VI	Central Panay mountains	105.58	94.56	90	93.27	88	-1.29	-1.36	-67.67	38

Region	Terrestrial Key Biodiversity Areas	Area of KBA*	Forest cover in 2000*	% Forest cover in 2000	Remaining forest cover in 2019*	% forest cover in 2019	Forest cover loss*	% Forest cover loss	Annual rate of forest loss (ha/year)	Priority ranking
III, II	North Central Sierra Madre Mountains	87.48	86.21	99	85.01	97	-1.20	-1.39	-62.92	39
VI	Mount Silay and Mount Mandalagan (Northern Negros)	68.88	45.21	66	44.06	64	-1.16	-2.56	-60.85	40
IV-B	Lake Manguao	6.45	5.32	82	4.18	65	-1.14	-21.46	-60.05	41
VIII	Mount Nacolod	33.49	32.80	98	31.67	95	-1.14	-3.47	-59.88	42
IV-B	Mount Halcon	50.95	44.43	87	43.30	85	-1.13	-2.55	-59.64	43
XI	Mount Hamiguitan (Tumadgo peak)	31.88	31.27	98	30.19	95	-1.08	-3.45	-56.69	44
IV-B	Busuanga Island	16.33	15.94	98	14.90	91	-1.04	-6.55	-54.99	45
X, IX	Mount Malindang	40.69	37.11	91	36.22	89	-0.90	-2.41	-47.16	46
IV-A	Taal Volcano Protected Landscape	65.93	31.98	49	31.10	47	-0.88	-2.76	-46.48	47
IV-B	Mount Hitding	17.77	16.56	93	15.70	88	-0.87	-5.24	-45.67	48
IV-B	Mount Siburan	11.57	9.53	82	8.68	75	-0.86	-9.00	-45.18	49
XIII	Mount Kambinlio and Mount Redondo	28.52	27.07	95	26.27	92	-0.80	-2.95	-41.97	50
VII	Mount Capayas	13.61	10.44	77	9.66	71	-0.78	-7.48	-41.07	51
VII, VI	Ban-ban	28.54	16.13	57	15.39	54	-0.74	-4.60	-39.07	52
VII	Central Cebu Protected Landscape	29.22	19.52	67	18.79	64	-0.73	-3.73	-38.27	53
VII	Cuernos de Negros	23.56	21.34	91	20.63	88	-0.71	-3.33	-37.41	54
XII	Mount Matutum	18.89	11.82	63	11.13	59	-0.69	-5.84	-36.35	55
III	Mount Dingalan	46.89	45.93	98	45.25	97	-0.67	-1.47	-35.49	56
CAR	Balbalasang-Balbalan National Park	81.54	77.79	95	77.12	95	-0.67	-0.86	-35.26	57
V	Catanduanes Watershed Forest Reserve	28.24	28.00	99	27.33	97	-0.67	-2.39	-35.18	58
IV-B	Balogo watershed	10.50	9.38	89	8.74	83	-0.63	-6.76	-33.35	59
III, NCR	Manila Bay	96.34	24.20	25	23.59	24	-0.60	-2.50	-31.81	60
V	Bacon-Manito	12.75	12.45	98	11.93	94	-0.53	-4.25	-27.84	61
V	Caramoan peninsula	18.85	18.72	99	18.23	97	-0.49	-2.64	-26.05	62
III	Angat watershed	15.41	13.29	86	12.82	83	-0.47	-3.52	-24.60	63
BARMM	Basilan Natural Biotic Area	4.48	4.45	99	4.02	90	-0.43	-9.58	-22.44	64
X	Mount Kalatungan Mountains Ranges Natural Park	35.77	31.90	89	31.48	88	-0.42	-1.31	-22.01	65
CAR, II	Mount Pulag National Park	13.29	12.56	94	12.18	92	-0.38	-3.03	-20.04	66
IX	Pasonanca Natural Park	10.42	10.03	96	9.66	93	-0.36	-3.63	-19.18	67
X	Mount Balatukan	35.25	29.24	83	28.90	82	-0.34	-1.16	-17.78	68
IV-B	Romblon Island	8.19	7.10	87	6.77	83	-0.32	-4.58	-17.10	69
IV-A	University of the Philippines Land Grants (Pakil and Real)	11.12	10.77	97	10.47	94	-0.30	-2.80	-15.87	70
III	Bataan Natural Park and Subic Bay Forest Reserve	25.25	23.47	93	23.17	92	-0.29	-1.24	-15.36	71
IV-B	Mount Hinunduang	8.22	8.08	98	7.79	95	-0.29	-3.59	-15.27	72
III	Mariveles mountains	12.10	11.23	93	10.94	90	-0.29	-2.57	-15.17	73
VIII	Biliran and Maripipi Island	12.76	12.36	97	12.07	95	-0.28	-2.29	-14.92	74
VI, VII	Mount Kanla-on Natural Park	24.78	16.22	65	15.94	64	-0.28	-1.74	-14.86	75
V, IV-A	Mount Labo	13.78	13.66	99	13.38	97	-0.28	-2.02	-14.52	76

Region	Terrestrial Key Biodiversity Areas	Area of KBA*	Forest cover in 2000*	% Forest cover in 2000	Remaining forest cover in 2019*	% forest cover in 2019	Forest cover loss*	% Forest cover loss	Annual rate of forest loss (ha/year)	Priority ranking
VI	North west Panay peninsula (Pandan)	12.06	11.70	97	11.44	95	-0.26	-2.18	-13.44	77
IV-B	Marinduque Wildlife Sanctuary (Central)	8.92	8.29	93	8.04	90	-0.25	-2.99	-13.06	78
VII	Nug-as and Mount Lantoy	10.46	6.67	64	6.47	62	-0.20	-2.96	-10.39	79
VII	Rajah Sikatuna Protected Landscape	12.40	11.22	91	11.03	89	-0.20	-1.74	-10.28	80
IV-A	Mount Makiling	6.23	5.92	95	5.76	93	-0.16	-2.71	-8.46	81
I	Kalbario-Patapat National Park	8.97	8.69	97	8.53	95	-0.16	-1.79	-8.17	82
V	Mount Isarog National Park	10.00	9.60	96	9.44	94	-0.16	-1.62	-8.16	83
IV-A	Pagbilao and Tayabas Bay	2.69	1.79	66	1.64	61	-0.15	-8.12	-7.63	84
IV-B	Mount Guiting-guiting Natural Park	15.34	15.22	99	15.07	98	-0.15	-0.99	-7.93	85
V	Bulusan Volcano Natural Park	3.72	3.42	92	3.30	89	-0.12	-3.45	-6.21	86
II	Buguey wetlands	10.87	2.34	22	2.26	21	-0.08	-3.52	-4.34	87
BARMM	Mount Dajo National Park	3.30	3.04	92	2.97	90	-0.07	-2.29	-3.67	88
X	Mount Kitanglad	31.02	29.55	95	29.48	95	-0.07	-0.24	-3.73	89
BARMM	Lake Lanao	36.35	3.14	9	3.08	8	-0.06	-2.01	-3.33	90
XII, XI	Mount Sinaka	1.75	1.54	88	1.48	85	-0.05	-3.46	-2.80	91
V	Mount Kulasi	3.05	3.03	99	2.97	98	-0.05	-1.81	-2.89	92
IV-A	Quezon National Park	1.98	1.95	98	1.90	96	-0.05	-2.39	-2.45	93
VII	Mount Kangbulagsing and Mount Lanaya	2.62	1.72	66	1.68	64	-0.04	-2.28	-2.07	94
IV-A	Mount Palay-Palay-Mataas Na Gulod National Park	1.83	1.77	97	1.74	95	-0.03	-1.55	-1.44	95
III	Candaba swamp	1.91	0.55	29	0.53	28	-0.03	-4.76	-1.39	96
IX	Mount Timolan	1.92	1.84	96	1.80	94	-0.03	-1.87	-1.81	97
IV-A	Mounts. Banahaw-San Cristobal Protected Landscape	11.33	10.68	94	10.65	94	-0.03	-0.27	-1.54	98
VII	Mount Bandila-an	1.78	1.60	90	1.57	88	-0.03	-1.65	-1.39	99
X	Timpoong and Hibok-hibok Natural Monument	3.73	3.45	93	3.44	92	-0.01	-0.31	-0.56	100
II	Malasi Lake	0.16	0.01	3	0.00	2	0.00	-52.57	-0.15	101
	Grand Total	**5129.8**	**4540.39**		**4270.33**		**-270.06**		**-14213.79**	
	Average			**86**		**81**		**-6**		

* Thousand ha

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COMMUNICATION

The woody flora of Shettihalli Wildlife Sanctuary, central Western Ghats of Karnataka, India - A checklist

Kanda Naveen Babu [1], Kurian Ayushi [2], Vincy K. Wilson [3], Narayanan Ayyappan [4] & Narayanaswamy Parthasarathy [5]

[1,3,5] Department of Ecology and Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry 605014, India.
[1–4] Department of Ecology, French Institute of Pondicherry, 11, Saint Louis Street, White town, Puducherry 605001, India.
[2] Manipal Academy of Higher Education, Madhav Nagar, Karnataka 576104, India.
[1] naveenbabu.k@ifpindia.org, [2] ayushi.k@ifpindia.org, [3] vincy.k@ifpindia.org, [4] ayyappan.n@ifpindia.org (corresponding author), [5] nparthasarathypu@gmail.com

Abstract: Documenting the biodiversity of protected areas and reserve forests is important to researchers, academicians and forest departments in their efforts to establish policies to protect regional biodiversity. Shettihalli Wildlife Sanctuary (SWS) is an important protected area located in the central Western Ghats of Karnataka state known for its diverse flora and fauna with distinct ecological features. For the last four decades the sanctuary has witnessed the loss of forest cover, yet the vegetation in few locations is relatively undisturbed. The current inventory was undertaken during 2019–2020 to provide a checklist of woody species from SWS under-researched earlier. The list comprises 269 species of trees, lianas and shrubs distributed in 207 genera and 68 families. The most diverse families are Fabaceae, Moraceae, Rubiaceae, Rutaceae, Lauraceae, Apocynaceae, Meliaceae, Malvaceae, Phyllanthaceae, and Anacardiaceae, representing 48% of total woody flora. The sanctuary shelters 263 native and six exotic plant species. Thirty-nine species were endemic to the Western Ghats, five species to peninsular India and one species to the Western Ghats and Andaman & Nicobar Islands. Four forest types, i.e., dry deciduous, moist deciduous, semi-evergreen, and evergreen forests, are represented in the sanctuary. Of the total species, only seven occurred in all forest types, while 111 species are exclusive to a single forest type. One-hundred-and-four taxa were assessed for the International Union for Conservation of Nature & Natural Resources (IUCN) Red List. Ten species that fall under Near Threatened, Vulnerable, and Endangered categories were encountered occasionally. The baseline data generated on plant diversity will be useful in highlighting the importance of these forests for species conservation and forest management. Such data form a cornerstone for further research. For instance, to understand the effect of invasive species and human impacts on the diversity of the region.

Keywords: Disturbance, endemic species, forest types, IUCN status, lianas, shrubs, trees.

Abbreviations: AN – Andaman & Nicobar Islands; DD – Data Deficient; DDF – tropical dry deciduous forest; EG – Eastern Ghats; EGF – tropical evergreen forest; EN – Endangered; HIFP – Herbarium of Institute Francis Puducherry; IFP – French Institute of Pondicherry; IUCN –International Union for Conservation of Nature & Natural Resources; LC – Least Concern; MDF – tropical moist deciduous forest; NE – Not Evaluated; NT – Near Threatened; PI – Peninsular India; SEGF – tropical semi-evergreen forest; SWS – Shettihalli Wildlife Sanctuary; VU – Vulnerable; WG – Western Ghats.

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INTRODUCTION

India is one of the 17 mega biodiversity countries globally (Singh et al. 2015), and the Western Ghats constitute one of the 36 biodiversity hotspots. The Western Ghats are known for their exceptional biological diversity, with a high degree of endemism (Ahamedullah & Nayar 1986; Reddy et al. 2021) and a long history of field studies within and outside protected areas. Over the past few decades, there has been growing concern about the loss of biodiversity from the hotspots subjected to numerous threats (Marchese 2015), with deforestation as the primary threat; for instance the Western Ghats lost 35% of forest cover between 1920 and 2013 (Reddy et al. 2016). On the other hand, recent reviews report that annually an average of 198 new plant species are discovered from India (Reddy et al. 2021), accounting for 10% of new plant discoveries globally. But with current extinction rates we may lose many species before documentation. Furthermore, it is necessary to assess a species based on the revised IUCN Red List criteria for effective conservation as currently protected areas experience numerous threats (IUCN 2017). In this context, it is crucial to investigate underexplored areas to identify species of importance for conservation actions.

Shettihalli Wildlife Sanctuary (SWS), one of the 25 sanctuaries of the central Western Ghats in the Shivamogga district, has undergone tremendous changes in the past. The region is home to rich plant diversity with a range of forest types due to variation in rainfall, elevation, and temperature. Over the past five decades, large areas have been cleared for hydroelectric projects, dams, plantations and agricultural operations (Anonymous 2005). A four-decadal analysis (1973–2012) of land use and land cover changes in the region reveals that the forest vegetation has declined by 21.5% (Ramachandra et al. 2013).

A review of the literature shows that botanical explorations in the Shivamogga region are poor except for the available district flora (Ramaswamy et al. 2001), the flora of Agumbe and Tirthahalli areas (Raghavan 1970; Rao & Krishnamurthy 2021) and a few ecological inventories: plant diversity of the Kaan forest in Sagar (Gunaga et al. 2015) and ethnobotanical information of Hosanagara (Shivanna & Rajakumar 2011). Specifically, the SWS was underexplored for floristic enumeration except for the only study by Ramaswamy et al. (2001), who sampled a part of the sanctuary. Therefore, this study was undertaken to document woody flora from deciduous and evergreen forests of SWS in the central Western Ghats with a note on endemic species diversity and conservation status.

MATERIALS AND METHODS

Study area

Shettihalli Wildlife Sanctuary is situated in the Malanad region of central Western Ghats, distributed over six forest ranges of three taluks in the Shivamogga district, Karnataka state, India (Figure 1). The spatial extent of SWS is 395.6 km^2 and lies between 75.167 to 75.583 longitude and 13.667 to 14.083 latitude (Anonymous 2005). It was notified in 1974 as it is of adequate ecological, faunal, floral, morphological, and zoological significance to protect wildlife and its environment. SWS experiences a tropical climate, with the mean annual precipitation that varies from 1,044 mm to 3,076 mm during the period 2010–2018 (Fick & HIjmans 2017; https://worldclim.org/). Similarly, the mean minimum and maximum temperatures range 17.50–19.38 °C and 27.76–29.92 °C, respectively. The site receives bulk rainfall during June–October, with maximum precipitation in July. March is reported as the driest month. The landscape is characterized by undulating hills with steep terrains in the western part of the sanctuary, with elevation ranging from 850 to 1,050m. The eastern slopes' terrain is plain with an elevation that starts from 600 m and experiences low rainfall and high temperature. The sanctuary has two large open water bodies (Image 1B), and acts as a catchment basin for the Kumudvathi river. Geologically, SWS consists of various rock formations of the Archean gneisses, sandstones, and granites. Soils of SWS are ferrallitic to lateritic and mostly acidic (Bourgeon 1989). The abandoned Manganese ore quarries occur in three different locations inside the sanctuary (Image 1E). The landscape is dominated by moist deciduous forest besides semi-evergreen and evergreen forests on the hilltops of the sanctuary's western side (Anonymous 2005). The sanctuary is the host for 32 enclosures and 75 villages. The people's livelihood is mainly on the agriculture and seasonal collection of forest resources, including fuelwood.

Sampling, identification, and herbarium

A reconnaissance survey was carried out in November 2018 to understand the land use and land cover types in the landscape. Botanical explorations for woody flora (trees, lianas and shrubs) were made from Feb–Mar 2019 and Oct–Nov 2020 in the study site using a random sampling approach. Efforts were made to cover the

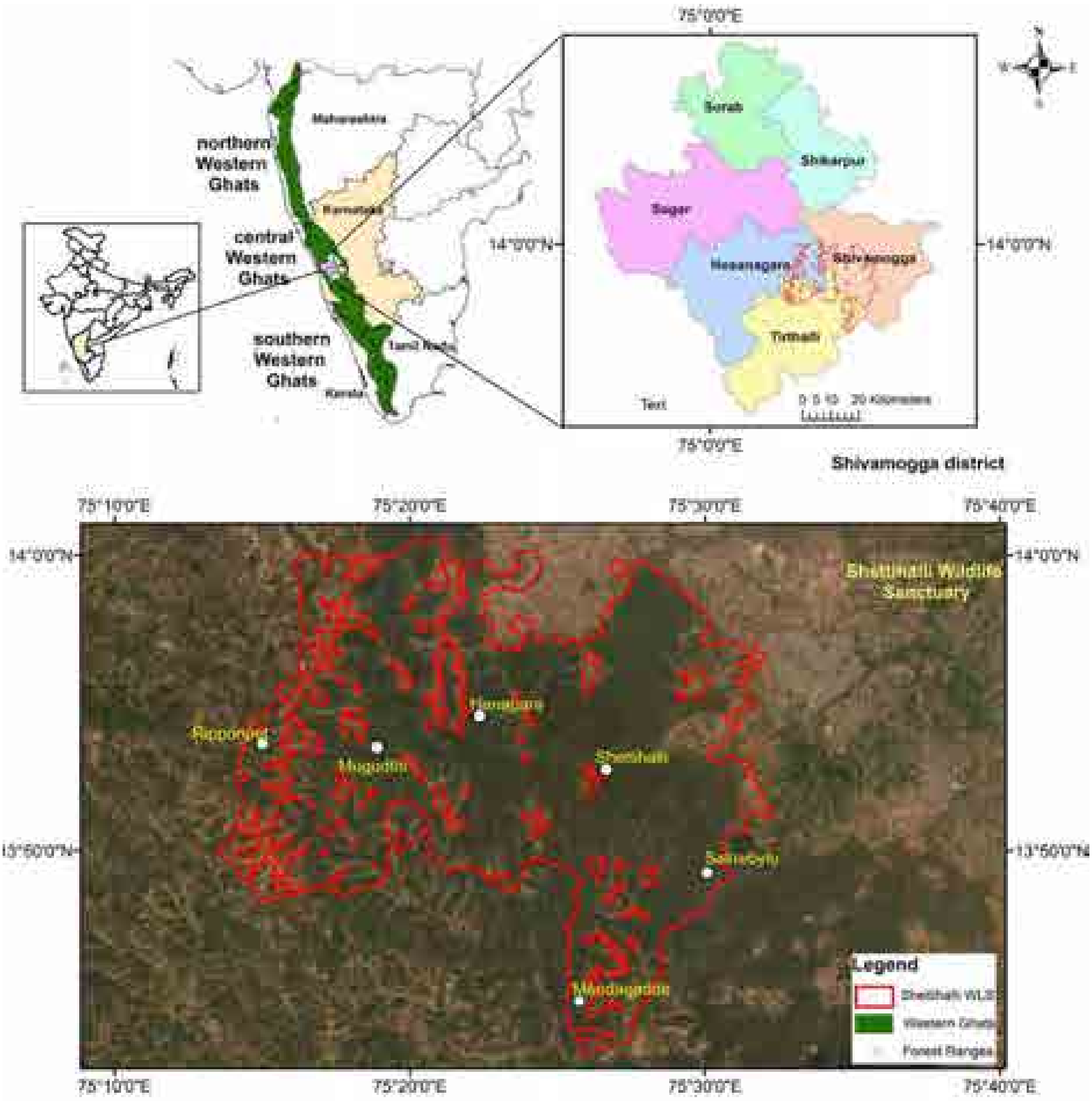

Figure 1. The geographic location of Shettihalli Wildlife Sanctuary in the central part of Western Ghats, Karnataka state.

maximum area of the region. Voucher specimens were collected, methodologically processed, and identified to the species level with assistance from botanists from IFP with expertise in the Western and Eastern Ghats flora identification (Saldanha & Nicholson 1976; Saldanha 1996; Gamble & Fischer 1915–1935; Ramaswamy et al. 2001). Species identification keys (Pascal & Ramesh 1987; Ramesh et al. 2010; http://www.biotik.org/), and specimens from the Herbier Institut Français de Pondichéry (HIFP) were used as reference. All mounted vouchers were deposited in the HIFP with the accession numbers (HIFP series). The current checklist follows APG IV classification, with the families listed alphabetically with their represented species (Chase et al. 2016). The species nomenclature was updated following Nayar et al. (2014). The endemic species distribution was assigned with the help of a published source (Singh et al. 2015), and conservation status was accessed from the IUCN (2021). Attempts were made to categorize species as common and rare, particularly for endemic and threatened species in the field.

RESULTS

Floristic diversity

This study recorded 269 woody species (trees, lianas and shrubs) belonging to 207 genera and 68 families as per the APG IV (Chase et al. 2016) classification, including three species not identified to the species level (Table 1). Of the species recorded, 269 are angiosperms and one was a gymnosperm: *Gnetum edule* (Gnetaceae). Dicots constituted the significant woody flora, with 263 species from 203 genera and 63 families, and the monocot contribution was six species belonging to seven genera and four families. Trees were represented by 184 (68%) species, followed by lianas with 67 (27%) and shrubs with 18 (7%) (Figure 2). The most diverse families include Fabaceae, Moraceae, Rubiaceae, Rutaceae, Lauraceae, Apocynaceae, Meliaceae, Malvaceae, Phyllanthaceae, and Anacardiaceae, which together represent 48% species and 46% genera of woody flora (Figure 3). The top 20 species-rich families comprised 69% (208 species) of the 269 species identified from the sanctuary. The most diverse genera include *Ficus* (13 species); *Dalbergia*, *Cissus*, *Diospyros*, and *Terminalia* (4 species each); *Artocarpus*, *Grewia*, *Holigarna*, *Jasminum*, *Litsea*, *Memecylon*, *Senna*, *Syzygium*, and *Ziziphus* (3 species each). Single species represent 174 (85.3%) genera and 30 (43.5%) families. The species diversity and dominant family composition varied among the life-forms (Table 2). Out of the 269 identified species, 263 are native to India, and six species are exotic but naturalized. Two alien invasives and *Lantana camara* and *Chromolaena odorata* (a non-woody herb to under-shrub; Image 1H), are distributed widely inside the sanctuary.

Distribution of taxa among the vegetation types

Four types of vegetation were identified from SWS, i.e., tropical dry deciduous forest (DDF), moist deciduous forest (MDF; Image 1D), semi-evergreen (SEGF; Image 1C) and evergreen forests (EGF). Taxa-wise distribution among the vegetation revealed that a maximum number of species inhabit MDF (106 species), followed by SEF (61 species), DDF (58 species), and EGF with 44 species (Table 1). Of the total species, just seven species (*Ehretia canarensis*, *Terminalia bellirica*, *Dillenia pentagyna*, *Lagerstroemia microcarpa*, *Grewia tiliifolia*, *Ziziphus oenoplia*, and *Schleichera oleosa*) occurred in all the forest types, while 111 species are exclusive to a single type of vegetation. The unique species varied greatly between 13 species from DDF to 27 to 39 species in

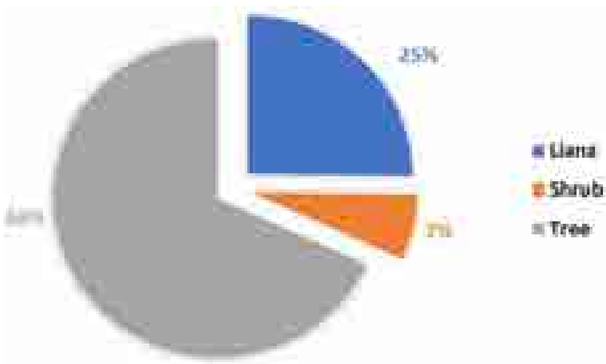

Figure 2. Percentage contribution by different plant life-forms recorded from SWS.

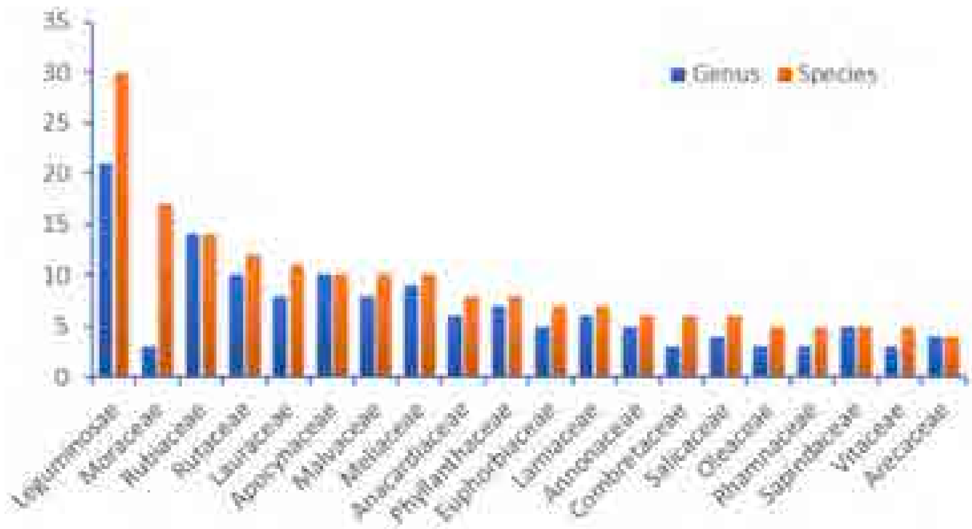

Figure 3. Top twenty families and their contribution to the genus and species richness.

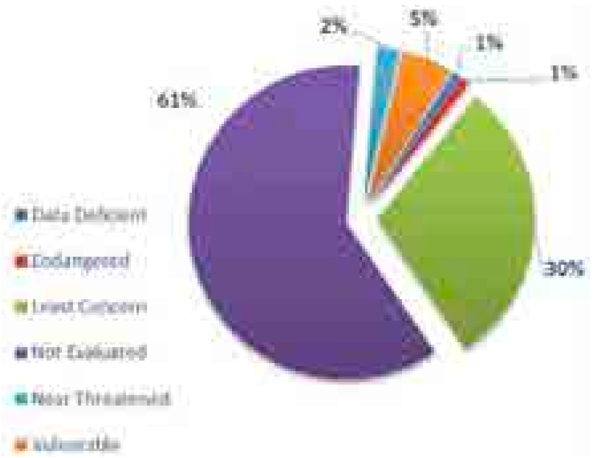

Figure 4. Percentage share of woody species of different IUCN categories from SWS.

other forest types (Table 1). Of the total liana species, *Ziziphus oenoplia* alone occurred in all forest types.

IUCN Red List categories

Out of 266 species identified to species level, only 104 (39%) are listed in the IUCN Red List assessment (Table 1; Figure 4). Categories such as Least Concern (with 79 species), Vulnerable (14), Near Threatened (six), Endangered (three), and Data Deficient (two) were listed from the study area.

Endemic distribution

From the woody flora documented from SWS, we recognized 38 species endemic to the Western Ghats, six species endemic to peninsular India and one species to the Western Ghats and Andaman & Nicobar Islands (Table 1; Images 2–5). Ninty-eight per-cent (44 species) of endemic species are reported from semi-evergreen and evergreen forest types (five and 13 species unique to SEGF and EGF, respectively). Of the 45 endemics, only two species *Ehretia canarensis* and *Lagerstroemia microcarpa,* were found in all the four vegetation types.

DISCUSSION

The study produced a comprehensive checklist of woody species of SWS, which indicates that the region is moderately diverse concerning angiosperms. The study revealed that the landscape is complex with mosaics of natural forests (dry to evergreen) to managed plantations (Teak, *Eucalyptus*, and *Acacia* species) and the human habitations surrounded by agricultural lands (Image 1G). Moist deciduous forests spread across the sanctuary, whereas semi-evergreen and evergreen forests were restricted to the western slopes of hilltops. Deciduous forests are limited to the eastern part, dominated by teak plantations.

In the present study, trees formed a major portion of the list, followed by lianas and shrubs (Figure 2). However, this can be confirmed by quantitative ecological inventories and botanical explorations in future from the region. Our results coincide with the floristic enumeration from the Agumbe region adjacent to SWS, wherein authors reported diverse woody flora (trees – 185 species; lianas – 117 species; shrubs – 62 species, Rao & Krishnamurthy 2021). Ramaswamy et al (2001) described 850 species of angiosperms from the Shivamogga district. The present checklist adds 92 woody species from SWS (69 trees, 16 lianas and seven shrubs; Table 2) to the district flora which were not reported earlier. This shows the floristic wealth of SWS and the importance of biodiversity documentation from unexplored areas. With an intensive exploration especially for herbs during the peak growing season, there is a scope for enriching the flora with new additions.

Species distribution pattern unveiled the adaptability of seven (2%) generalist species across all vegetation types despite variations in topographic, environmental and edaphic features. Similarly, 111 (44%) are specialists, exhibiting restricted distribution to other forest types might be due to the variation in micro-climatic conditions and restricted ecological niche. In our study area, the occurrence of a large number of tree populations of valuable timber species such as *Tectona grandis*, *Lagerstroemia microcarpa*, *Dalbergia latifolia* and four species of *Terminalia* portray the economic value of the forest. Of these, except *T. grandis* and *L. microcarpa,* all others are having a higher wood specific density (>0.72 g cm-3; Agarwal 1970), which is a typical value for hardwood species (as per Nogueira et al. 2005) and obviously, such species likely to contain more carbon compared to other tropical tree species. This characterizes the landscape with considerably higher carbon sequestration potential, which deserves further investigation.

Of the 10 biogeographic zones in the country, Western Ghats harbours the maximum number of endemic species (2,327 species; Reddy et al. 2021). In our study, we found 45 species that are endemic to the Western Ghats and peninsular India. Although the number is low, few species like *Lagerstroemia microcarpa*, *Terminalia paniculata*, *Flacourtia montana*, *Tabernaemontana alternifolia*, and *Cinnamomum*

Table 1. Checklist of woody species from Shettihalli Wildlife Sanctuary, central Western Ghats, India.

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
	Achariaceae					
1	*Hydnocarpus pentandrus* (Buch.-Ham.) Oken	Tree	EGF	VU	WG	HIFP 27150
	Anacardiaceae					
2	*Buchanania lanzan* Spreng.	Tree	DDF; MDF; SEGF	NE	-	HIFP 27202
3	*Holigarna arnottiana* Hook. f.	Tree	EGF; SEGF	NE	WG	HIFP 27219
4	*Holigarna beddomei* Hook. f.	Tree	EGF	NE	WG	HIFP 27256
5	*Holigarna grahamii* (Wight) Kurz	Tree	SEGF; EGF	NE	WG	SWS 41
6	*Lannea coromandelica* (Houtt.) Merr.	Tree	DDF; MDF; SEGF	LC	-	HIFP 27231
7	*Mangifera indica* L.	Tree	MDF; SEGF; EGF	DD	-	HIFP 27159
8	*Nothopegia racemosa* (Dalzell) Ramamoorthy	Tree	EGF	NE	WG	HIFP 27228
9	*Spondias pinnata* (L. f.) Kurz	Tree	MDF; SEGF	NE	-	SWS 62
	Ancistrocladaceae					
10	*Ancistrocladus heyneanus* Wall. ex J. Graham	Liana	EGF	NE	WG	HIFP 27269
	Annonaceae					
11	*Artabotrys zeylanicus* Hook. f. & Thomson	Liana	EGF	NE	-	HIFP 27270
12	*Desmos chinensis* var. lawii (Hook. f. & Thomson) Ban	Liana	DDF; MDF; SEGF	NE	-	HIFP 27304
13	*Miliusa indica* Lesch. ex A. DC.	Tree	DDF	NE	-	HIFP 27182
14	*Miliusa velutina* (Dunal) Hook. f. & Thomson	Tree	DDF	NE	-	SWS 47
15	*Polyalthia fragrans* (Dalz.) Bedd.	Tree	SEGF	NE	WG	HIFP 27170
16	*Uvaria narum* (Dunal) Wall. ex Wight & Arn.	Liana	MDF; SEGF; EGF	NE	-	HIFP 27152
	Apocynaceae					
17	*Alstonia scholaris* (L.) R. Br.	Tree	EGF; MDF; SEGF	LC	-	HIFP 27174
18	*Anodendron paniculatum* (Roxb.) A. DC.	Liana	MDF	NE	-	HIFP 27285
19	*Carissa spinarum* L. var. spinarum	Liana	SEGF	LC	-	SWS 10
20	*Chonemorpha fragrans* (Moon) Alston	Liana	SEGF	NE	-	HIFP 27298
21	*Gymnema sylvestre* (Retz.) R. Br. ex Schult.	Liana	MDF; SEGF	NE	-	HIFP 27274
22	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don	Tree	DDF; MDF; SEGF	LC	-	SWS 40
23	*Ichnocarpus frutescens* (L.) W.T. Aiton	Liana	SEGF	NE	-	HIFP 27284
24	*Secamone emetica* (Retz.) R.Br. ex Schult.	Liana	SEGF	NE	-	SWS 58
25	*Tabernaemontana alternifolia* L.	Tree	MDF; SEGF	NT	WG	HIFP 27142
26	*Wrightia tinctoria* (Roxb.) R. Br.	Tree	DDF; MDF; SEGF	NE	-	HIFP 27126
	Araceae					
27	*Pothos scandens* L.	Liana	EGF	NE	-	SWS 54
	Araliaceae					
28	*Schefflera venulosa* (Wight & Arn.) Harms	Liana	SEGF	NE	-	HIFP 27286
	Arecaceae					
29	*Arenga wightii* Griff.	Tree	EGF	VU	WG	HIFP 27247
30	*Calamus gamblei* Becc. ex Becc. & Hook. f.	Liana	SEGF; EGF	NE	WG	HIFP 27309
31	*Caryota urens* L.	Tree	EGF; SEGF	LC	-	HIFP 27179
32	*Pinanga dicksonii* (Roxb.) Blume	Tree	EGF	NE	WG	SWS 52
	Asparagaceae					
33	*Asparagus racemosus* Willd.	Liana	MDF; EGF	NE	-	SWS 6
	Bignoniaceae					
34	*Dolichandrone arcuata* (Wight) C. B. Clarke	Tree	DDF	NE	PI (WG &EG)	HIFP 27196
35	*Radermachera xylocarpa* (Roxb.) K. Schum.	Tree	DDF; MDF; SEGF	NE	PI	HIFP 27157

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
36	*Stereospermum colais* (Buch.-Ham. ex Dillwyn) Mabb.	Tree	MDF; SEGF	NE	-	HIFP 27122
	Boraginaceae					
37	*Cordia dichotoma* G. Forst.	Tree	MDF; SEGF	LC	-	SWS 77
38	*Cordia macleodii* (Griff.) Hook. f. & Thomson	Tree	DDF; MDF	NE	-	HIFP 27197
39	*Ehretia canarensis* (C. B. Clarke) Gamble	Tree	DDF; MDF; SEGF; EGF	NE	PI	HIFP 27164
	Burseraceae					
40	*Canarium strictum* Roxb.	Tree	SEGF	NE	-	HIFP 27165
41	*Garuga pinnata* Roxb.	Tree	DDF; MDF	NE	-	HIFP 27117
	Calophyllaceae					
42	*Calophyllum polyanthum* Wall. ex Choisy	Tree	EGF; SEGF	NE	-	HIFP 27209
	Cannabaceae					
43	*Aphananthe cuspidata* (Blume) Planch.	Tree	SEGF	NE	-	HIFP 27120
44	*Celtis philippensis* Blanco	Tree	EGF; SEGF	LC	-	SWS 14
45	*Celtis tetrandra* Roxb.	Tree	SEGF	LC	-	SWS 15
46	*Trema orientalis* (L.) Blume	Tree	MDF; SEGF	LC	-	HIFP 27189
	Casuarinaceae					
47	*Casuarina equisetifolia* L.*	Tree	SEGF	LC	-	SWS 13
	Celastraceae					
48	*Cassine glauca* (Rottb.) Kuntze	Tree	EGF; SEGF	NE	-	SWS 12
49	*Celastrus paniculatus* Willd.	Liana	DDF; MDF; SEGF	NE	-	HIFP 27283
50	*Loeseneriella arnottiana* (Wight) A.C. Sm.	Liana	MDF; SEGF	NE	-	HIFP 27262
51	*Maytenus emarginata* (Willd.) Ding Hou	Shrub	DDF	NE	-	SWS 45
	Clusiaceae					
52	*Garcinia gummi-gutta* (L.) N. Robson	Tree	SEGF; EGF	LC	WG	HIFP 27212
53	*Garcinia morella* (Gaertn.) Desr.	Tree	SEGF	LC	-	HIFP 27241
	Combretaceae					
54	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.	Tree	DDF; MDF	NE	-	SWS 4
55	*Calycopteris floribunda* (Roxb.) Lam. ex Poir.	Liana	MDF; SEGF	NE	-	HIFP 27275
56	*Terminalia bellirica* (Gaertn.) Roxb.	Tree	DDF; MDF; SEGF; EGF	LC	-	HIFP 27151
57	*Terminalia chebula* Retz.	Tree	MDF	LC	-	SWS 68
58	*Terminalia elliptica* Willd.	Tree	DDF; MDF; SEGF	NE	-	HIFP 27236
59	*Terminalia paniculata* Roth	Tree	DDF; MDF; SEGF	NE	PI	HIFP 27259
	Connaraceae					
60	*Connarus wightii* Hook. f.	Liana	SEGF; EGF	NE	WG	HIFP 27279
61	*Rourea minor* (Gaertn.) Alston	Liana	MDF; SEGF	NE	-	HIFP 27281
	Convolvulaceae					
62	*Erycibe paniculata* Roxb.	Liana	EGF	NE	-	HIFP 27261
63	*Stictocardia tiliifolia* (Desr.) Hallier f.	Liana	MDF; SEGF	LC	-	SWS 63
	Cornaceae					
64	*Alangium salviifolium* ssp. *sundanum* (Miq.) Bloemb.	Liana	MDF; SEGF; EGF	NE	-	HIFP 27263
	Dichapetalaceae					
65	*Dichapetalum gelonioides* (Roxb.) Engl.	Tree	SEGF; EGF	LC	-	HIFP 27258
	Dilleniaceae					
66	*Dillenia pentagyna* Roxb.	Tree	DDF; MDF; SEGF; EGF	NE	-	HIFP 27206

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
	Dioscoreaceae					
67	*Dioscorea hispida* Dennst.	Liana	MDF	NE	-	HIFP 27300
	Dipterocarpaceae					
68	*Dipterocarpus indicus* Bedd.	Tree	EGF	EN	WG	SWS 25
69	*Hopea ponga* (Dennst.) Mabb.	Tree	EGF	VU	WG	HIFP 27245
70	*Shorea roxburghii* G. Don	Tree	SEGF	VU	-	HIFP 27249
	Ebenaceae					
71	*Diospyros assimilis* Bedd.	Tree	MDF; SEGF; EGF	NE	PI	HIFP 27124
72	*Diospyros melanoxylon* Roxb.	Tree	DDF; SEGF	NE	-	HIFP 27130
73	*Diospyros montana* Roxb.	Tree	DDF; MDF; SEGF	NE	-	HIFP 27195
74	*Diospyros sylvatica* Roxb.	Tree	SEGF; EGF	NE	-	HIFP 27234
	Elaeagnaceae					
75	*Elaeagnus conferta* Roxb.	Liana	MDF; SEGF	LC	-	HIFP 27264
	Elaeocarpaceae					
76	*Elaeocarpus serratus* L.	Tree	MDF; SEGF; EGF	NE	-	HIFP 27235
	Erythroxylaceae					
77	*Erythroxylum monogynum* Roxb.	Tree	DDF	NE	-	SWS 27
	Euphorbiaceae					
78	*Blachia andamanica* ssp. *denudata* (Benth.) N. P. Balakr. & Chakrab.	Tree	EGF	NE	WG	HIFP 27255
79	*Croton caudatus* Geiseler	Liana	SEGF; EGF	NE	-	SWS 22
80	*Croton malabaricus* Bedd.	Tree	SEGF	NE	WG	HIFP 27149
81	*Givotia moluccana* (L.) Sreem.	Tree	DDF; MDF	NE	-	SWS 34
82	*Macaranga peltata* (Roxb.) Muell.-Arg.	Tree	MDF; SEGF; EGF	NE	-	HIFP 27204
83	*Mallotus philippensis* (Lam.) Muell.-Arg.	Tree	MDF; SEGF; EGF	LC	-	HIFP 27161
84	*Mallotus repandus* (Rottler ex Willd.) Muell.-Arg.	Shrub	SEGF	NE	-	HIFP 27292
	Gnetaceae					
85	*Gnetum edule* (Willd.) Blume	Liana	SEGF; EGF	LC	-	HIFP 27287
	Hernandiaceae					
86	*Gyrocarpus asiaticus* Willd.	Tree	EGF	NE	-	SWS 39
	Icacinaceae					
87	*Miquelia dentata* Bedd.	Liana	EGF	NE	WG	SWS 48
88	*Nothapodytes nimmoniana* (J. Graham) Mabb.	Tree	MDF; SEGF; EGF	NE	-	HIFP 27184
	Lamiaceae					
89	*Callicarpa tomentosa* (L.) Murray	Tree	EGF; MDF	NE	-	HIFP 27201
90	*Clerodendrum infortunatum* L.	Tree	EGF	NE	-	HIFP 27229
91	*Gmelina arborea* Roxb.	Tree	MDF	LC	-	SWS 36
92	*Gmelina asiatica* L.	Shrub	DDF	LC	-	SWS 37
93	*Isodon coetsa* (Buch.-Ham. ex D. Don) Kudô	Shrub	MDF	NE	-	SWS 42
94	*Tectona grandis* L. f.	Tree	DDF; MDF	NE	-	SWS 67
95	*Vitex altissima* L. f.	Tree	MDF; SEGF; EGF	NE	-	HIFP 27210
	Lauraceae					
96	*Actinodaphne angustifolia* (Blume) Nees	Tree	EGF; SEGF	LC	WG	HIFP 27251
97	*Actinodaphne tadulingamii* Gamble	Tree	EGF; SEGF	NT	WG	HIFP 27198
98	*Alseodaphne semecarpifolia* Nees	Tree	MDF; SEGF	NE	-	HIFP 27193

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
99	*Beilschmiedia wightii* (Nees) Benth. ex Hook.f.	Tree	SEGF	NT	WG	HIFP 27139
100	*Cinnamomum malabatrum* (Burm.f.) J. Presl	Tree	EGF; MDF; SEGF	LC	WG	HIFP 27178
101	*Cryptocarya wightiana* Thwaites	Tree	EGF	VU	-	HIFP 27250
102	*Litsea floribunda* (Blume) Gamble	Tree	MDF; SEGF; EGF	NT	WG	HIFP 27138
103	*Litsea ghatica* C. J. Saldanha	Tree	MDF; SEGF	VU	WG	HIFP 27137
104	*Litsea mysorensis* Gamble	Tree	MDF; SEGF	VU	WG	HIFP 27191
105	*Persea macrantha* (Nees) Kosterm	Tree	MDF; SEGF; EGF	NE	-	HIFP 27163
106	*Phoebe paniculata* (Nees) Nees	Tree	SEGF	LC	-	HIFP 27192
	Lecythidaceae					
107	*Careya arborea* Roxb.	Tree	MDF; SEGF	NE	-	SWS 9
	Fabaceae					
108	*Acacia auriculiformis* Benth.	Tree	MDF	LC	-	SWS 1
109	*Acacia caesia* (L.) Willd.	Liana	DDF; MDF; SEGF	LC	-	HIFP 27282
110	*Acacia sinuata* (Lour.) Merr.	Liana	DDF; MDF; SEGF	NE	-	HIFP 27280
111	*Albizia lebbeck* (L.) Benth.	Tree	MDF	LC	-	HIFP 27136
112	*Albizia odoratissima* (L. f.) Benth.	Tree	DDF; MDF; SEGF	LC	-	HIFP 27145
113	*Bauhinia malabarica* Roxb.	Tree	MDF; SEGF	LC	-	HIFP 27187
114	*Bauhinia racemosa* Lam.	Tree	DDF; MDF	NE	-	HIFP 27200
115	*Butea monosperma* (Lam.) Taub.	Tree	DDF; MDF	LC	-	SWS 8
116	*Caesalpinia cucullata* Roxb.	Liana	SEGF; EGF	NE	-	HIFP 27289
117	*Cassia fistula* L.	Tree	MDF; SEGF	LC	-	SWS 11
118	*Dalbergia horrida* (Dennst.) Mabb.	Liana	SEGF; EGF	NE	WG	HIFP 27302
119	*Dalbergia lanceolaria* L. f.	Tree	DDF; MDF	NE	-	SWS 23
120	*Dalbergia latifolia* Roxb.	Tree	DDF; MDF; SEGF	VU	-	SWS 24
121	*Dalbergia volubilis* Roxb.	Liana	MDF; SEGF	NE	-	HIFP 27303
122	*Derris trifoliata* Lour.	Liana	EGF	NE	-	HIFP 27276
123	*Endosamara racemosa* (Roxb.) R. Geesink	Liana	MDF	NE	-	HIFP 27295
124	*Entada rheedii* Spreng.	Liana	SEGF	NE	-	SWS 26
125	*Erythrina stricta* Roxb.	Tree	MDF	NE	-	HIFP 27143
126	*Moullava spicata* (Dalzell) Nicolson	Liana	MDF; SEGF; EGF	NE	WG	HIFP 27301
127	*Mucuna pruriens* (L.) DC.	Liana	MDF	NE	-	HIFP 27272
128	*Phyllodium pulchellum* (L.) Desv.	Shrub	MDF	LC	-	SWS 51
129	*Pongamia pinnata* (L.) Pierre	Tree	MDF; SEGF	LC	-	SWS 53
130	*Pterocarpus marsupium* Roxb.	Tree	DDF; MDF; SEGF	NT	-	SWS 55
131	*Pterolobium hexapetalum* (Roth) Santapau & Wagh	Liana	DDF	NE	-	SWS 56
132	*Senna hirsuta* (L.) H. S. Irwin & Barneby*	Shrub	MDF	NE	-	SWS 73
133	*Senna siamea* (Lam.) H. S. Irwin & Barneby	Tree	MDF	LC	-	HIFP 27154
134	*Senna tora* (L.) Roxb.	Shrub	DDF; MDF	NE	-	SWS 59
135	*Spatholobus parviflorus* (Roxb. ex DC.) Kuntze	Liana	DDF; MDF; SEGF	LC	-	HIFP 27288
136	*Tamarindus indica* L.*	Tree	DDF	LC	-	HIFP 27217
137	*Xylia xylocarpa* (Roxb.) W. Theob.	Tree	MDF; SEGF	LC	-	HIFP 27237
	Loganiaceae					
138	*Strychnos nux-vomica* L.	Tree	MDF; SEGF	LC	-	SWS 64
139	*Strychnos potatorum* L. f.	Tree	MDF	NE	-	SWS 65

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
	Lythraceae					
140	*Lagerstroemia microcarpa* Wight	Tree	DDF; MDF; SEGF; EGF	NE	WG	HIFP 27244
141	*Lagerstroemia parviflora* Roxb.	Tree	DDF	NE		SWS 43
	Magnoliaceae					
142	*Magnolia champaca* (L.) Baill. ex Pierre	Tree	SEGF	LC	-	HIFP 27127
	Malpighiaceae					
143	*Hiptage benghalensis* (L.) Kurz	Liana	MDF; SEGF	LC	-	HIFP 27277
	Malvaceae					
144	*Bomax ceiba* L.	Tree	DDF; MDF	LC	-	SWS 7
145	*Firmiana colorata* (Roxb.) R. Br.	Tree	SEGF	NE	-	HIFP 27211
146	*Grewia nervosa* (Lour.) Panigrahi	Tree	MDF	NE	-	HIFP 27169
147	*Grewia rhamnifolia* Roth	Liana	SEGF	NE	-	HIFP 27306
148	*Grewia tiliifolia* Vahl	Tree	DDF; MDF; SEGF; EGF	NE	-	HIFP 27207
149	*Helicteres isora* L.	Shrub	DDF; SEGF	NE	-	SWS 74
150	*Kydia calycina* Roxb.	Tree	MDF; SEGF	LC	-	HIFP 27223
151	*Pterospermum diversifolium* Blume	Tree	SEGF; EGF	LC	-	HIFP 27129
152	*Pterygota alata* (Roxb.) R. Br.	Tree	EGF	NE	-	HIFP 27220
153	*Sterculia guttata* Roxb. ex DC.	Tree	MDF; SEGF	NE	-	HIFP 27183
	Melastomataceae					
154	*Memecylon talbotianum* Brandis	Tree	SEGF	NE	WG	HIFP 27254
155	*Memecylon umbellatum* Burm. f.	Tree	SEGF	NE	-	HIFP 27253
156	*Memecylon wightii* Thwaites	Tree	EGF	NE	-	HIFP 27248
	Meliaceae					
157	*Aglaia elaeagnoidea* (A. Juss.) Benth.	Tree	SEGF	LC	-	HIFP 27181
158	*Aglaia lawii* (Wight) C. J. Saldanha	Tree	EGF; SEGF	LC	-	SWS 2
159	*Aphanamixis polystachya* (Wall.) R. Parker	Tree	MDF	LC	-	HIFP 27199
160	*Chukrasia tabularis* A. Juss.	Tree	MDF; SEGF	LC	-	HIFP 27185
161	*Cipadessa baccifera* (Roth) Miq.	Shrub	MDF	LC	-	SWS 18
162	*Dysoxylum malabaricum* Bedd. ex Hiern	Tree	MDF; SEGF; MDF	EN	WG	HIFP 27218
163	*Melia dubia* Cav.	Tree	MDF; SEGF	NE	-	SWS 46
164	*Reinwardtiodendron anamalaiense* (Bedd.) Mabb.	Tree	EGF	NE	WG	HIFP 27119
165	*Toona ciliata* M. Roem.	Tree	MDF	LC	-	SWS 69
166	*Trichilia connaroides* (Wight & Arn.) Bentv.	Tree	MDF; SEGF	NE	-	HIFP 27175
	Menispermaceae					
167	*Anamirta cocculus* (L.) Wight & Arn.	Liana	EGF	NE	-	SWS 3
168	*Coscinium fenestratum* (Gaertn.) Colebr.	Liana	EGF	DD	-	SWS 21
169	*Diploclisia glaucescens* (Blume) Diels	Liana	MDF; SEGF	NE	-	HIFP 27290
170	*Tinospora cordifolia* (Willd.) Miers ex Hook. f. & Thomson	Liana	MDF	NE	-	HIFP 27265
	Moraceae					
171	*Artocarpus gomezianus* ssp. *zeylanicus* Jarrett	Tree	MDF; SEGF	NE	-	HIFP 27177
172	*Artocarpus heterophyllus* Lam.	Tree	EGF; MDF; SEGF	NE	-	HIFP 27140
173	*Artocarpus hirsutus* Lam.	Tree	EGF; SEGF	LC	WG	SWS 5
174	*Ficus arnottiana* (Miq.) Miq. var. *arnottiana*	Tree	MDF	NE	-	HIFP 27230
175	*Ficus benghalensis* L.	Tree	DDF	NE	-	SWS 29

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
176	*Ficus callosa* Willd.	Tree	MDF; SEGF	NE	-	HIFP 27186
177	*Ficus drupacea* var. *pubescens* (Roth) Corner	Tree	MDF; SEGF	NE	-	HIFP 27215
178	*Ficus exasperata* Vahl	Tree	MDF	LC	-	HIFP 27224
179	*Ficus hispida* L. f.	Tree	MDF	LC	-	SWS 30
180	*Ficus microcarpa* L. f.	Tree	EGF	LC	-	HIFP 27243
181	*Ficus nervosa* B. Heyne ex Roth	Tree	SEGF; EGF	LC	-	HIFP 27146
182	*Ficus racemosa* L.	Tree	MDF	LC	-	SWS 31
183	*Ficus talbotii* King	Tree	MDF; SEGF	NE	-	HIFP 27232
184	*Ficus tinctoria* ssp. *gibbosa* (Blume) Corner	Tree	MDF	NE	-	SWS 32
185	*Ficus tsjahela* Burm.f.	Tree	MDF; SEGF	NE	-	HIFP 27225
186	*Ficus virens* Aiton	Tree	SEGF; EGF	LC	-	HIFP 27226
187	*Streblus asper* Lour.	Tree	MDF	LC	-	HIFP 27155
	Myristicaceae					
188	*Knema attenuata* (Wall.ex Hook. f. & Thomson) Warb.	Tree	SEGF	LC	WG	HIFP 27214
	Myrtaceae					
189	*Eucalyptus* sp.*	Tree	DDF	-	-	SWS 28
190	*Syzigium cumini* (L.) Skeels	Tree	MDF; SEGF; EGF	LC	-	HIFP 27188
191	*Syzygium caryophyllatum* (L.) Alston	Tree	SEGF	EN	-	HIFP 27257
192	*Syzygium laetum* (Buch. -Ham.) Gandhi	Tree	EGF	NE	WG	SWS 66
	Oleaceae					
193	*Chionanthus mala-elengi* (Dennst.) P.S. Green	Tree	EGF; MDF; SEGF	NE	PI	HIFP 27173
194	*Jasminum angustifolium* (L.) Willd.	Liana	SEGF	NE	-	HIFP 27308
195	*Jasminum flexile* Vahl	Liana	MDF; SEGF	NE	-	HIFP 27297
196	*Jasminum multiflorum* (Burm. f.) Andrews	Liana	SEGF; EGF	NE	-	HIFP 27299
197	*Olea dioica* Roxb.	Tree	MDF; SEGF; EGF	NE	-	HIFP 27158
	Opiliaceae					
198	*Cansjera rheedei* J. F. Gmel.	Liana	SEGF	NE	-	HIFP 27305
	Phyllanthaceae					
199	*Aporosa cardiosperma* (Gaertn.) Merr.	Tree	MDF; SEGF	VU	-	HIFP 27203
200	*Bischofia javanica* Blume	Tree	EGF; SEGF	LC	-	HIFP 27135
201	*Breynia retusa* (Dennst.) Alston	Shrub	SEGF	LC	-	SWS 75
202	*Bridelia stipularis* (L.) Blume	Liana	SEGF; EGF	LC	-	HIFP 27268
203	*Flueggea virosa* (Roxb. ex Willd.) Royle	Shrub	MDF	LC	-	SWS 33
204	*Glochidion ellipticum* Wight	Tree	MDF; SEGF; EGF	NE	-	HIFP 27222
205	*Glochidion* sp.	Tree	MDF	-	-	SWS 35
206	*Phyllanthus emblica* L.	Tree	DDF; MDF; SEGF	LC	-	HIFP 27208
	Piperaceae					
207	*Piper nigurm* L.	Liana	SEGF; EGF	NE	-	HIFP 27293
	Primulaceae					
208	*Ardisia solanacea* (Poir.) Roxb.	Shrub	MDF; SEGF; EGF	NE	-	HIFP 27121
209	*Maesa indica* (Roxb.) A. DC.	Tree	SEGF	LC	-	HIFP 27128
	Putranjivaceae					
210	*Drypetes confertiflora* (Hook. f.) Pax & Haffm.	Tree	EGF	NE	WG	HIFP 27133
	Rhamnaceae					
211	*Gouania microcarpa* DC.	Liana	EGF	NE	-	HIFP 27294

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
212	*Smythea bombaiensis* (Dalz.) S. P. Banerjee & P. K. Mukh.	Liana	SEGF; EGF	NE	WG	HIFP 27266
213	*Ziziphus oenoplia* (L.) Mill.	Liana	DDF; MDF; SEGF; EGF	NE	-	SWS 71
214	*Ziziphus rugosa* Lam.	Liana	MDF; SEGF	NE	-	HIFP 27153
215	*Ziziphus xylopyrus* (Retz.) Willd.	Tree	DDF	NE	-	SWS 72
	Rhizophoraceae					
216	*Carallia brachiata* (Lour.) Merr.	Tree	SEGF	NE	-	HIFP 27144
	Rubiaceae					
217	*Canthium angustifolium* Roxb.	Liana	SEGF; EGF	NE	-	HIFP 27267
218	*Catunaregam spinosa* (Thunb.) Tirveng.	Tree	DDF; MDF; SEGF	NE	-	HIFP 27233
219	*Gardenia latifolia* W. Aiton	Tree	DDF; MDF	NE	-	HIFP 27227
220	*Haldina cordifolia* (Roxb.) Ridsdale	Tree	DDF; MDF; SEGF	NE	-	HIFP 27125
221	*Hymenodictyon obovatum* Wall.	Tree	DDF; MDF	NE	WG	HIFP 27176
222	*Ixora nigricans* R. Br. ex Wight & Arn.	Tree	SEGF; EGF	NE	-	HIFP 27238
223	*Meyna laxiflora* Robyns	Tree	DDF; MDF; SEGF	NE	-	HIFP 27180
224	*Mitragyna parvifolia* (Roxb.) Korth.	Tree	MDF; SEGF	NE	-	HIFP 27221
225	*Morinda pubescens* Sm.	Tree	SEGF	NE	-	SWS 49
226	*Mussaenda frondosa* L.	Liana	MDF; SEGF	NE	-	HIFP 27278
227	*Pavetta indica* L.	Shrub	MDF; SEGF	NE	-	HIFP 27190
228	*Psychotria nigra* (Gaertn.) Alston	Shrub	SEGF	NE	-	HIFP 27252
229	*Psydrax dicoccos* Gaertn.	Tree	MDF; SEGF	VU	-	HIFP 27132
230	*Wendlandia thyrsoidea* (Roem. & Schult.) Steud.	Tree	MDF; SEGF	NE	-	HIFP 27123
	Rutaceae					
231	*Acronychia pedunculata* (L.) Miq.	Tree	EGF; SEGF	LC	-	HIFP 27118
232	*Chloroxylon swietenia* DC.	Tree	DDF	VU	-	SWS 16
233	*Citrus medica* L.	Tree	SEGF	NE	-	HIFP 27242
234	*Clausena anisata* (Willd.) Hook. f. ex Benth.	Tree	MDF; EGF	LC	-	HIFP 27246
235	*Glycosmis pentaphylla* (Retz.) DC.	Shrub	MDF; SEGF; EGF	LC	-	HIFP 27162
236	*Melicope lunu-ankenda* (Gaertn.) T. G. Hartley	Tree	MDF; SEGF	LC	-	HIFP 27148
237	*Murraya koenigii* (L.) Spreng.	Tree	MDF; SEGF	LC	-	HIFP 27194
238	*Murraya paniculata* (L.) Jack	Tree	EGF	NE	-	SWS 50
239	*Paramignya monophylla* Wight	Liana	MDF; SEGF; EGF	NE	-	HIFP 27240
240	*Toddalia asiatica* (L.) Lam.	Liana	MDF; SEGF; EGF	NE	-	HIFP 27271
241	*Zanthoxylum ovalifolium* Wight	Liana	SEGF	LC	-	HIFP 27273
242	*Zanthoxylum rhetsa* (Roxb.) DC	Tree	MDF	LC	-	SWS 70
	Salicaceae					
243	*Casearia ovata* (Lam.) Willd.	Tree	EGF; MDF; SEGF	NE	-	HIFP 27167
244	*Casearia tomentosa* Roxb.	Tree	MDF; SEGF	NE	-	HIFP 27168
245	*Flacourtia indica* (Burm.f.) Merr.	Tree	DDF; MDF; SEGF	LC	-	HIFP 27134
246	*Flacourtia montana* J. Graham	Tree	MDF; SEGF; EGF	NE	WG	HIFP 27216
247	*Homalium zeylanicum* (Gardner) Benth.	Tree	SEGF; EGF	NE	-	HIFP 27213
248	*Scolopia crenata* (Wight & Arn.) Clos	Tree	SEGF	NE	-	HIFP 27239
	Santalaceae					
249	*Santalum album* L.	Tree	MDF	VU	-	SWS 57

	Family/Species	Life-form	Forest type	IUCN status	Endemic distribution	Accession number
	Sapindaceae					
250	*Allophylus cobbe* (L.) Raeusch.	Liana	MDF; SEGF; EGF	NE	-	HIFP 27260
251	*Dimocarpus longan* Lour.	Tree	MDF; SEGF; EGF	NT	-	HIFP 27141
252	*Harpullia arborea* (Blanco) Radlk.	Tree	SEGF	LC	-	HIFP 27131
253	*Sapindus emarginatus* Vahl	Tree	MDF; SEGF; EGF	NE	-	HIFP 27156
254	*Schleichera oleosa* (Lour.) Oken	Tree	DDF; MDF; SEGF; EGF	LC	-	HIFP 27205
	Sapotaceae					
255	*Chrysophyllum roxburghii* G.Don	Tree	SEGF	LC	-	HIFP 27147
256	*Madhuca indica* J. F. Gmel.	Tree	MDF; SEGF	NE	-	HIFP 27160
257	*Mimusops elengi* L.	Tree	SEGF; EGF	LC	-	HIFP 27171
258	*Xantolis tomentosa* (Roxb.) Raf.	Tree	SEGF	NE	-	HIFP 27172
	Smilacaceae					
259	*Smilax zeylanica* L.	Liana	MDF; EGF	NE	-	HIFP 27291
	Solanaceae					
260	*Solanum giganteum* Jacq.	Shrub	MDF	LC	-	SWS 60
261	*Solanum seaforthianum* Andrews	Liana	MDF; SEGF	NE	-	SWS 61
	Symplocaceae					
262	*Symplocos macrocarpa* Wight ex C.B. Clarke ssp. *kanarana* (Talbot.) Noot.	Tree	MDF; SEGF; EGF	VU	WG	HIFP 27166
	Thymelaeaceae					
263	*Gnidia glauca* (Fresen.) Gilg	Tree	DDF; MDF; SEGF	NE	-	SWS 38
	Verbenaceae					
264	*Lantana camara* L.*	Shrub	DDF; MDF	NE	-	SWS 44
	Vitaceae					
265	*Cayratia pedata* (Lam.) Juss. ex Gagnep.	Liana	SEGF; EGF	VU	-	HIFP 27307
266	*Cissus discolor* Blume	Liana	SEGF	NE	-	SWS 19
267	*Cissus gigantea* (Bedd.) Planch.	Liana	MDF	NE	-	HIFP 27296
268	*Cissus* sp.	Liana	MDF	-	-	SWS 20
269	*Leea indica* (Burm. f.) Merr.	Shrub	MDF; SEGF	LC	-	SWS 76

Legend: DDF—tropical dry deciduous forest | MDF—tropical moist deciduous forest | SEGF—tropical semi-evergreen forest | EGF—tropical evergreen forest | IUCN—International Union for Conservation of Nature & Natural resources | VU—Vulnerable | NE—Not Evaluated | LC—Least Concern | NT—Near Threatened | EN—Endangered | DD—Data Deficient | WG—Western Ghats | PI—Peninsular India | EG—Eastern Ghats | AN—Andaman & Nicobar | *—Exotic species | #—Monocots.

Table 2. Summary of diversity, dominant families and species of woody flora from SWS.

Life-form	Diversity			Dominant family	Common species
	Richness	Genera	Family		
Tree	184	139	50	Moraceae Fabaceae Lauraceae Euphorbiaceae Rubiaceae	*Terminalia paniculata, Lagerstroemia macrocarpa, Terminalia elleptica* *Tectona grandis* *Xylia xylocarpa* *Aporosa cardiosperma*
Liana	68	61	32	Fabaceae Apocynaceae Menispermaceae Rhamnaceae Vitaceae	*Calycopteris floribunda, Moullava spicata* *Gnetum edule* *Stictocardia tiliifolia* *Elaeagnus conferta*
Shrub	18	16	13	Fabaceae Phyllanthacaeae Rubiaceae Lamiaceae	*Ardisia solanacea* *Cipadessa baccifera* *Glycosmis pentaphylla, Solanum giganteum* *Leea indica*

Image 1. A—Landscape view of Shettihalli Wildlife Sanctuary (SWS) | B—Water reservoir (Purudal), with SWS on the background | C—A view of tropical semi-evergreen forest | D—A view of tropical moist deciduous forest | E—Abandoned mines (manganese) inside the sanctuary | F—Cultural service: A famous temple in Maleshankara that attracts thousands of people every year | G—Disturbed environment: Forest landscape used for agricultural practices inside SWS | H—Dense growth of invasive species – *Chromolaena odorata* inside the sanctuary. © K. Naveen Babu

Image 2. Some endemic species from SWS: A—*Ancistrocladus heyneanus* | B—*Arenga wightii* | C—*Blachia andamanica* ssp. *denudata* | D—*Calamus gamblei* | E—*Actinodaphne tadulingamii* | F—*Cinnamomum malabatrum* | G—*Dipterocarpus indicus* | H—*Connarus wightii*. © K. Naveen Babu

Image 3. Some endemic species from SWS: A—*Holigarna beddomei* | B—*Pinanga dicksonii* | C—*Moullava spicata* | D—*Litsea floribunda* | E—*Memecylon talbotianum* | F—*Miquelia dentata* | G—*Polyalthia fragrans*. © Vincy K Wilson

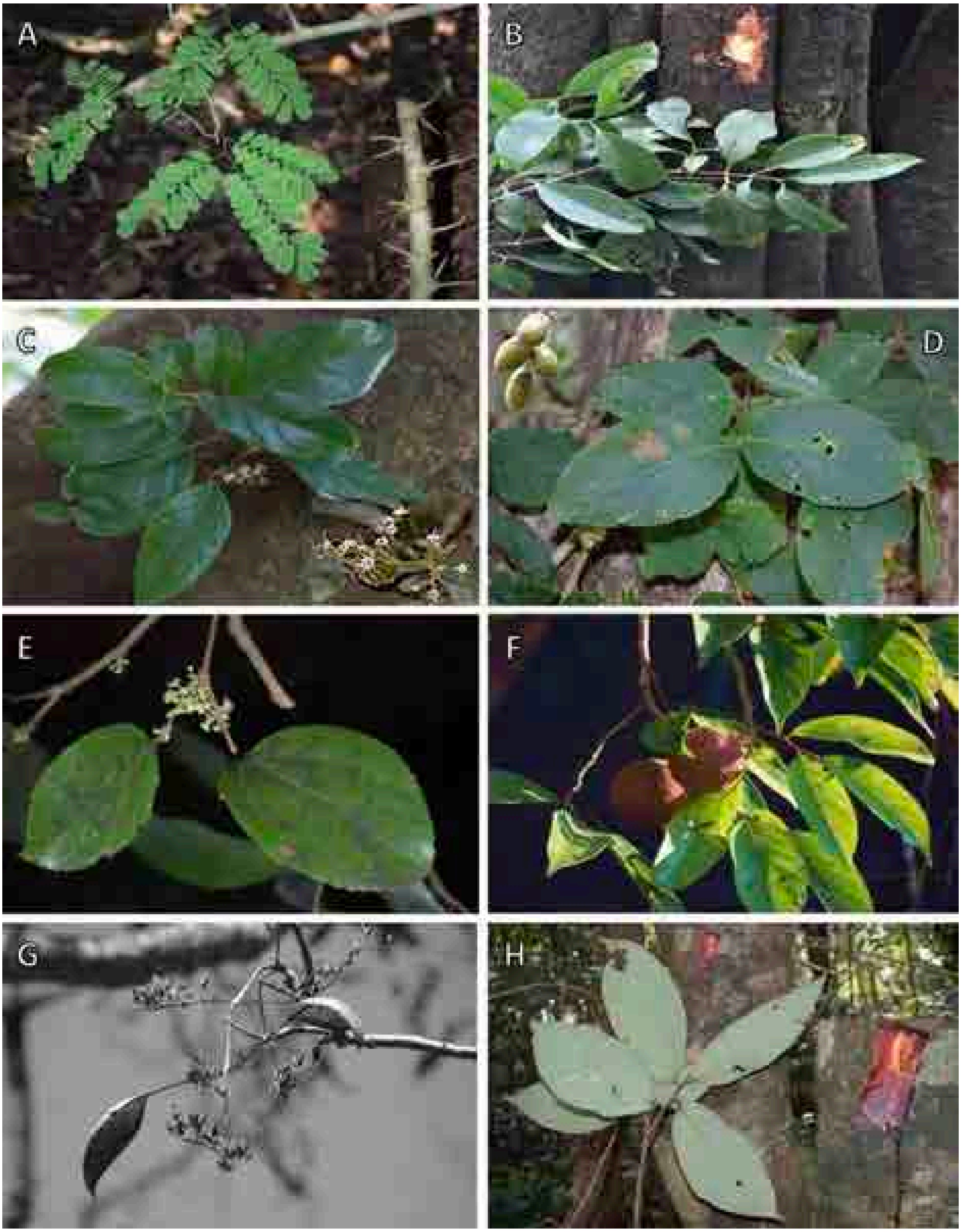

Image 4. Some endemic species from SWS: A—*Dalbergia horrida* | B—*Garcinia gummi-gutta* | C—*Ehretia canarensis* | D—*Lagerstroemia macrocarpa* | E—*Flacourtia montana* | F—*Hydnocarpus pentandrus* | G—*Hymenodictyon obovatum* | H—*Knema attenuata*. © K. Naveen Babu

Image 5. Some endemic species from SWS: A—*Radermachera xylocarpa* | B—*Reinwardtiodendron anamalaiense* | C—*Tabernaemontana alternifolia* | D—*Terminalia paniculata*. © Vincy K Wilson

malabatrum are encountered commonly across the sanctuary. Conversely, 13 endemic species were found occasionally (rare category). They include *Arenga wightii*, *Drypetes confertiflora*, *Pinanga dicksonii*, *Polyalthia fragrans*, *Dolichandrone arcuata*, *Miquelia dentata*, *Blachia andamanica* ssp. *denudata*, *Croton malabaricus*, *Syzygium laetum*, *Calamus gamblei*, *Holigarna grahamii*, *Hymenodictyon obovatum*, and *Beilschmiedia wightii*). Moreover, SWS is also host to 10 species of elevated conservation concern (*A. wightii*, *Santalum album*, *Cryptocarya wightiana*, *Cayratia pedata*, *Hopea ponga*, *Syzygium caryophyllatum*, *Beilschmiedia wightii*, *Dipterocarpus indicus*, *Symplocos macrocarpa* ssp. *kanarana*, *Chloroxylon swietenia*; IUCN 2021), which were found occasionally. Lastly, the study site harboured four medicinal species (as per Ravikumar & Ved 2000; Gowthami et al. 2021) of elevated conservation concern such as *Dysoxylum malabaricum* (Endangered), *Cayratia pedata* (Vulnerable), *Hydnocarpus pentandrus* (Vulnerable), and *S. album* (Vulnerable). Conservation effort needs to be directed towards protecting these species before they become rare from the region.

In the past, the sanctuary was subjected to many anthropogenic disturbances, including settlements, forest encroachment, mining and agricultural activities, and monoculture plantations. During our botanical explorations, authors have noticed dense growth of invasive alien species, i.e., *Chromolaena odorata* and *Lantana camara,* especially in the eastern parts of the sanctuary, posing a threat to the native flora. Due to the presence of 70 villages inside the sanctuary, most places are accessed by humans. Harvesting of plants for local use and grazing by livestock are evident in addition to the ongoing agricultural practices inside the sanctuary. Also, frequent forest fires are a major threat to the plant biodiversity of the region, especially around human habitations (Anonymous 2005). Considering the above facts and the plant biodiversity of the SWS with important endemic and threatened taxa coupled with distinct microclimatic conditions, the area deserves

Image 6. Evergreen trees of SWS: A—*Diospyros montana* | B—*Bischofia javanica* | C—*Mallotus philippensis* | D—*Elaeocarpus serratus* | E—*Nothapodytes nimmoniana* | F—*Magnolia champaca* | G—*Callicarpa tomentosa* | H—*Mimusops elengi*. © Vincy K Wilson

Image 7. Common deciduous trees of SWS: A—*Anogeissus latifolia* | B—*Catunaregam spinosa* | C—*Kydia calycina* | D—*Haldina cordifolia* | E—*Terminalia elliptica* | F—*Wrightia tinctoria* | G—*Xylia xylocarpa* | H—*Dillenia pentagyna*. © K. Naveen Babu

Image 8. Some liana species from SWS: A—*Elaeagnus conferta* | B—*Gnetum edule* | C—*Calycopteris floribunda* | D—*Acacia sinuata* | E—*Dioscorea hispida* | F—*Stictocardia tiliifolia* | G—*Toddalia asiatica* | H—*Smilax zeylanica* | I—*Ziziphus oenoplia*. © K. Naveen Babu

Image 9. Commonly seen shrubs in SWS: A—*Ardisia solanacea* | B—*Cipadessa baccifera* | C—*Glycosmis pentaphylla* | D—*Solanum giganteum*. © K. Naveen Babu

further research on investigating plant diversity, population assessment of endemic and threatened species, and forest structure concerning forest types and disturbances in the sanctuary in order to formulate strategies for conservation and better management.

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COMMUNICATION

Reproductive biology of *Ophiorrhiza caudata* C.E.C.Fisch. (Rubiaceae), an endemic and endangered creeping perennial herb of the Western Ghats, India

Maria Theresa [1], Appukuttan Kamalabai Sreekala [2] & Jayalakshmi Mohanlal [3]

[1–3] Division of Conservation Biology, Jawaharlal Nehru Tropical Botanic Garden and Research Institute, Pacha-Palode, Thiruvananthapuram, Kerala 695562, India.

[1] mariavempally@gmail.com, [2] ak.sreekala@gmail.com (corresponding author), [3] jeevaa88@gmail.com

Abstract: *Ophiorrhiza caudata* is a creeping, perennial herb distributed along wet and shady areas. The species is distylous with two distinct floral morphs: pin and thrum. Flowering usually occurs during the monsoon season. No particular difference was noticed in the flowering phenology of the two morphs. Presently the species is self-incompatible, however, it shows a tendency towards intramorph compatibility. Fruit set is above 60% in open pollination and intermorph pollination. Bees and butterflies are the major pollinators. The pollen flow between the two floral morphs varies depending upon floral morphology and pollinators. Fruit is a bi-valved capsule which dehisces by a splashing drop mechanism. The seeds are very minute. The rate of seed germination and seedling establishment in the wild condition is very poor due to adverse climatic factors. *Ophiorrhiza caudata* is struggling for survival in its natural habitat, where habitat fragmentation, climatic factors and poor seedling establishment could account for its narrow distribution.

Keywords: Floral morphs, flowering phenology, perennial herb, pollination, seed germination.

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Author details: Dr. Maria Theresa has been awarded PhD by the University of Kerala. She joined as assistant professor (on contract) in the department of botany, Newman College, Thodupuzha, Idukki. Dr. A.K. Sreekala is working as Principal scientist in the division of conservation biology, JNTBGRI, Palode. She has published more than 85 research papers in national and international journals. Also presented 60 research papers in national and international conferances. Dr. Jayalakshmi Mohanlal has been awarded PhD by the University of Kerala and presently she is working as guest lecturer in the department of botany, Vimala College (Autonomous), Thrissur.

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INTRODUCTION

The genus *Ophiorrhiza* L. (Rubiaceae) is believed to be Indo-Malaysian in origin (Mabberly 2008), and different species are scattered throughout tropical-subtropical Asia, New Guinea, Australia, and the Pacific islands. The roots of these herbaceous plants were used against snake venom from ancient times, and various plant parts are characterised by the presence of the alkaloid camptothecin and its derivatives (Yamazaki et al. 2003). Camptothecin is an inhibitor of the enzyme topoisomerase-1 (Uday & Kondapi 2010) and has anti-cancerous properties. Some *Ophiorrhiza* species such as *O. barnesii*, *O. brunonis* and *O. incarnata* are also under threat of extinction due to climatic change, habitat disturbance, natural calamities and obstruction to pollination mechanisms and reproduction.

The genus has been considered as distylous (Deb & Mondal 1977) with two floral morphs: pin (long-styled) and thrum (short-styled). Distyly is usually associated with self-incompatibility, that is, the flower of one morph cannot be fertilized by the pollen from the same flower or from another flower of same morph. This kind of heteromorphic incompatibility is reported from 25 plant families including Rubiaceae (Ganders 1979; Lloyd & Webb 1992). Darwin (1877) considered distyly as an adaptation to promote cross breeding. *Ophiorrhiza caudata* C.E.C.Fisch. is a creeping herb distributed along the wet and shady regions of southern Western Ghats. The species was considered extinct (Deb & Mondal 1997), and IUCN (1997) included it under the extinct category. It was rediscovered in 2009 (Joseph & Joseph 2009), 70 years after its last report. Considering the medicinal value and present status of this endemic distylous species, a study on its reproductive mechanism is needed for conservation. The present investigation was carried out during 2013–2016 to examine the flowering phenology, floral biology, breeding system, pollination and seed biology of *O. caudata*.

MATERIALS AND METHODS

Study area

A clumped population of *O. caudata* was located in the Mankulam and Kallar forest areas of Idukki district (Image 1a) in Kerala ($10^0$11.9230"N $76^0$92.884"E, 340–2,102 m). The average rainfall in the area ranges from 2,500–3,000 mm, with 70% occurring during the south-west monsoon; mist and frost prevail during the winter months and high humidity during the monsoon season. *O. caudata* is distributed along the wet and shady areas of Mankulam and Kallar (Figure 1). *Ophiorrhiza mungos, O. barberi*, and *O. barnesii are* the other *ophiorrhiza* species distributed along this area. *Dictyospermum montanum, Neanotis decipiens, Plectanthus malabaricus, Cleome speciosa, Impatiens elegans, Impatiens maculata, Cyanotis pilosa*, and *Pilea melastomoides* are other associated plants in the area.

Phenology and floral morphology

Twenty-five healthy individuals of approximately the same age from both floral morphs (i.e., pin and thrum) were marked, and periodic observations were made on different developmental events from the emergence of vegetative buds up to seed germination and successful establishment of seedlings. The observations were made as per the method suggested by Dafni (2007). The time of anthesis and anther dehiscence, flower colour and odour, nectar production, stigma type, and flower longevity were noticed. The flower morphology of each morph was studied with the help of hand lens and dissection microscope. Floral measurements were taken in millimetres by using a digital vernier calliper. For this purpose, 20 flowers of each morph were collected from the field, preserved in 70% ethanol and detailed study was conducted in the laboratory. This was helpful to analyse heterostyly in the species.

The mean number of pollen grains per flower was calculated by dissecting a single anther in a drop of acetocarmine: glycerine (3: 1) on a microscopic slide and counting all the grains; the number obtained was multiplied by five (the number of anthers per flower). In this way the pollen count was taken from anthers of 10 flowers (from 10 different individuals of each morph) and the mean number of pollen grains per flower was calculated. The average number of ovules per ovary was counted by dissecting young pistils under a microscope. Pollen-ovule ratio was calculated as per the method suggested by Cruden (1977).

Pollination biology

Field observations of flower visitors were carried out from 0600 to 1630 h. Insect foraging activity was noted by visual observation. Number of floral visits per hour by each pollinator, their foraging behaviour, time spent by the insect on each flower and stigma touch were recorded. Temporal activities of the insects on pin and thrum morphs were distinctly noted.

Pollinators were trapped using insect nets, pan traps and sticky traps (Toler et al. 2005). Trapped insects were preserved individually in small screw cap vials (10 ml)

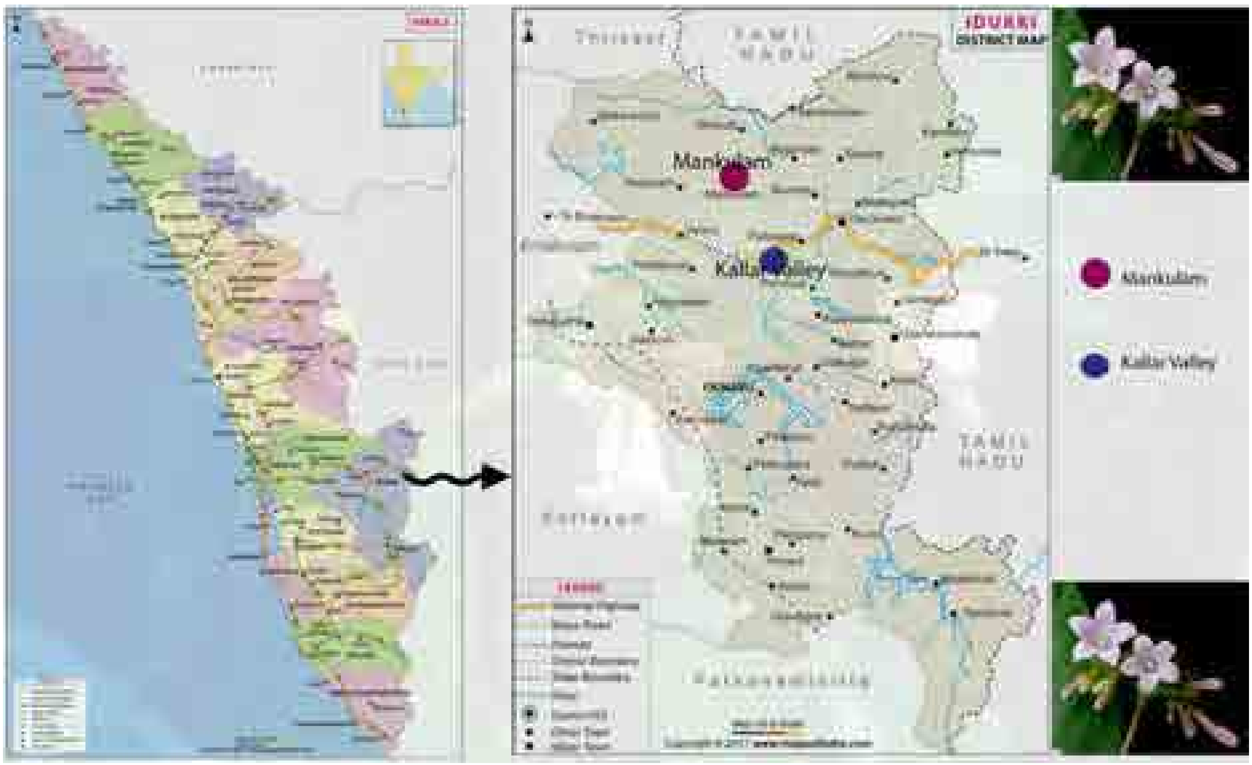

Figure 1. Study area in Idukki district—Mankulam and Kallar Valley

containing 4 ml of ethyl alcohol. The vials were vigorously shaken for two minutes to remove pollen grains from the insect's body. The insects were taken out from the vial and the suspension was allowed to evaporate. After evaporation, pollen grains were mounted in a few drops of acetocarmine-glycerin stain and observed under a microscope. The number of stained and unstained pollen grains of the selected plant species was counted. The pollinators were identified with the help of entomologists from the school of biology, IISER, Thiruvananthapuram, and an insect manual.

Breeding system

The mating system of the distylous species was analysed by fruit set comparisons in the field after various breeding experiments such as self-pollination, intramorph pollination, intermorph pollination, emasculation & bagging, and bagging without emasculation. Fruit set after these experiments were compared with the fruit set after open pollination. For each of the breeding experiment, 150 flowers were chosen from different individuals. The results were compared with Student's t-test. (SPSS ver.16.0 at the significance level of α= 0.05)

Self-pollination was conducted to check whether the species is self-compatible. For this, flower buds one day before anthesis were bagged using butter paper bags and pollinated the next day using pollen from flowers of the same individual. The pollinated flowers were bagged again, and periodically observed for fruit set. For intramorph pollination, flower buds were emasculated and bagged one day before anthesis using butter paper bags. On the next day, pollen grains were transferred from flowers of other individuals of the same morph into the opened flower. For intermorph pollination, the flower buds were emasculated, bagged and were pollinated with pollen grains from flowers of the other morph. Another set of flowers were emasculated and bagged to check the occurrence of apomictic fruit test. Several flower buds were bagged without emasculation to test autogamous self-pollination within each morph.

Fruit and Seed biology

Fruit development was observed from the day of pollination until its maturation and dehiscence. Mature fruits from each morph were harvested and seeds collected. The average number of seeds developed per fruit/capsules was calculated. For analysing the reproductive success of flowers after pollination, the number of flowers per day in a 10 x 10 m quadrate of the population and the number of mature fruits developed from these flowers were scored and the flower-fruit ratio was calculated.

For the evaluation of seed dispersal, laboratory experiments were preferred because the seeds of *Ophiorrhiz*a were minute to count from the intact soil. Peduncles with an open capsule containing mature seeds were placed in individual bottles and set on a floor covered with three square meters of white paper for easy detection of the scattered seeds. One 2 ml syringe fixed at a height of 2 m and water drops were allowed to fall onto the open capsule. Each water drop was approximately 0.1 ml. After the seeds scattered by water droplets, the longest distance from the peduncle to the seed was measured. The experiments were repeated at least five times for each morph (Nakanishi 2002).

For analysing seed germination, mature fruits were covered with paper bags before dehiscence and seeds were collected from each morph separately. Seeds were stored under laboratory conditions and allowed to germinate in petri dishes under different conditions: 1) Whatman filter paper (Grade 1); 2) soil from natural habitat; 3) soil from JNTBGRI campus. Samples of seeds were also allowed to germinate in the natural habitat to assess the influence of environmental factors on seed germination. Five replicates of 30 seeds of each morph were allowed to germinate every month to determine the optimal month for seed germination and seedling establishment. Quantitative features such as the number of days taken for seed germination and percentage of seed germination and seedling establishment in the field as well as in the laboratory conditions were analyzed periodically.

RESULTS

Phenology and floral morphology

O. caudata is a perennial creeping herb that sprouts at the end of May. Vegetative buds arise from the nodes of creeping stems during the monsoon, and the young leaves are yellowish-green. When mature, it becomes dark green in its upper surface and brownish green in the lower surface. The plants started to bloom in June and continued to January (Figure 2). New seedlings take 75–86 days to flower. Peak blooming was noticed from mid-August to mid-September (Figure 2). When the fruit matures, each fruit contains 45–110 minute brownish seeds which are dispersed by rain water

The inflorescence of *O. caudata* is a terminal capitate cyme with 1–6 flowers, with the flowers arranged in a centrifugal manner. Flower development completes within 7–10 days (Image 1d). Anthesis was noticed in

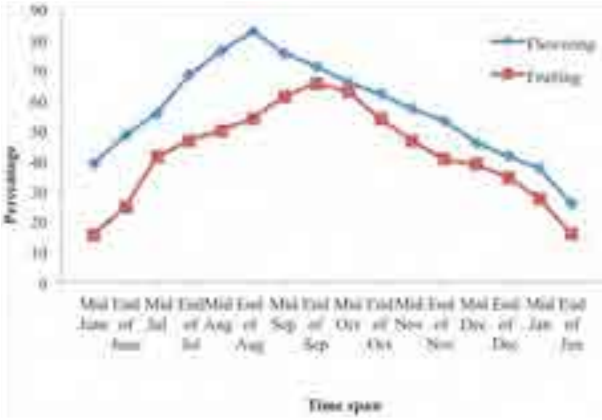

Figure 2. Flowering and fruiting phenology of *Ophiorrhiza caudata*.

the morning hours between 0600–0845 h and anther dehiscence occurs soon after flower opening. Flowers of thrum morphs open earlier than pin ones. Flowers are white with a mild fragrance and the nectar is located on the semicircular disc present above the ovary. Average life span of each flower is 20–24 hours. Blooming lasts for an average of 215 days in a year. Fruit development was completed within 25-35 days after pollination. During heavy rain, dehiscence of fruits occurs by splashing drop mechanism.

The inflorescence and peduncles are glabrous, and 2.5–3.5 cm long. The flowers are white, lanceolate and 9.3–13.5 mm long. Pedicels are 1–1.5 mm long. Hypanthium is cup shaped. Calyx lobes are 5, ovate-lanceolate, acute and shortly keeled at back. Corolla is white and infundibuliform with 5 lobes. They are 8–10 mm long and glabrous outside with a ring of hairs on the throat of corolla tube. Stamens are 5 and are epipetalous; anthers are oblong and longitudinally dehiscent. Average length of the stamen is different in the two different morphs, 2.45 mm in pin flowers and 7.19 mm in thrum flowers. Ovary is obovoid, 0.59–0.85mm x 0.31–0.41 mm in pin flowers and 0.65–0.81mm x 0.33–0.41 mm in thrum flowers. Style is slender in both morphs but its length varies among the two different morphs, 5.95 mm in pin flowers and 1.79 mm in thrum flowers. Stigma-bifid and capitate in pin flowers and lanceolate in thrum flowers (Image 1b,c).

Pollination Biology

Butterflies, flies, bees and ants were the major floral visitors of *O. caudata,* and they were attracted by the mild fragrance of flowers. Flowering was in rainy season, and rainwater promotes pollination (Hydrophily) in *O. caudata*. One unidentified insect visits the flowers frequently; it spend around 45 ± 15 sec per flower in

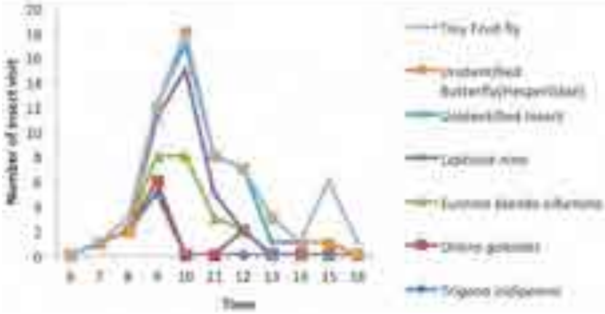

Figure 3. Foraging activity of pollinators: *Ophiorrhiza caudata* – pin morph.

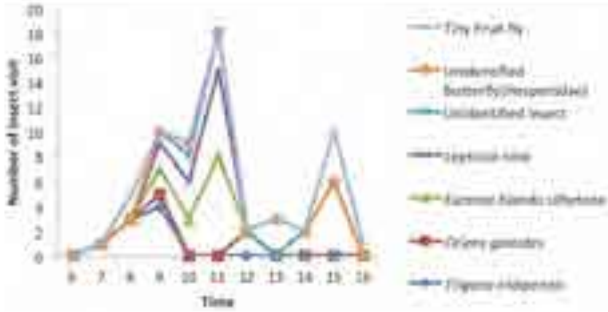

Figure 4. Foraging activity of pollinators: *Ophiorrhiza caudata* – thrum morph.

pin morphs and 46 ± 21 sec per flower in thrum morphs (Figure 3, 4). This insect either collects pollen from the exposed anthers of thrum flowers or enters the corolla tube to collect nectar. In pin morph, they enter into the corolla tube for collecting both pollen and nectar. Pollen flow into the thrum morphs by this insect was comparatively poor because the stigma is positioned under the throat of the corolla tube and therefore there was a reduced stigma touch. The prime floral visitor was stingless bee (*Trigona iridipennis*). It can enter up to the throat of the corolla tube and collects both pollen and nectar. The tiny fruit flies also make irregular visits and collects nectar. *Oriens goloides* is a butterfly visitor with more foraging time comparing to the other butterflies. *Eurema blanda silhetana* and *Leptosia nina* are the other butterflies visiting on the same time (Figure 3, 4). However, they spend only less time per visit but have more frequent visits per flower. These tiny butterflies make frequent movements in the flower which facilitates cross-pollination. Butterflies normally rest on the corolla, exert their proboscis and collect the nectar present on the disc above the ovary. Therefore, the pollen transfer from the inserted anthers of pin morph flowers into the stigma of thrum flowers which is also located inside the corolla tube will be comparatively less.

Table 1. Percentage of fruit set in six pollination methods in pin and thrum morphs of *Ophiorrhiza caudata*.

	Treatment	Number of flowers examined	Fruit set (%)
1	Self-pollination		
	Pin	150	00
	Thrum	150	00
2	Intramorph pollination		
	Pin x Pin	150	6.67
	Thrum x Thrum	150	3.33
3	Intermorph pollination		
	Pin (female) x Thrum(male)	150	72. 51
	Thrum(female) x Pin(male)	150	69. 07
4	Emasculation and netting		
	Pin	150	00
	Thrum	150	00
5	Netting without emasculation		
	Pin	150	00
	Thrum	150	00
6	Open pollination		
	Pin	150	66. 76
	Thrum	150	64. 13

Breeding System

Fruit set was not observed after self-pollination, emasculation and netting, netting without emasculation experiments in both the morphs. This indicated that the species was self-incompatible and there is no apomixis or parthenocarpic fruit development in this species. The percentage of fruit set after intramorph pollination in pin and thrum morphs are 6.67% and 3.33%, respectively. These results indicated that *O. caudata* has a tendency towards intramorph compatibility. Pin (female) x Thrum (male) and Thrum (female) x Pin (male) crosses resulted in 72% and 69% fruit set respectively and no notable difference between the morphs (t= 3.21, P >0.05). Therefore, the male and female organs of both the morphs were functional. Open pollination resulted in a fruit set of 66% in pin morphs and 64% in thrum ones. Comparison of these results with the manual intermorph pollination treatments showed no notable difference (Pin (female) x Thrum (male), inter-morph pollination vs. open pollination, 72% vs. 66%, t= 4.33, P >0.05 and thrum (female) x pin (male), inter-morph pollination vs. open pollination, 69% vs. 64%, t= 4.90, P >0.05) (Table 1).

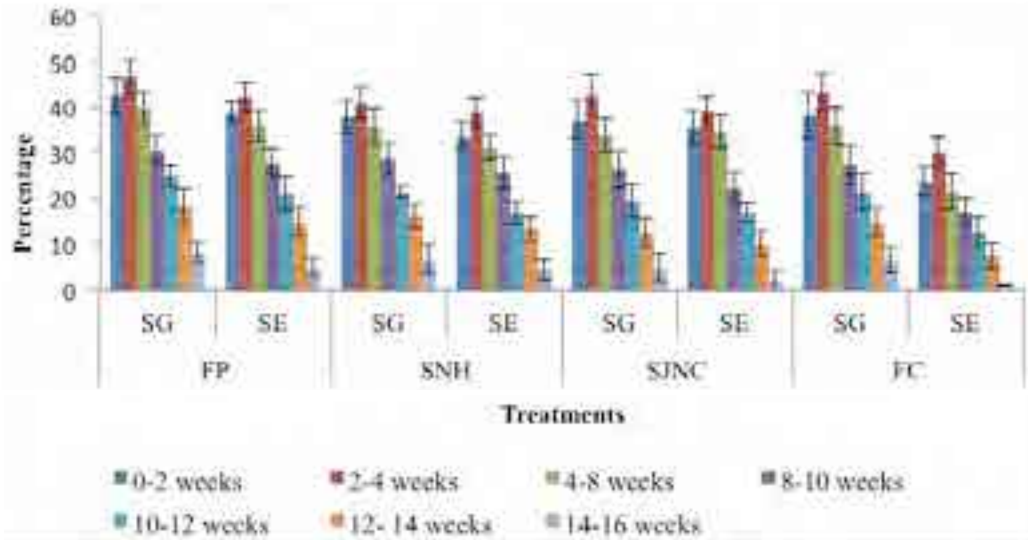

Figure 5. Seed germination of O. caudata (pin morph) at different conditions: SG—seed germination | SE—seedling establishment | FP—filter paper | SJNC—soil from JNTBGRI campus | SNH—Soil from natural habitat | FC—field condition.

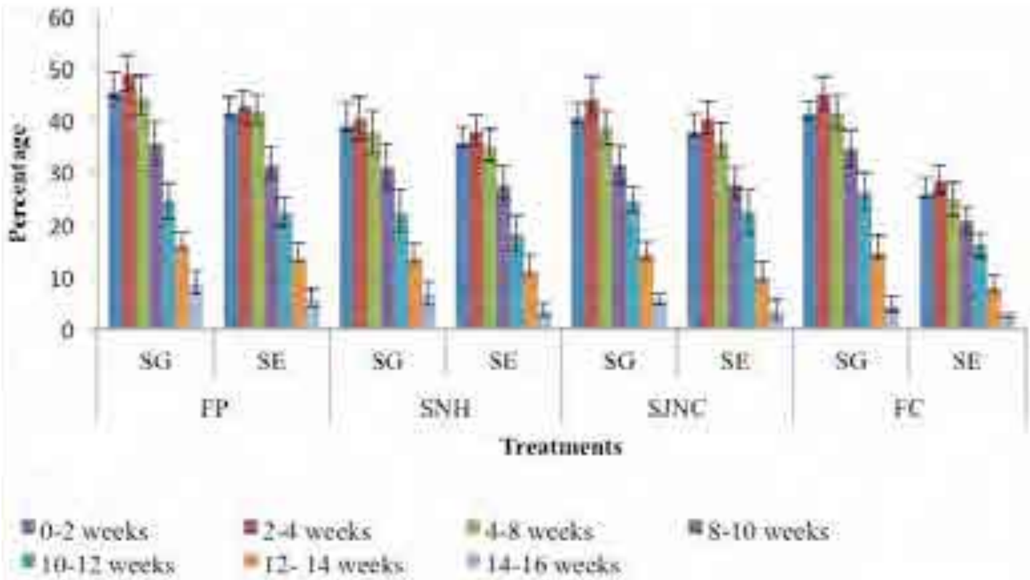

Figure 6. Seed germination of O. caudata (thrum morph) at different conditions: SG—seed germination | SE—seedling establishment | FP—filter paper | SJNC—soil from JNTBGRI campus | SNH—soil from natural habitat | FC—field condition.

Fruit and seed biology

The fruit is a boat-shaped, bi-valved capsule which dehisces along the dorsal surface (Image 1e). The capsule attains its maximum size (6.7 ± 0.51 mm x 5.4 ± 0.72 mm in pin morphs and 6.7 ± 0.32 mm x 5.5 ± 0.63 mm in thrum morphs) within 25–35 days after pollination. Each fruit contains 86 ± 12 seeds in both morphs and the number of seeds in the two locules may vary. The seeds were minute (0.68 ± 0.06 mm x 0.54 ± 0.05mm in pin plants and 0.64 ± 0.07 mm x 0.58 ± 0.08 mm in thrum plants), angular, glabrous and were brown coloured. Flower-fruit ratio of pin morphs in natural condition was calculated as 1.5:1 and that of thrum flowers was 1.6:1.

Seed dispersal

The seed dispersal mechanism in *O. caudata* was splash seed dispersal by raindrops. During rain, the water drops were collected in the boat-shaped capsule containing the seeds, which are splashed out and flushed away over certain distance. Thus the raindrops provide

Image 1. Floral biology of *Ophiorrhiza caudata* C.E.C. Fisch.: a—population | b—flower of pin morph | c—flower of thrum morph | d—flower development | e—fruit | f—seed germination.

energy for the seeds to come out of the capsule. The maximum dispersal distance of seeds under laboratory conditions in pin morphs was 93 ± 5.9 cm and 93 ± 5.6 cm in thrum morph seeds.

Seed germination and seedling establishment

The freshly harvested seeds of *O. caudata* shows dynamic germination in all the conditions, which indicates the seeds, are recalcitrant. Seed germination was hypogeal. In both morphs, maximum seed germination 40–45 % was noticed within 2–4 weeks after harvest (Figure 5, 6; Image 1f). The rate of germination was noticed to be declining in the next weeks. But the seedling establishment was at a reduced level while comparing to the seed germination rate in the natural habitat. This poor rate of seedling establishment may due to the heavy rain in the fruiting season. In natural condition, during heavy rain, the minute seeds are either buried in the mud or carried away by the rain water and only an average of 25% seedlings were established in the wild. However, seeds germinated in the plastic pots when transferred to the natural habitat also failed to establish due to heavy rainfall. In the natural condition, about 3% seeds inside the capsule exhibit viviparous germination which can be considered as an adaptation for establishment of young seedlings during heavy precipitation.

DISCUSSION

The genus *Ophiorrhiza* L. is characterised by white or pinkish white flowers and most of the species exhibit heterostyly. Majority of the *Ophiorrhiza* species reported from Western Ghats exhibit the similar pattern of flowering except the varieties of *O. brunonisis* which flowers during the summer months (Deb & Mondal 1997). Anthesis occurs in both the morphs in the early morning around 0600 h, and all the flowers completely open within around 0845 h. Distylous species with white tubular flowers in Rubiaceae such as *Psychotria carthagenesis* (Consolaro et al. 2011) follow the same pattern of anthesis. Simultaneous opening of flowers of both the morphs have a positive influence on the pollen transfer between them.

The family Rubiaceae is characterised by different pollen transfer mechanisms and functional gender of pin and thrum morphs with various pollination systems (Wolff & Liede-Schumann 2007). Several investigations were conducted on the pollination biology of heterostylous plants in Rubiaceae, and there are species which have evolved functional dioecy in the family (Li et al. 2010). Flowering of *O. caudata* is during monsoon. The earlier studies (Wolda 1988; Fonseca et al. 2006; Silva et al. 2011) reported highest foraging activities of Hymenoptera and Lepidoptera during the rainy season.

This observation agrees with the pollinators of candidate species, and can be considered an adaptation to suitable conditions for pollination, i.e., species tend to flower when vector availability is higher, as reported in other plant groups (Almeida & Alves 2000; Koptur et al. 1988; Martin-Gajardo & Morellato 2003).

The stingless bee *Trigona iridipennis* is a major pollinator of the selected species. Pollination by *Trigona* was observed in other members of Rubiaceae, including *Psychotria barbiflora* (Texeira & Machado 2004) and *Manettia cordifolia* (Consolaro et al. 2005). They visit the flowers in morning immediately after anthesis. High level of nectar concentration in morning hours stimulated the visit of *Trigona spinipes* in both the morphs of *Psychotria poeppigiana* (Valois-Cuesta et al. 2009). In *Ophiorrhiza*, the nectar is present in trace amounts and was too viscous in the selected species to be measured by conventional hand refractometers. *Trigona*, the tiny bees can enter into the corolla tube, feed pollen and nectar from both morphs. *Trigona* and fruit flies can enter the narrow corolla and comes in contact with the short stigma of thrum flowers but other hymenopterans and lepidopterans are less able to enter the narrow corolla tube of thrum morphs and moreover there is a ring of hairs along the corolla tube above the stigma. If these hairs are absent, even short stigmas of thrum flowers can effectively receive pollen grains from pin flowers (Stone & Thomson 1995) *Eurema blanda silhetana* and *Leptosia nina* are the common butterflies visiting *Ophiorrhiza caudata*. They usually visit the flowers after two hours of anthesis and there is a competition between them for nectar. These restless butterflies spend less time per flower but have frequent visits. *Oriens goloides* and an unidentified butterfly from Hesperiidae visits *O. caudata* for nectar. Butterflies usually alight near or on flowers when foraging for nectar (Naiki & Kato 1999), and in *Ophiorrhiza caudata* they took the exudates secreted from the disc above the ovary by extending their proboscides into the corolla tube. Therefore, butterflies most often come in contact with the exposed floral parts from the corolla tube; anthers of thrum flowers and stigmas of pin flowers. Thus the pollen transfer from pin morphs to thrum was comparatively poor. No significant difference was observed in the foraging time, foraging period, and number of visits per flower and stigma touch among the morphs of the selected species.

According to some authors, thrum (short-styled) flowers are efficiently pollinated by insects with longer mouthparts (Beach & Bawa 1980; Lloyd & Webb 1992), while short-tongued insects would be more efficient pollinators of pin (long-styled) flowers (Beach & Bawa 1980). In another view, reproductive interference might interrupt the proper functioning of disassortative pollination between short-level organs, which promote asymmetric pollen flow due to extremely narrow corollas of the species pollinated by Lepidopterans (Marten-Rodriguez et al. 2013). *Ophiorrhiza caudata* do not totally depend on lepidopterans for their pollination; bees, fruit flies and even rain water act as pollinating agents. Here, lepidopterans are efficient pollinators of pin morphs and asymmetry in pollen flow by insect vectors is noticed because of the narrow corolla tube. Fruit flies and *Trigona* can enter the narrow corolla and comes in contact with the short stigma of thrum flowers but other Hymenopterans and Lepidopterans are less able to enter the narrow corolla tube of thrum morphs. There is a ring of hairs along the corolla tube above the stigma. If these hairs are not present, even short stigmas of thrum flowers can effectively receive pollen grains from pin flowers (Stone & Thomson 1995). Even though the pollen grains from pin flowers were attached to the proboscis of an insect, most of them would be easily swept off by the hairs in a thrum flower, which results in asymmetric pollen flow between the pin and thrum flowers (Naiki & Kato 1999). When considering pollination by lepidopterans, some butterflies collect the nectar without the stigma touch (Naiki & Kato 1999). However, these butterflies efficiently transfer pollen from the exposed anthers of thrum flowers to the exposed stigmas of pin flowers with their proboscis and other mouthparts or with legs and wings.

Manual pollination treatments confirmed that the species is self-incompatible and no fruits are developed by apomixis. After interpreting the results of illegitimate pollination, it is found that a small percentage of fruit set is obtained after intra-morph crossing. This indicates that the species shows a tendency towards intra-morph compatibility. Heterostylous species are usually self- and intra-morph incompatible and produce fruits only after legitimate (intermorph) pollination. However, self- and intra-morph compatibility was reported from both distylous (Ornduff 1976) and tristylous (Barrett 1985; Eckert & Barrett 1994) species. Intra-morph compatibility accompanied by self-incompatibility is reported from tristylous *Narcissus triandrus* (Barrett et al. 1995) in Amaryllidaceae, from the distylous *Anchusa hybrid* (Dulberger, 1970), and from *Anchusa officinalis* (Philipp & Schou, 1981) in Boraginaceae. In Rubiaceae, partial intramorph compatibility was reported from several self- incompatible distylous species like *Psychotria nuda* (Castro & Araujo 2004), *P. homalosperma* (Watanabe et al. 2014) and *Gaertnera vaginata* (Pailler & Thompson 1997) where fruit set was obtained after illegitimate pollination in one morph and no fruit set in the other one. Intramorph incompatibility may gradually decrease in the species and may become intramorph and self-compatible in the future. The heterostylous species which are self-compatible were considered to be derived from self-incompatible ancestors (Baker 1966; Ganders 1979).

Fruit of *O. caudata* is a bi-valved capsule which dehisces along the dorsal surface. According to Deb & Mondal (1997), many seeded dehiscent fruit of *Ophiorrhiza* which releases and disperses seeds is a primitive character while comparing to the few seeded indehiscent fruit. Flower-fruit ratio in the two morphs specifies that above 60% fruit set was obtained in natural conditions. Seed dispersal mechanism is splash or ballistic seed dispersal by rain drops in which the seeds are dispersed into the surroundings due to the pressure exerted by the rain drops falling in the loculicidal capsule. This kind of seed dispersal was reported in *O. japonica* in which the seeds are dispersed to a maximum distance of 95.0 ± 6.2 cm (Nakanishi 2002). Nakanishi (2002) reported the same mechanism of seed dispersal in *Sagina* spp. (Caryophyllaceae), *Sedum* spp. (Crassulaceae), *Gentiana* spp. (Gentianaceae) and several members of Saxifragaceae and Scrophulariaceae. All these plants are herbaceous and splash rain dispersal might be an advantage for small plants because dispersal is not affected by plant height. Occasionally, in the absence of rain, the seeds of *Ophiorrhiza* sp. are dispersed by wind.

The minute seeds of *Ophiorrhiza* showed maximum seed germination within 2–4 weeks after the harvest. The seeds of *Ophiorrhiza caudata* showed more than 40–45 % germination in all the conditions, but only a few seedlings are establishing in the wild habitat. In natural conditions, most of the seeds are leached along with the rain water or buried in the muddy soil. The germinating seeds were also destroyed by heavy rain. There is increasing evidence that the events which occur during seedling establishment influences the distribution and abundance of adults in a plant community (Marks 1974; Platt 1975; Werner 1977; Rabinowitz 1978; Gross & Werner 1982). Seeds leached out by the rain water which may germinate in a long distance apart which leads to habitat fragmentation.

CONCLUSION

Ophiorrhiza caudata is an endangered species endemic to the southern Western Ghats. It exhibits heterostyly, but shows some deviations from the typical characters of a heterostylous species. Its breeding system is self-incompatible but shows some degree of intra-morph compatibility, which has an evolutionary significance. Poor seedling establishment in wild conditions, habitat fragmentation, and anthropogenic activities are the major threats for the survival of the species. Only 25% of seedlings were established in the wild condition due to climatic problems. The seedlings were successfully established in Jawaharlal Nehru Tropical Botanic Garden and Research institute campus. Conservation of this rediscovered medicinal plant is of great significance in the present scenario. The self-incompatible heteromorphic species which is phasing environmental and other threats in its natural habitat is conserved in our campus. Both the morphs are protected, thereby promote cross pollination and further establishment of the species.

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SHORT COMMUNICATION

Successful rescue, medical management, rehabilitation, and translocation of a Red Panda *Ailurus fulgens* (Mammalia: Carnivora: Ailuridae) in Arunachal Pradesh, India

Jahan Ahmed [1], Sorang Tadap [2], Millo Tasser [3], Koj Rinya [4], Nekibuddin Ahmed [5] & Sunil Kyarong [6]

[1] College of Veterinary Science, Assam Agricultural University, Guwahati, Assam 781022, India.
[2] Biological Park, Itanagar, Arunachal Pradesh 791111, India.
[3,4] Department of Environment, Forest and Climate Change, Arunachal Pradesh 791111, India.
[5] Lakhimpur College of Veterinary Science, Assam Agricultural University, North Lakhimpur, Assam 787051, India.
[6] Wildlife Trust of India, F-13, Sector 8, National Capital Region (NCR), Noida 201301, India.
[1] jahan.ahmed6@gmail.com, [2] sorangtadap@gmail.com, [3] tasser.m@gmail.com, [4] dfoziro@gmail.com,
[5] nekibahmeds@gmail.com (corresponding author), [6] sunil@wti.org.in

Abstract: We document the rescue of a Red Panda from Yachuli circle, Lower Subansiri district and successful translocation to Eaglenest Wildlife Sanctuary, West Kameng district of Arunachal Pradesh, India. The head injury was surgically managed under the anaesthetic combination of ketamine and xylazine, and reversed with yohimbine. The animal was successfully rehabilitated and translocated in the Eaglenest Wildlife Sanctuary.

Keywords: Ailuridae, Anaesthetic combination, Eaglenest Wildlife Sanctuary, head injury, translocate, Yachuli circle.

Red Panda *Ailurus fulgens* is the only living member of the genus *Ailurus* and the family Ailuridae. Its present natural home range in India includes the states of Sikkim, West Bengal (Darjeeling district), and Arunachal Pradesh (Glatston et al. 2015). The largest population is in Arunachal Pradesh (Choudhury 2001), and it has been rapidly declining due to habitat loss & fragmentation, poaching, and inbreeding depression (Glatston et al. 2015). Based on the population estimate, the International Union for Conservation of Nature (IUCN) Red List of Threatened Species 2015 has listed the Red Panda under the 'Endangered' species category (Glatston et al. 2015). There is limited information on its management in captivity and use of anaesthesia for surgical interventions (Jha 2014). This paper documents the chance rescue of a Red Panda from Yachuli circle of Lower Subansiri district, its management in captivity and translocation to Eaglenest Wildlife Sanctuary, West Kameng district of Arunachal Pradesh, India.

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Case description

Mr. Taba Nepa, a Block Educational Officer in profession of Kebi village under the Yachuli circle, Lower Subansiri district of Arunachal Pradesh encountered an injured male Red Panda in his agricultural field on 6th February, 2016. He rescued the animal and informed the local veterinarian on the next day for veterinary care. After providing first aid, further contact was made with the officials at the Biological Park, Itanagar, Arunachal Pradesh for better health management of the animal. The animal was handed over to the wildlife veterinarian at the Park on 8th February at around 22.00 hours for further treatment and rehabilitation.

Results

Clinical findings

At arrival in the Biological Park, the weight of the animal was recorded as 5 kg. It had very feeble body movement, unresponsiveness to external stimuli, and dyspnoea. There was a visible swelling on the left side of the axis of head near the zygomatic process, with a laceration over the lateral canthus of the left eye which required suturing. The animal was moderately dehydrated owing to anorexia which was ascribed to the injury, followed by pain and stress during transportation. Based on overall clinical status we assessed the condition as critical necessitating emergency veterinary care.

Image 1. Radiographic image of Red Panda skull.

Veterinary care

A whole body radiographic investigation revealed no evidence of skeletal damage (Image 1). The cut injury was cleaned with antiseptic solution and topical antibiotic ointment was applied. The animal was immediately put under treatment with parenteral long acting antibiotic [enrofloxacin @ 7.5 mg/kg body weight i.m. (Fortivir, Virbac Animal Health India Pvt. Ltd.)], NSAID [nimesulide @ 5 mg/kg body weight i.m. (Nimovet, Indian Immunologicals Ltd.)], steroid [Dexamethasone @ 2 mg i.m. [Dexona, Zydus Animal Health Ltd.)], liver supportive [@5 ml orally (Liv.52, The Himalaya Drug Company)] and multivitamin supplement [@ 5 ml orally (Intacal Pet, Intas Pharmaceuticals Ltd.)]. The condition was monitored at every hour. After 24 hours of medication and care, there was improvement in the body condition, evidenced by physical movement and slight responses to external stimuli. The treatment regime was continued for seven days with a daily recommended diet as practiced elsewhere (Padmaja Naidu Himalayan Zoological Park, Darjeeling, West Bengal, India). Initially, the feeding schedule was divided into three times a day (morning, afternoon and evening). Gradually the frequency was narrowed down to twice a day (morning and evening) and then once daily (evening) as the Red Panda is a nocturnal animal. The diet composition was gradually substituted to its natural diet, i.e., bamboo leaves and

Image 2. Weighing of the Red Panda.

Table 1. Diet composition of Red Panda.

Constituents	Quantity
Milk	200 ml
Honey	20 ml
Banana	1 no.
Apple	200 g
Bamboo shoots and leaves	4 kg
Raw egg	1 no.
Drinking water	1 l

Table 2. Data of vital parameters during anaesthesia.

Parameters	Recorded data
Body temperature	37.6 ^{0}C
Heart rate	93 beats/min
Respiratory rate	21 breathes/min
Ocular reflex	Present

Image 3. Red Panda in lateral recumbency under anesthesia.

Image 4. Suturing of the skin with black braided silk.

shoots by decreasing the feeding of supplements (Table 1). There was significant recuperation on a daily basis after hospitalization in the Park facility. The swelling on the head subsided. After two weeks of hospitalization, the Red Panda was administered with albendazole @ 25 mg/kg b.w. orally (Wormer Vet, Legend Remedies Pvt. Ltd.) for three consecutive days along with liver supportive supplement @ 5 ml orally (Liv.52, The Himalaya Drug Company). On the 3rd week the Red Panda was vaccinated against Rabies virus @ 1 ml intramuscular (Raksharab, Indian Immunologicals Ltd.) to be followed by a booster after one month, thereafter to be repeated annually.

As the clinical condition was significantly improved, the animal had to be translocated to a rehabilitation facility located at the Eaglenest Wildlife Sanctuary in the West Kameng district, which is 290 km west from the Biological Park. Prior to translocation a thorough health check-up was warranted. This demanded sedation of the animal on 32nd day of hospitalization.

Preoperative, operative and post-operative procedures

Before sedation, food and water was withheld for 12 hours. Weight of the animal was recorded to be 5 kg (Image 2). Accordingly, two anaesthetics were selected for intramuscular administration, i.e., ketamine HCl and xylazine HCl combination @ 10 mg/kg b.w. and 0.4 mg/kg b.w., respectively. The drug induction and down time was at three and seven minutes after administration of anaesthesia, respectively (Image 3). The vital parameters of the animal were recorded (Table 2). Anaesthesia was maintained for 25 minutes to complete suturing of the wound.

During complete sedation, the lacerated wound was cleaned with non-irritant antiseptic. The lesion was closed with simple interrupted sutures (Image 4). Postoperatively, it was medicated with antibiotic [Ceftriaxone @ 20 mg/kg body weight (Intacef, Intas Pharmaceuticals Ltd.)], NSAID [Meloxicam @ 0.2 mg/kg body weight (Melonex, Intas Pharmaceuticals Ltd.)] with multivitamin supplement (Tribivet, Intas Pharmaceuticals Ltd.) to be continued for five consecutive days. Once the post-operative procedures were accomplished, different physical and physiological parameters were recorded (Image 5, 6; Table 3, 4) and a microchip was implanted with No - 961 001000005995 subcutaneous on the left side of the neck region (Image 7).

Anaesthetic reversal

As reversal, yohimbine HCl @ 0.4 mg/kg b.w., i.m. was selected. Recovery was completed in 14 minutes of

Image 5. Measuring of the Red Panda.

Image 6. Blood collection from cephalic vein.

Table 3. Mean physical measurements of body

Parameters	Length
Length from nostril to base of tail	68.5 cm
Length of tail (base to tip)	42 cm
Neck girth	23cm
Height of fore leg	20.5 cm
Height of hind leg	20.5 cm

Table 4. Haematological and biochemical parameters

Parameter	Value
Haemoglobin (g/dl)	12.5
Glucose (mg/dl)	75.5
Total protein (g/dl)	6.8
Alkaline phosphatase (IU/L)	35.8
Asparatate aminotransferase (IU/L)	74.5
Alanine aminotransferase (IU/L)	77.1
Total bilirubin (mg/dl)	0.3
Creatinine (mg/dl)	0.8

reversal administration.

Translocation and rehabilitation

For transportation of the animal to the rehabilitation facility, a cage was prepared (Image 8) by mobile veterinary service unit of the Wildlife Trust of India (WTI). On the 41st day of hospitalization the animal was successfully translocated and rehabilitated in the Eaglenest Wildlife Sanctuary into a separate enclosure (Image 9). The enclosure was cuboidal in shape, measured 60 feet in diameter and height of 12 feet at the periphery and 17 feet in the centre. There was a refuge den which was covered inside the enclosure with facility for watering and feeding (Image 10).

Discussion

The present episode reveals a sustained rescue operation of an injured individual from an endangered (IUCN Red List of Threatened Species 2015) and Schedule-I species (Wildlife Protection Act, 1972) from Yachuli circle of Lower Subansiri district, its successful veterinary care with translocation and rehabilitation effort to Eaglenest Wildlife Sanctuary in the West Kameng district of Arunachal Pradesh, India. Red Pandas have been recorded from 11 districts of Arunachal Pradesh: Changlang, Dibang Valley, East Kameng, East Siang, Lohit, Lower Subansiri, Upper Siang, Upper Subansiri, West Kameng, West Siang and Tawang (Choudhury 2001; Chakraborty et al. 2015). Clandestine wildlife poaching and illegal trade is rampant worldwide wherever there is rich biodiversity. Under what circumstances the present Red Panda was rescued from its habitat is unclear, but the presence of traumatic swelling on head and the laceration was possible indication of a malicious attempt on its life. However, adequate veterinary care and medication in time could sustain its life. The treatment and feeding schedule with feed ingredients were found effective which progressively restored the animal's

Image 7. Microchip reading.

Image 8. Red Panda inside the transportation cage.

Image 9. Release in Eaglenest Wildlife Sanctuary.

health. The confinement of the animal into a dark area during induction of anaesthesia was also suggested by Roberts & Glatston (1994). This minimizes excitement and stress to the patient, and lowers the amount of anaesthetic drugs required. Dissociative anaesthetics in combination with sedatives or tranquilizers are the choice of anaesthesia for Red Pandas as ketamine HCl at the dose rate of 11–14 mg/kg body weight alone usually results in extreme muscle rigidity and minor Central Nervous System (CNS) stimulations. Hence, ketamine HCl at the dose rate of 5–10 mg/kg b.w. in combination with xylazine HCl at the dose rate of 0.2–0.4 mg/kg b.w. for immobilization in juvenile and adult Red Pandas was indicated (Wolff et al. 1990; AZA Small Carnivore TAG 2012; Jha 2014). Use of above combinations of anaesthetics and dose rate induced anaesthesia smoothly which was reproducible and found safe. Vital parameters recorded during anaesthesia (Table 2) were in agreement with the observations of Willesen et al. (2012). The physical parameters recorded (Table 3) may be of use for further growth and development studies in captivity. Present physical findings were similar to the observations of previous researchers (Burrell et al. 2018). The haematological and biochemical parameters (Table 4) were in corroboration with the findings of Wolff et al. (1990) for healthy male and female Red Pandas of all age groups indicating the normal physiological activity of the animal. These data may be used as baseline data for rescue and rehabilitation facility managers. In the present study yohimbine HCl was used @ 0.4 mg/kg b.w. intramuscularly. Philippa & Ramsay (2011) recorded that the effects of xylazine HCl can be reversed with yohimbine HCl @ 0.125 mg/kg b. w. using subcutaneous, intramuscular or intravenous route. There are also reports that yohimbine antagonized the xylazine HCl portion of ketamine-xylazine HCl anaesthetic combinations and thereby hastened smooth recovery from anaesthesia in Asiatic Lions, Tigers, and Leopards (Sontakke et al. 2009). The anaesthetic effect was successfully reversed in 14 minutes after the use of reversal indicating the procedure was safe and effective. The animal started normal feeding from the evening of same day and recovered uneventfully.

Combination of ketamine HCl and xylazine HCl is frequently used for immobilization, rescue and surgical interventions in wildlife. This paper represents a successful rescue, chemical immobilization for surgical management of head injury, rehabilitation, and translocation of a Red Panda in the Indian state of Arunachal Pradesh. This rescue operation was the first instance record of Red Panda in Yachuli circle, Lower

Image 10(a). External view of enclosure.

Image 10(b). Internal view of enclosure.

Subansiri district of Arunachal Pradesh, India.

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SHORT COMMUNICATION

A rare photographic record of Eurasian Otter *Lutra lutra* with a note on its habitat from the Bhagirathi Basin, western Himalaya, India

Ranjana Pal [1], Aashna Sharma [2], Vineet Kumar Dubey [3], Tapajit Bhattacharya [4], Jeyaraj Antony Johnson [5], Kuppusamy Sivakumar [6] & Sambandam Sathyakumar [7]

[1,2,3,5,6,7] Wildlife Institute of India, Chandrabani, Dehradun 248001, Uttarakhand, India.
[4] Durgapur Government College, Durgapur, West Bengal 713214, India.
[1] ranjana.biocon@gmail.com, [2] aashna.wildlife@gmail.com, [3] vineetkrdubey@gmail.com, [4] tapajit@gmail.com , [5] jaj@wii.gov.in, [6] ksivakumar@wii.gov.in, [7] ssk@wii.gov.in (corresponding author)

Abstract: The Eurasian Otter *Lutra lutra* is an elusive, solitary animal that has one of the widest distributions of all palearctic mammals. Once widely distributed in Asia, the Eurasian Otter population is now vulnerable to urbanization, pollution, poaching, and dam construction. Eurasian Otter distribution in the Indian Himalayan rivers is little explored, and information from this high-altitude riverine ecosystem is sparse. This publication reports a rare photographic record of the Eurasian Otter which confirms its presence in the high-altitude temperate forest of the Upper Bhagirathi Basin, western Himalayan region. The otter was recorded during investigations of terrestrial and aquatic fauna in the Bhagirathi Basin (7,586 km^2, 500–5,000 m) of Uttarakhand State, India from October 2015 to May 2019. Among aquatic fauna, Brown Trout were found to be abundant in high altitude river stretches, with a catch per unit effort of 1.02 kg h^{-1}. Additionally, 26 families of freshwater macroinvertebrates underscored a rich diet available for the Brown Trout, which in turn is a potential food source for the otters. The riverine ecosystem is undergoing dramatic changes because of the increasing demand for hydropower plants in the Bhagirathi Basin. Although mitigation measures are currently in place for fish, the presence of otters further necessitates the need for targeted management for high-altitude Himalayan rivers. There is an imperative need for intensive otter surveys using methods such as camera traps in riparian habitats along the Bhagirathi River and its tributaries.

Keywords: Anthropogenic pressures, camera trapping, hydropower projects, otter, riverine ecosystem.

Information on otters of the high-altitude riverine ecosystems in the Indian Himalayan region is lacking. Eurasian Otter *Lutra lutra* (Linnaeus, 1758), is the only otter found in high altitude (>2,000 m) mountain streams and rivers (Prater 1971). The species has the widest distributions of all palearctic mammals (Corbet 1966); however, due to human pressures, they have disappeared from most of their range (Yoxon & Yoxon 2019). There is lack of information about its population status in Asia,

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where it is believed to be under tremendous pressure because of poaching (Roos et al. 2015). The species is classified as 'Near Threatened' on the IUCN Red List, and is vulnerable to the pelt trade (Roos et al. 2015), climate change (Gupta et al. 2020), and habitat destruction & pollution (Roos et al. 2015). It is listed in Appendix I of CITES, and in India, is listed in Schedule II (Part 2) of the Wildlife (Protection) Act, 1972.

Scattered records across Asia are indicative of otter distribution along all the major river systems, ranging to the southernmost parts of Sumatra, Indonesia (Corbet & Hill 1992). However, its distributional range in the Indian Himalayan region is still unclear, with research suggesting that it is mostly confined to river plains and foothills (Atkinson 1882; Hussain 2002) with the exception of a few high-altitude records from the Trans-Himalayan regions of Ladakh and Himachal Pradesh (Conroy et al. 1998). The earliest records of otter from the state of Uttarakhand (Atkinson 1882) date to the 19^{th} century, when they were recorded from the Ramganga River and Dehradun. According to Atkinson (1882), the Eurasian Otter was found throughout the Terai and in all the larger streams along the Himalayan foothill. Apart from its distribution in the Indian Himalayan region, this species has been recorded from the northern mountainous region of Pakistan and Punatshanghchu basin of Bhutan (Yoxon & Yoxon 2019). There are no recent confirmed records of the Eurasian Otter from Nepal (Yoxon & Yoxon 2019). Based on their distribution records from mountainous habitats in neighbouring regions (Image 1), their presence was long anticipated in the high-altitude river systems of Uttarakhand state. However, studies in low elevation areas have indicated that otters have declined drastically from most stretches of the rivers in Uttarakhand due to habitat loss/degradation caused by hydropower projects, anthropogenic pressures, and poaching (Nawab 2008; Chopra et al. 2014). Recent attempts to confirm otter presence in lower part of Bhagirathi and adjacent Alaknanda basin using sign surveys yielded no sightings or any indirect evidence of their presence, although suitable habitats were found in both the basins (Hussain 2002; Rajvanshi et al. 2012).

Here, we report a photographic record of Eurasian Otter from the high-altitude temperate forest of the Upper Bhagirathi River Basin, Uttarakhand state. The study is the part of a long-term monitoring of wild flora and fauna under the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) project (Task force IV). Surveys were carried out in different areas of Bhagirathi Basin (7,586.71 km^2), to develop baseline information on faunal species of terrestrial and aquatic components. Based on their records specifically from the high-elevations in other basins of Himalaya, we also aimed to understand the habitat availability in our study area, as well as the potential faunal composition which supports the dietary needs of the Eurasian Otter in such landscapes. As such the camera trapping surveys were paralleled with the aquatic habitat, fish and macroinvertebrate faunal surveys to investigate the reasons dictating their rare preference for the high-elevation streams and rivers of Himalaya.

Materials and Methods

The Bhagirathi is a large glacial fed and turbulent Himalayan river that emerges from Gangotri glacier (Gaumukh), 30.925^{0}N & 79.082^{0}E at an elevation of 3,812m. The valley has a broad U-shape at higher elevations characteristic of glacial origin, but at lower elevations the river has cut a narrow V-shaped fluvial valley. Along the 217km long river the elevation ranges from 480m to 3,200m with an average gradient of 1.25% (Rajvanshi et al. 2012). The basin encompasses diverse habitats: tropical and sub-tropical forests (500–1,200 m), temperate forests (1,200–2,800 m), sub-alpine forests (2,900–3,200 m), alpine scrub and meadows above 3,200 m (Rajwar 1993). Human habitations in the study area are confined below the elevation of 3,000 m (Image 1).

Data on the seasonal distribution of mammal species were collected using camera traps (Cuddeback C1, WI, USA) from October 2015 to March 2019 broadly covering two seasons: summer and winter. Camera trapping was carried out in two stages. In the first stage (October 2015–September 2017), preliminary survey for all the mammals was carried out along the elevation gradient of 500 m to 5,200 m. At each site, camera traps were deployed in locations likely to be used by animals inside the forest, alpine meadows, along the river beds and other such microhabitats (Sathyakumar et al. 2013). In the second stage (October 2017 to March 2019), camera traps exercise was carried out only in the high elevation habitats (2500 m to 5200 m) targeting Snow Leopard *Panthera uncia*, Leopard *Panthera pardus*, and their prey species. To survey evenly across the various habitats, we divided the basin into 16 x 16 km grids, which corresponds to the average home range of the largest mammal in the area, the Himalayan Brown Bear *Ursus arctos isabellinus*. We subdivided these cells into 4 × 4 km (first stage) and 3 x 3 km cells (second stage) deployed camera traps in 3–6 of these smaller cells within each 16 x 16 cell. A total of 318 locations were sampled during this period (Image 1).

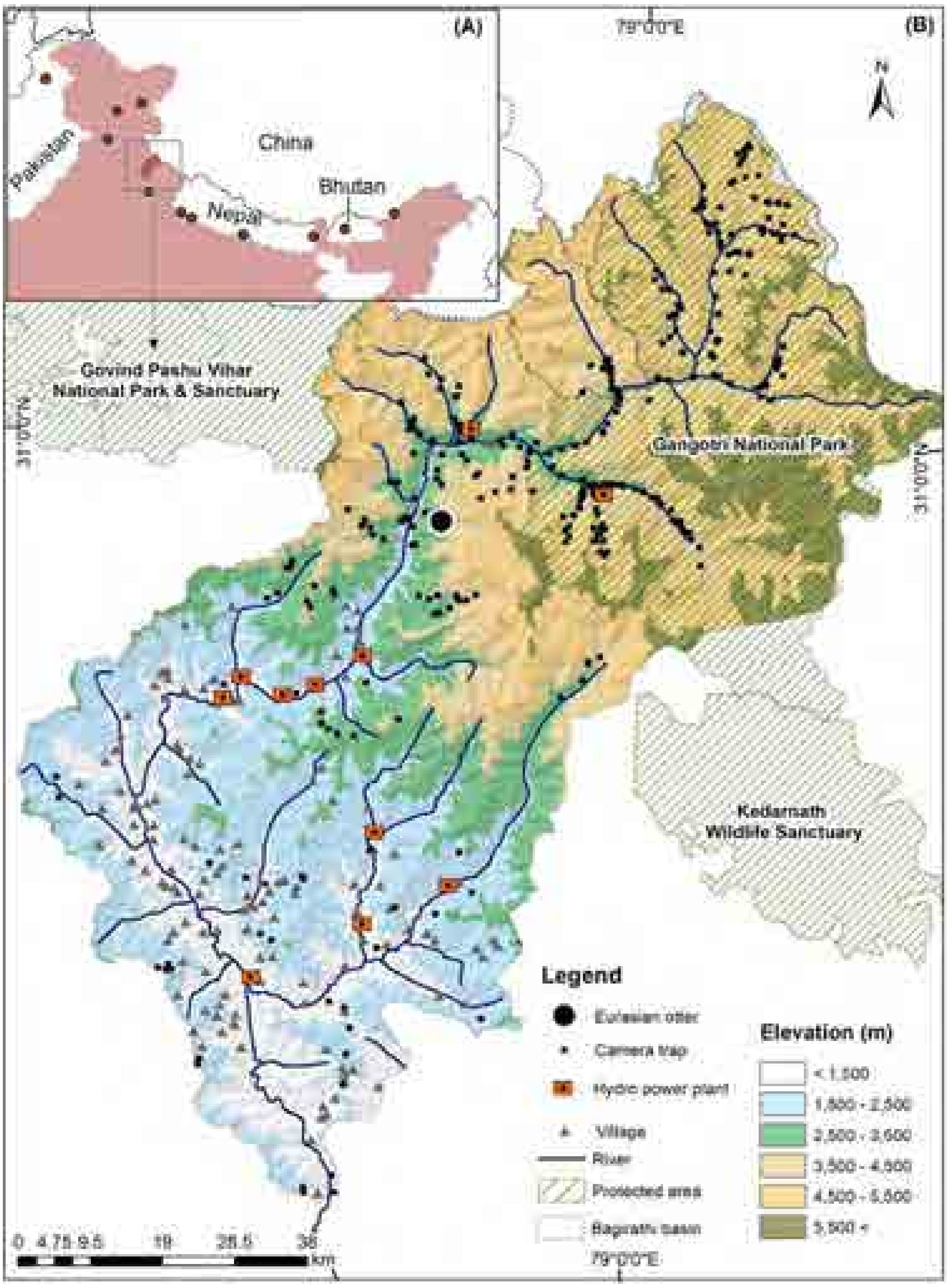

Image 1. A—Map showing location of the Bhagirathi Basin. The red points show the recent confirmed records from different Himalayan regions | B—Map showing distribution of camera trapping locations along the Bhagirathi Basin and Eurasian Otter captured location.

Simultaneously, fish and macroinvertebrate sampling was also conducted in the river stretches of Bhagirathi Basin. Rivers were sampled from March 2016 to December 2018 at every 500 m for the higher-order streams (4th and higher) and 200 m interval for the lower order streams (3rd and lower). This method was followed to target equivalent representation of all streams, as the lower order streams often did not extend more than 500 m in length (Sharma et al. 2021). In total, 38.92 km of river stretch was sampled with a total of 51 sampling points spanning across the Bhagirathi River and three of its major tributaries *Kakori*, *Jalandhari,* and *Sian* using cast nets for fishes and D-frame dip net for macroinvertebrates. The catch per unit effort (CPUE) of the cast net was calculated by dividing the catch of each sampling site by the number of hours fished (Morgan & Burgess 2005). The fishes were caught and released post-sampling. The water quality parameters were recorded using a multi-parameter water monitoring kit, while the microhabitat characterization was done based on Bain & Stevenson (1999).

Results

Camera trapping effort (78,828 trap nights) across the basin resulted in 28,257 captures of different mammal species. Excluding Eurasian Otter, a total of 39 species of mammals were recorded during the survey belonging to 13 families in five orders (Pal et al. 2020). A solitary otter was likely first photo-captured on 25 September 2018 at 1352 h, although the species could not be definitively identified as the capture was too close to the camera. Another photo of an individual was captured on 14 February 2019 at 0546 h (Image 2). Based on the characteristic features such as the conical tail, lighter underside, the bare and black rhinarium with a W-shaped upper margin, the otter species was confirmed as the Eurasian Otter (Hussain 2013; Menon 2014). Along with photographic capture we also captured a 30-sec video recording, where the otter was observed moving on snow. The species is known to survive in extreme cold conditions and has previously been reported at an elevation of 3,700 m in the Himalaya (Prater 1971) and up to 4,120 m in Tibet (Mason & Macdonald 1986).

An image of the Eurasian Otter was captured near the Dabrani region, which is the confluence point of Jaulighad, and Songhad tributaries with Bhagirathi River. It was captured at an elevation of 2,700 m near the bank of Jualighad approximately two km away from its confluence with the main river. The area is characterized by highly rugged mountainous terrain (Image 2). The river forms a deep constricted V-shaped valley in Dabrani together with a high runoff and steep gradient. The area where the otter was captured is characterized by big rocks, boulder fields, and deep crevices. Such habitats are considered as ideal denning and breeding sites for the Eurasian Otters (Hussain 2013). Dense bankside vegetation is also an important determinant of otter's presence as crucial resting sites (Kruuk 2006). The vegetation in the area where otter was photocaptured is a dense temperate riverine habitat with steep slopes covered with conifer- broadleaved mixed forests characterized by the presence of tree species such as *Alnus nepalensis*, *Betula alnoides*, and *Cedrus deodara*. The habitat in the upstream river changes to sub-alpine where species such as *Rhododendron* sp. and *Pinus wallichiana* are found. Other mammals recorded from the same location are common leopard, Himalayan Goral *Nemorhaedus goral*, Himalayan Tahr *Hemitragus jemlahicus*, Himalayan Serow *Capricornis thar*, Himalayan Langur *Semnopithecus schistaceus,* and Yellow-throated Marten *Martes flavigula.*

Adapted for a semi-aquatic life, Eurasian Otters are primarily piscivorous with fish contributing 80% of their diet (Webb 1975; Ruiz-Olmo & Palazon 1997). Throughout our surveys we found the exotic Brown Trout *Salmo trutta* to be the only fish species inhabiting elevations above 2,500 m, with a CPUE of 1.02 kg h^{-1} ranging between 0.22 to 2.65 kg hr^{-1} across all the sampling locations. As accounted for in our surveys, the high elevation streams (>2,500 m) of Bhagirathi Basin comprise 26 families of macroinvertebrates most of which belong to the Order Trichoptera, which is considered as a major diet of the Brown Trout (Fochetti et al. 2003). This underscores a habitat rich in diet for sustenance of the Brown Trout, which in turn could be a potential food source for the Eurasian Otter in the high elevation river stretches. The aquatic habitat in the high-elevation basin was characterized with dissolved oxygen (8.65±0.59 mg/l) and total dissolved solids (44.72±20.02 ppm) with a low water temperature (7.55±3.09 °C) across the sampling duration supporting the sustenance of Brown Trout. The water flow was recorded to be swift across the width of the river ranging between 1.5 to 4.4 ms^{-1} with a microhabitat predominantly defined by fast flowing cascades, runs and rapids. Further, the Eurasian Otters are known to move large distances (adult male: 38.8±23.4; adult female: 18.7±3.5 km) (Durbin 1998; Green et al. 1984; Kruuk et al. 1993; Kruuk 1995) along the length of the river (which possibly include lower elevations). As such, other studies documenting the presence of fish species such as *Pseudecheneis sulcata*, *Tor tor, Schizothorax richardsonii, Opsarius bendelisis* and loaches of the genus *Schistura* possibly indicate a rich ichthyofaunal diet for the Eurasian Otter (Rajvanshi et at. 2012). It thus makes it evident that the potential food available for Eurasian Otter has been identified along the stretches of Bhagirathi River and necessitates the need for more surveys to document Eurasian Otters in the Himalayan region.

Discussion

In a four year effort, Otters were recorded only twice. Although a large network of camera traps was used in the study, very few were deployed near rivers or streams. Of 318 cameras deployed in the basin, only five cameras placed within 1 km distance from the river

Image 2. A—A solitary Eurasian Otter was captured at an elevation of 2,700 m near the bank of Jualighad, a tributary of the Bhagirathi River. The area is characterized by highly rugged mountainous terrain (© WII_DST-NMSHE camera trap) | B—The vegetation in the area is a temperate riverine habitat with steep slopes covered with conifer- broadleaved mixed forests (© Ranjana Pal).

or stream. Otters may have been present in deep gorge areas, but as the sites were inaccessible they could not be sampled. Otter presence often goes unnoticed because of their elusive, solitary, and nocturnal habits. We recommend more dedicated surveys using camera traps to understand the status and distribution of Eurasian Otter in the region. A large chain of tributaries supports Bhagirathi; most of them are still in pristine conditions. Additionally, their presence should be explored in the similar habitat in other catchments of Uttarakhand. There is an urgent need to understand the scattered population of Eurasian Otter in order to effectively protect this species. Removal of bank side-vegetation, construction of dams, draining of wetlands, aquaculture, and associated human-made impacts are some of the potential threats to Eurasian Otters (Roos et al. 2015). Dams have further been implicated in the decline of the Eurasian Otter (Foster-Turley et al. 1990; Macdonald & Mason 1994).

Currently the Bhagirathi River is dammed at 11 locations (Image 1), which has changed the hydro geomorphology of the river. The river has been altered drastically from a swiftly flowing stretch (due to steep gradient) into a vast stretch of semi stagnant water with a characteristic flat gradient and large volumes of water (Agarwal et al. 2018). Fish diversity in Bhagirathi River is also currently declining and is threatened by blockage of migration routes, disconnection of the river and floodplain, changes in flow regime, change in physiochemical attributes (Agarwal et al. 2018). Destructive fishing practices in the lower order tributaries of the Bhagirathi, which are potential spawning grounds and nursery sites for many cold-water fish, are risking the viability of the fish populations imperative for the otter's diet. In addition to the existing pressures on the aquatic ecosystem, there are four more dams commissioned, one under construction and one proposed hydropower project in Bhagirathi River, which will potentially affect 70% of river length (Chopra et al. 2014). While mitigation strategies are currently being adapted to reduce impact on fish, otter presence further necessitates targeted management for the high-altitude Himalayan rivers. Mitigation strategies need to be revised to include a wider range of flora & fauna and consider the impact on the riparian ecosystem.

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OPEN ACCESS

SHORT COMMUNICATION

The first record of Medog Gliding Frog *Rhacophorus translineatus* Wu, 1977 (Anura: Rhacophoridae) from Chhukha District, Bhutan

Sonam Lhendup [1] & **Bal Krishna Koirala** [2]

[1] Gedu Territorial Forest Division, Department of Forests and Park Services, Ministry of Agriculture and Forests, PB 21007, Chhuka, Bhutan.
[2] Trashigang Forest Division, Department of Forests and Park Services, Ministry of Agriculture and Forests, PB 42001, Trashigang, Bhutan.
[1] sonamlhendup20@gmail.com, [2] bkgelephu@gmail.com (corresponding author)

Abstract: *Rhacophorus* is a genus of tree frogs in the family Rhacophoridae commonly referred to as parachuting or gliding frogs, distinguished by extensive digital webbing. A rare species, *Rhacophorus translineatus* Wu, 1977, was recorded for the first time in Bhutan. Information on morphological characters, geographical distribution, habitat and natural history notes is provided.

Keywords: Conservation status, distribution range, habitat, morphological characters, morphology, tree frongs.

Rhacophoridae is a large group of arboreal frogs containing 430 recognized species in 20 genera (Frost 2020). Of these, *Rhacophorus* Kuhl & Van Hassalt, 1822 contains 44 species distributed across southern India to Bhutan and eastern Xizang (China) east and south to Hunan, Hainan, Yunnan & Guangxi, through Myanmar, Thailand, Laos, Cambodia, Vietnam to Sumatra, Borneo, Sulawesi (Indonesia), and the Philippines (Frost 2020; AmphibiaWeb 2020).

In Bhutan, the Rhacophoridae are represented by four species: two from the genus *Polypedates* and two *Rhacophorus* species (Wangyal 2014; Das et al. 2016; Tshewang & Letro 2018; Koirala et al. 2019). *Rhacophorus smaragdinus* (Blyth, 1852) formerly *Rhacophorus maximus*, was reported from Zhemgang (Wangyal 2014) and Jigme Dorji National Park (Koirala et al. 2016). In 2016, *Rhacophorus bipunctatus* Ahl, 1927 was reported from Royal Manas National Park (Das et al. 2016). Currently, the anuran fauna of Bhutan is represented by 83 recognized species distributed among seven genera (Das et al. 2016; Nidup et al. 2016; Tshewang & Letro 2018; Koirala et al. 2019; Wangyal 2013, 2014; Tenzin & Wangyal 2019; Wangyal & Gurung 2017; Wangyal et at. 2020). These earlier studies did not provide evidential records of *R. translineatus* from Bhutan. *R. translineatus* was first described by Wu (Fei et al. 1977) and its type locality given as “Motuo, Xizang (= Tibet), China” was provided by Li et al. (2011). More than two decades after its first discovery in China in 1977, Bordoloi et al. (2002), and Borah & Bordoloi (2004) reported *R. translineatus* from Dihang Dibang Biosphere Reserve, a new record for India.

The distribution range of *R. translineatus* is restricted to Medog county in Xizang (Tibet) autonomous region, China (Jiang & Lau 2004), and the Indian state of Arunachal Pradesh (Saikia et al. 2017; Roy et al. 2018). Currently, 14 species of *Rhacophorus* are known to occur in countries neighboring India (Frost 2017), and nine are recorded from China (Pan et al. 2017). Here we present

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the first record of *R. translineatus* from Bhutan.

Materials and Methods

Study area

Gedu Territorial Forest Division covers entire Chhukha district (Figure 1) which lies within the 26.716–27.3⁰N and 89.250—89.816⁰E. It borders with Samtse to the west, Ha to the north-west, Paro & Thimphu to the north, and Dagana to the east. Towards the south, it borders with India. It covers an area of approximately 1,879.77 km^2. The Chhukha district has an altitudinal range between 200 to 4,400 m and forest cover about 89.26% with corresponding vegetation types of tropical forest, sub-tropical forest, warm broadleaved forest, cool broadleaved forest, mixed conifer, and alpine meadows (RFMD 2017) that harbor rich repositories of biodiversity. Annual precipitation ranges from 750 mm in the north to 4,000 mm in the south (WCSD 2018).

The tropical and subtropical zone of the Chhukha experiences a hot summer with moderate to high rainfall, whereas in the warm temperate and cool temperate zones at higher altitudes, the climatic conditions are characterized by warm summers and cold winters. The higher region of the park is covered by perennial snow; a home of glacial rivers which serves as an important source of water for household use, agriculture and hydropower generation in the downstream valleys.

Methods

A single individual female of *R. translineatus* was observed by the first author in Gurung Dara, a hill district inhabited by the Gurung ethnic group in Chhukha district, Bhutan. Photographs were taken of the live specimen using a Canon EOS 80D digital camera, and locality data were collected using GPS (Garmin eTrex). The collected frog was euthanized humanely by using recommended dose of (1.0 g/L) of maximum strength Orajel (Cecala et al. 2007) and fully sedated specimen was put to death by placing it in a 40% ethyl alcohol bath for 30 minutes. The specimen was fixed using 10% formalin and preserved in 75% ethanol. Beside the snout-vent length (SVL), which was made with a flexible ruler to the nearest 1 mm, all other measurements of morphological characters were made with a digital slide caliper to the nearest 0.01mm. Since there is no standard system in the country to assign e-voucher number series; specimen was designated with

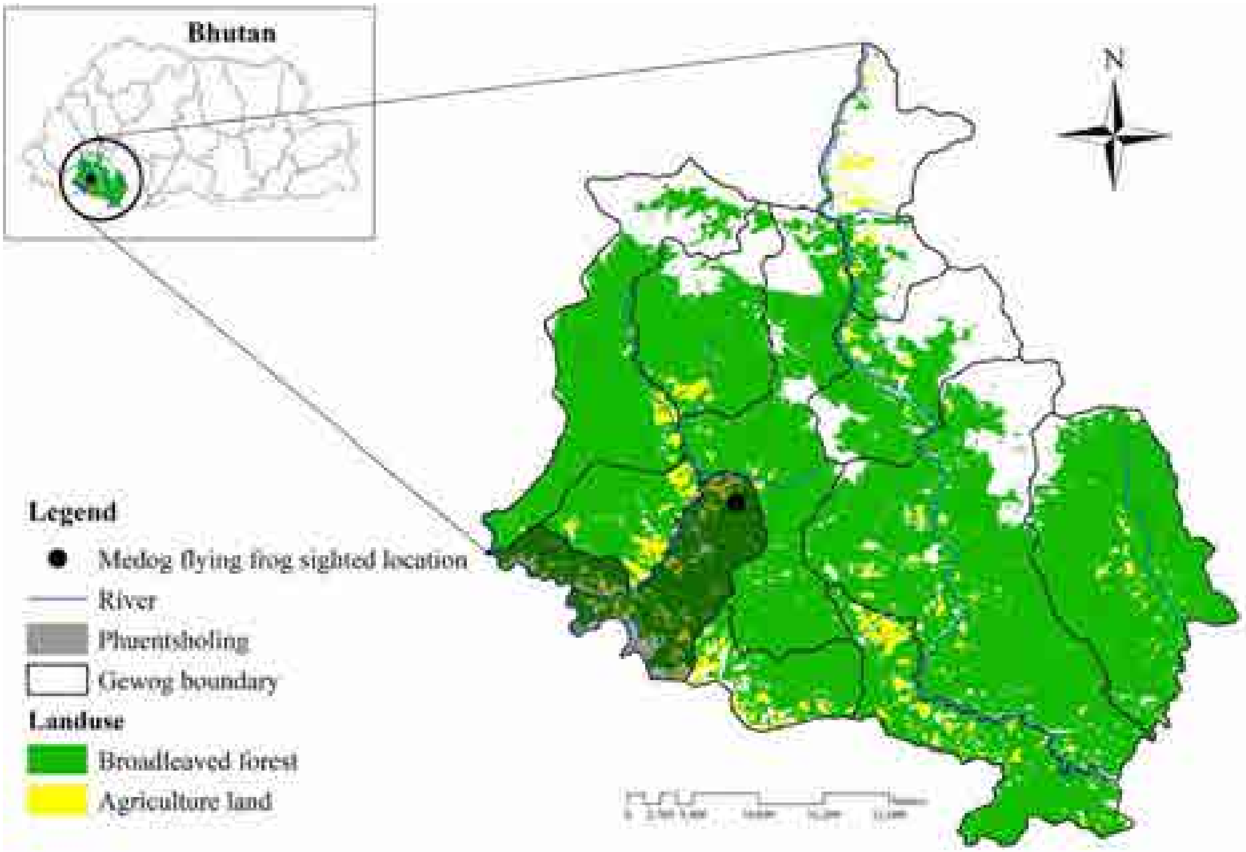

Figure 1. Map of study area. Phuntsholing geog, Chhukha district, Bhutan.

field collection number and deposited by first author to Gedu Forest Division for future reference.

Terminology for morphological characters followed Li et al. (2011) and Watters et al. (2016). Abbreviations are as follows: SVL: Snout-vent length- measured from tip of snout to vent, HL: Head length-distance from the posterior jaws to the tip of the snout, HW: Head width-maximum distance between angle of jaws, IN: Internarial distance between inner margins of nostrils, IOD: Interorbital distance-minimum distance between upper eyelids, SL: Snout length- measured from anterior border of eye to tip of snout, ED: Eye diameter- horizontally from anterior to posterior corners of eye, UWE: Width of eyelid- greatest width of upper eyelid margin, TD: Tympanum diameter-greatest horizontal width of the tympanum, AGL: Axilla to Groin length- measured from posterior base of forelimb to anterior base of hindlimb, DNE: nostril-eye length- measured from nostril to eye, THL: Thigh length- distance from vent to knee, TIL: Tibia length- distance from knee to foot, LAL: Lower arm length- distance from the elbow to the tip of Finger III, UAL: Upper arm length-measured from the axilla to the elbow, FAL: Forearm length- from the flexed elbow to the base of the outer palmar tubercle, HAL: Hind limb length- from vent to tip of longest toe, FLL: Forelimb length- measured from axilla to tip of disk of finger III, FL: Foot length- measured from proximal end of inner metatarsal tubercle to tip of toe IV, HTL: TRL- Tarsus length; Hand length- base of outer palmer tubercle to tip of finger III.

Results

Specimen examined: Field collection No (GFD. AMP.20.001), *R. translineatus* (Figure 2) an adult female collected on 9 July 2020, at 2230 h from Gurung Dara (26.972^{0}N and 89.452^{0}E), WGS84, elevation 1,727 m) in Phuntsholing geog (geog= sub district), Gedu Territorial Forest Division, Chhukha district, Bhutan.

Morphology and measurements

Currently reported *R. translineatus* was compared with morphological characters of *R. translineatus* presented in literatures (Table 1). Dorsally light brown in colour (Image 1); very fine granules on dorsum with 11 narrow transverse dark brown line from snout to vent (Image 2A); head flat, longer than broad; tympanum distinct; eye large, pupil is horizontally oval (Image 2B); tip of the snout is pointed, protruding forward; ventrally whitish with series of markings; second, third, and fourth fingers near full webbed, toes fully webbed (Image 2C); ventrolaterally marked with a series of white spots; hind

Image 1. *Rhacophorus translineatus* recorded from Gurung Dara, Gedu Forest Division, Chhukha Bhutan.

Table 1. Comparison of morphological characters of currently studied *R. translineatus* with the Holotype (CIB 73II0031), type locality: Motuo, Xizang (= Tibet), China. Data taken from (Li et al. 2011). "–" indicates data unavailable.

Characters (in mm)	Currently studied *R. translineatus* Field collection No: GFD. AMP.20.001	*R. translineatus* Holotype: CIB 73II0031
SVL	66.50	54.68
HL	22.10	18.10
HW	1 8.35	16.38
IND	6.08	5.04
IOD	7.01	5.57
SL	9.89	9.75
ED	6.10	5.57
UWE	5.40	–
TD	2.95	1.97
AGL	35.56	–
DNE	5.20	4.46
THL	33.50	23.54
TIL	36.07	26.68
LAL	32.81	26.28
UAL	15.50	–
FAL	14.03	–
HLL	116.50	–
FLL	48.31	–
FL	28.71	25.61
HTL	18.78	18.11
TRL	18.22	–

Image 2. *Rhacophorus translineatus* recorded from Chuuka district: A—Dorsal view of live specimen | B—Lateral view of live specimen | C—Ventral view of preserved specimen | D—Lateral view of preserved specimen. © Sonam Lhendup.

limbs are slender (Image 2D).

Distribution and natural history

Besides having its distribution in China and India, this species is currently known from Gurung Dara, Phuntsholing geog, Chhukha District, Bhutan. In Bhutan, unless otherwise stated, *R. translineatus* is found up to an elevation of 1,727 m. This record raises the upper elevation limit which was previously reported for the species from Motuo, Xizang (= Tibet), China as 1,200–1,500 m (Li et al. 2011) and Tiwarigaon and the Ahini Ango, Dibang River Basin, Arunachal Pradesh, India, as 920–1,480 m (Roy et al. 2018). The single individual was collected from water catchment area of Tomi River, one of the tributaries of Toorsa River which ultimately enters into the Indian state of West Bangal via Phountsholing. The frog was on farm road, situated close proximity to small seasonal freshwater pond when it was first sighted. The immediate micro-habitat was small seasonal freshwater pool surrounded by marshy, abandoned agriculture fallow land currently being used for cattle grazing by local inhabitants. The macro habitat type is characterized by forested hill represented by subtropical broadleaved forest, mostly dominated by Nepal Alder *Alnus nepalensis*, Red Cedar *Toona ciliata*, Needle Wood Tree *Schima wallichii,* Chinquapin Tree *Castanopsis* sp., *and Symplocos sp.* The observed vegetation types and altitudinal gradient of specific site falls in subtropical zone of Bhutan, based on vegetation types described by Ohsawa (1978) for Bhutan.

Discussion

In 2000 Das & Palden (2000) reported seven amphibians from three families: 1 megophryid, 1 bufonid, and 5 ranids, all new records for Bhutan. After a comprehensive review of the Bhutanese herpetological literature, 35 confirmed species of anurans were reported to occur in Bhutan until 2014 (Wangyal 2014). Subsequently in 2016, a species of Cascade Frog *Amolopos himalayanus* (Boulenger, 1888) was reported as first record for Bhutan by Nidup et al. (2016) from Trashigang district. In the same year two more anurans species *R. bipunctatus* and *Uperodon globulosus* (Günther, 1864) were reported by Das et al. (2016) from Royal Manas National Park as new records for Bhutan. Until 2017, Bhutan was represented by 59 species of amphibians (Wangyal & Gurung 2017). Subsequently, two species of amphibian viz., *Polypedates teraiensis* and *Leptobrachium bompu* Sondhi & Ohler, 2011 were added as new records for Bhutan (Tshewang & Letro 2018; Tenzin & Wangyal 2019). An addition of 22 new records by Wangyal et al. (2020) increased the amphibian checklist of Bhutan to 83 recognized species. The current record of *Rhacophorus translineatus* demonstrates that Bhutan is now home to at least 84 confirmed species of amphibian.

Historically, due to the rugged terrain, cold climatic conditions, and largely inaccessible landscape, the biological diversity of eastern Himalaya remained largely unexplored. Herpetofauna have received disproportionate scientific attention compared to large vertebrates since conservation efforts began in Bhutan. In recent decades the frequent discovery of new species and new range extensions in the eastern Himalayas demonstrates a serious need for further exploration in the region. The Himalayan foothills, the locality of currently observed *R. translineatus,* shares similar bio-geographic elements of the eastern Himalayan locations from where most of the *Rhacophorus* species including *R. translineatus* have been reported. However, altitudinal boundary extension demonstrated by currently observed *R. translineatus* was relatively higher than altitudinal records previously reported as, 920–1,500 m (Li et al. 2011; Roy et al. 2018). This first record of *R. translineatus* from Bhutan raises a total of 84 confirmed species of anurans in Bhutan. In addition, it also provides vital information on new distribution range of this species in Bhutan besides China and India.

Conservation status

The IUCN (2004) has assessed *R. translineatus* as a Data Deficient (DD) species in view of continuing uncertainties as to its extent of occurrence, ecological requirements, and its unknown population trend (Jiang & Lau 2004). Data Deficient species must be given high research priority as most of such species often receive disproportionate scientific attention, contributing to uncertainty in estimates of extinction risk. Currently, information on its habitat requirement is very scanty; however present study revealed that the species is adaptable to human modified landscape particularly associated with agriculture development. Although there is no adequate evidence to ascertain whether the species is facing survival threat within its present locality, but in general, amphibians are perceived to be more threatened in human dominated landscape and response rapidly to environmental change. Therefore, a more holistic, education-focused conservation strategy combined with ecological research may be needed for more effective conservation of the amphibian fauna of Bhutan.

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SHORT COMMUNICATION

First record of a freshwater crab, *Maydelliathelphusa masoniana* (Henderson, 1893) (Decapoda: Brachyura: Gecarcinucidae) from West Bengal, India

Ram Krishna Das

Department of Industrial Fish & Fisheries, Asutosh College, 92, S.P. Mukherjee Road, Kolkata, West Bengal 700026, India.
ramkrishnazoology@gmail.com

Abstract: The genus *Maydelliathelphusa* Bott, 1969 includes five species, *M. masoniana* (Henderson, 1893), *M. edentula* (Alcock, 1909), *M. falcidigitis* (Alcock, 1910), *M. harpax* (Alcock, 1909), and *M. lugubris* (Wood-Mason, 1871), and is endemic to India. Out of the five species, only *Maydelliathelphusa lugubris* (Wood-Mason, 1871) was reported from West Bengal previously. Present study reports the second species, *M. masoniana* (Henderson, 1893), from West Bengal, India for the first time.

Keywords: Crustacea, Decapoda, description, diagnosis, endemic, freshwater crabs, Gecarcinucidae, taxonomy.

Freshwater crabs belonging to infraorder Brachyura of order Decapoda are important in terms of nutrient cycles, bio-indicators of environments, disease transmission and small scale fisheries (Cumberlidge et al. 2009; Valarmathi 2017; Harhoglu et al. 2018; Kotwal & Sharma 2020). They are characterized by a broad carapace-covered cephalothorax having five pairs of thoracic legs or pereiopods (one pair of chelipeds, four pairs of walking legs) and a reduced abdomen (Deb 1999; Yeo et al. 2008). These crabs complete their entire life cycle in freshwater environments without moving to saltwater (Yeo et al. 2008).

The freshwater crab diversity of India comprises a total of 127 species divided into two families: Potamidae Ortmann, 1896 and Gecarcinucidae Rathbun, 1904 (Pati 2021). The genus *Maydelliathelphusa* Bott, 1969 belongs to the Gecarcinucidae and is represented by five species: *M. masoniana* (Henderson, 1893), *M. edentula* (Alcock, 1909), *M. falcidigitis* (Alcock, 1910), *M. harpax* (Alcock, 1909), and *M. lugubris* (Wood-Mason, 1871) (Ng et al. 2008). All of these are found in India (Valarmathi 2017), but only *M. lugubris* is reported from West Bengal (Deb 1999). The present study records *M. masoniana* for the first time from West Bengal.

Materials & Methods

During an ichthyological survey, two specimens of *M. masoniana* were collected from a small stream (26.229^0N, 89.255^0E, elevation 32m) of the Brahmaputra River system in Cooch Behar district, West Bengal, India (Image 1). The collected specimens were immediately photographed; morphometric measurements were taken and preserved in 70% alcohol after anaesthetized. The specimens were identified as per the standard identification keys of Henderson (1893), Alcock (1910a,b), and Ng et al. (2008). The specimens were deposited in the Aquatic Animal Biodiversity Museum of the Department of Industrial Fish & Fisheries, Asutosh College, Kolkata (Reg. No. AABM/IFF/AC/CRUSTACEA/CRAB-1 to 2).

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Image 1. Location of the study area (26.229^{0}N, 89.255^{0}E, elevation 32m). Source: Official website of Cooch Behar district, Government of West Bengal <www.coochbehar.gov.in>

TAXONOMY

Class Malacostraca Latreille, 1802
Order Decapoda Latreille, 1802
Infraorder Brachyura Linnaeus, 1758
Section Eubrachyura Saint Laurent, 1980
Superfamily Gecarcinucoidea Rathbun, 1904
Family Gecarcinucidae, Rathbun, 1904
Genus Maydelliathelphusa Bott, 1969

***Maydelliathelphusa masoniana* (Henderson 1893)**
(Image 2A & 3A)

Holotype: *Telphusa masoniana* Henderson, 1893 (pl. XXXVII. fig. 1–4)

Type locality: River Jumna, a series; North-West Provinces, four males (Day); "India" two dried specimens (Brit. Mus.)

Material examined: Reg. No. AABM/IFF/AC/CRUSTACEA/CRAB/1 to 2, Date 16.v.2021, two individual (01 male and 01 female), small stream (26.229^{0}N, 89.255^{0}E) of the Brahmaputra River system in Cooch Behar district, West Bengal, India, collected by R.K. Das.

Measurement: Carapace length 55–60 mm, carapace width 75–82 mm, weight 180–190 g) (Details are presented in Table 1).

Diagnosis: The carapace is broader than long, slightly depressed; epigastric cristae distinct, rugose, located somewhat anterior to postorbital cristae without merging with the latter (Image 2A, 3A); postorbital cristae well defined towards the sides; a wide gap between frontal margin and postorbital cristae; external orbital tooth prominent; anterolateral margin with prominent epibranchial tooth; wide frontal margin, frontal median triangle incomplete (Image 2B & 3B); cervical groove well developed; mesogastric furrow deep, slightly bifurcated posteriorly; chelipeds asymmetric and massive (Image 2 E), carpus with a strong spine, propodus and dactylus with strong teeth which can meet only at the tips creating a wide gap between them (Image 2E); 6th pleonal somite of adult male slightly longer than breadth with concave lateral margin (Image 2F).

Description: The morphometric measurements of the identified species are presented in Table 1. The carapace enlarged, broader than length (cw/cl= 1.36), slightly depressed, dorsal surface smooth; epigastric cristae distinct, rugose, located anterior to postorbital cristae without merging with the latter; postorbital cristae well defined towards the sides, a wide gap between frontal margin and postorbital cristae (Image 2A, 3A); orbits large, external orbital tooth prominent; wide frontal margin (fw/cw= 0.18); anterolateral margin with prominent epibranchial tooth; cervical groove well defined; mesogastric furrow deep, slightly bifurcated posteriorly; eyes smaller than orbital space, eyestalk short, narrow (Image 2B, 3B); mandibular palp three-segmented; 1st, 2nd maxilliped with long flagellum on exopods; 3rd maxilliped almost cover buccal cavity when closed (Image 2B, 3B);

Table 1. Morphometric measurement of carapace and right cheliped of the identified crab (mm).

Characters	*M. masoniana* (n= 1) (Male)	*M. masoniana* (n= 1) (Female)
Carapace length	60	55
Carapace width	82	75
Distance between epibranchial tooth	62	60
Frontal width	15	14
Posterior width of the carapace	28	26
Merus length	38	32
Merus width	25	20
Carpus length	30	25
Carpus width	27	20
Propodus length	80	57
Propodus width	36	27
Dactylus length	55	42

Table 2. Morphometric measurement of chelipeds (right and left) of *M. masoniana* (Male) in mm.

Podomeres	Right cheliped	Left cheliped
Merus length	38	37
Merus width	25	21
Carpus length	30	27
Carpus width	27	23
Propodus length	80	62
Propodus width	36	27
Dactylus length	55	42

Table 3. Morphometric measurement of chelipeds (right and left) of *M. masoniana* (Female) in mm.

Podomeres	Right cheliped	Left cheliped
Merus length	32	30
Merus width	20	18
Carpus length	25	23
Carpus width	20	18
Propodus length	57	52
Propodus width	27	22
Dactylus length	42	33

ischium subrectangular, longer than broad, with a narrow medial groove; merus nearly pentagonal, broader than long; exopod slender, longer than ischium, reaching the base of merus, with a long flagellum (Image 2D).

Chelipeds smooth, asymmetrical and massive, right cheliped larger than the left (Table 2, 3) carpus, with strong spine, propodus and dactylus with 12 to 13 strong teeth which can meet only at the tips creating a wide gap between them (Image 2E); ambulatory legs (P2–P5) stout, shorter than chelipeds; P3 longest and P5 shortest, dactylus longer than propodus with four rows of spines on the margins.

Pleon of the male smooth, glabrous, conical; pleonal somites 1, 2 almost rectangular, narrower than somite 3; pleonal somites 3–5 trapezoidal; 6th pleonal somite slightly longer than breadth with concave lateral margin; telson conical with equal length and breadth (Image 2C, 2 F); thoracic sternites smooth, glabrous; suture S4/S5, S5/S6, S7/S8 discernible; sternopleonal cavity deep, long, reaching to imaginary line joining cheliped coxae; G1 stout, distal portion tapering gradually, slightly turned outward; G2 elongated; G1 longer than G2, approximately 1.7 times the length of G2 (Image 2G).

In the female, pleonal somite 1 is the shortest; pleonal somites 2–5 are progressively longer; 6th pleonal somite is longest (Image 3C, 3D); telson triangular; vulvae on S6 (VD/SW= approximately 0.38), large, deep, touching the suture S5/S6 (Image 3 E).

Colour: Dark brown in fresh condition.

Habit & Habitat: *M. masoniana* creates small burrows at the adjoining areas of soil and water of the stream for living and breeding purpose (Image 4A–C). Their preferred habitat is the small or narrow canals or streams with slow-moving water. They are nocturnal in habit.

Distribution: India: Uttar Pradesh (Krishnamurthy 1995), Assam, Meghalaya, Jammu & Kashmir (Kotwal & Sharma 2020), West Bengal (present study).

Conservation status: As per the IUCN Red List of threatened species, the species belongs to the Least Concern (LC) category (Cumberlidge 2008).

Discussions

The freshwater crab, *M. masonia* was originally described as *Telphusa masonina* in the year 1893 by Henderson using type locality of river Jumna, North-West Provinces, India. Alcock (1910) transferred the species to the sub-genus *Barythelphusa* Alcock, 1909 of the Genus *Parathelphusa* Edwards, 1853 using a specimen from northern to central India. Bott (1970) created the subgenus *Maydelliathelphusa* and placed the species in that subgenus in a revisionary work. Specimen collected in the present study is in agreement with the original description of *M. masoniana*. In an earlier study, Krishnamurthy (1995), reported the species from Uttar Pradesh, India. Recently, the species has been reported from Jammu & Kashmir (Kotwal & Sharma 2020).

Image 2A. *Maydelliathelphusa masoniana* (Henderson, 1893) (Male) (Dorsal view). © R.K. Das.

Image 2B. *M. masoniana* (Henderson, 1893) (Male) (Frontal view). © R.K. Das.

Image 2C. *M. masoniana* (Henderson, 1893) (Male) (Ventral view). © R.K. Das.

Image 2E. Right cheliped of a male *M. masoniana*. © R.K. Das.

Image 2D. 3rd maxilliped of a male *M. masoniana.* © R.K. Das.

Image 2F. Pleon of a male *M. masoniana*. © R.K. Das.

Image 2G. Sternopleonal cavity of a male crab showing G1 and G2. © R.K. Das.

Image 3A. *M. masoniana* (Henderson, 1893) (Female) (Dorsal view). © R.K. Das.

Image 3B. *M. masoniana* (Henderson, 1893) (Female) (Frontal view). © R.K. Das.

Image 3C. *M. masoniana* (Henderson, 1893) (Female) (Ventral view). © R.K. Das

Image 3D. Pleon of a female *M. masoniana* © R.K. Das.

Image 3E. Thoracic sternite showing vulvae in female crab. © R.K. Das.

Conclusion

The present study extends the distribution of *M. masoniana* to West Bengal. As all the five species of the genus *Maydelliathelphusa* are similar morphologically, molecular taxonomy to confirm the morphological taxonomy of the species is warranted. Further studies are needed to investigate the biology, threat and conservation of this species, and to evaluate the potentiality of the species for commercial fisheries in that region.

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Image 4A. Crab burrow in the marginal area between soil and water. © R.K. Das.

Keys to the species of *Maydelliathelphusa*

1 (a) Epigastric and postorbital crests on either side united .... ***M. edentula***
1 (b) Epigastric and postorbital crests are incompletely or indistinctly separated from one another **2**

2 (a) External orbital tooth broad and blunt; lateral epibranchial tooth small and blunt, or obsolescent; carapace flattish **3**
2 (b) External orbital tooth and lateral epibranchial tooth prominent; carapace convex/ tumid **4**

3 (a) 6th abdominal segment of male squarish with lateral side slightly concave .... ***M. lugubris***
3 (b) 6th abdominal segment of male is longer than distal breadth .... ***M. falcidigitis***

4 (a) Carapace less convex; chelipeds are symmetric ....***M. harpax***
4 (b) Carapace greatly convex; chelipeds are asymmetric .... ***M. masoniana***

Image 4B. Crab burrow. © R.K. Das.

Image 4C. Location of a crab in a crab burrow. © R.K. Das.

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SHORT COMMUNICATION

Butterflies of Amrabad Tiger Reserve, Telangana, India

Deepa Jaiswal [1], B. Bharath [2], M. Karuthapandi [3], Shrikant Jadhav [4], S. Prabakaran [5] & S. Rehanuma Sulthana [6]

[1–6] Freshwater Biology Regional Centre, Zoological Survey of India, Hyderguda, Attapur, Hyderabad, Telangana 500048, India.
[1] deepajzsi@gmail.com, [2] bhupathibharath23@gmail.com, [3] kpandi83@gmail.com (corresponding author),
[4] shrikantjadhavzsi@gmail.com, [5] prabakaranzsi@yahoo.co.in, [6] rehansiddhu@gmail.com

Abstract: The butterfly diversity of Amrabad Tiger Reserve was assessed from March 2018 to February 2021. A total of 106 species belonging to the families Nymphalidae (36 species), Lycaenidae (30 species), Pieridae (18 species), Hesperiidae (14 species), and Papilionidae (8 species) were recorded. Of these, 12 species belonged to the Schedules I, II & IV of the Indian Wildlife Protection Act, and four were common in this region.

Keywords: Butterfly diversity, Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, Pieridae, status.

Telangana state having a wide range of ecosystems is rich in its biodiversity (Khartade et al. 2019). Approximately, 26,900 km^2 area constituting 24% of the total area are under forest. There are 12 protected areas, which consists of seven wildlife sanctuaries, three national parks and two tiger reserves. Amrabad Tiger Reserve is located in the northern part of Nallamala Hills, Eastern Ghats and on the banks of river Krishna. It has an area of 2,611.39km^2 with deciduous forest harbouring a wide variety of flora and fauna. It was previously a part of Nagarjunasagar Srisailam Tiger Reserve (NSTR), Andhra Pradesh. After bifurcation of Andhra Pradesh, the area of NSTR falling under the newly formed Telangana state was designated as Amrabad Tiger Reserve.

A total of 2,450 faunal species have been reported so far from the state of Telangana (Chandra et al. 2021), including 165 species of butterflies (Sailu et al. 2021). Earlier studies from adjacent habitats of the Eastern Ghats by Rao et al. (2004) reported 89 butterfly species from NSTR, Andhra Pradesh; Raju et al. (2003) reported 68 species from Visakhapatnam; Venkataramana (2010) reported 70 species from Visakhapatnam, Ananthagiri and Ratnagiri hills of Eastern Ghats; Ramamurty et al. (2013) reported 78 species from Visakhapatnam, Andhra Pradesh; and Goswami et al. (2018) recorded 102 species of butterflies from northern Eastern Ghats of Andhra Pradesh. In this study, an attempt has been made to document the butterfly diversity of Amrabad Tiger Reserve, Telangana.

Materials and Methods

Sampling of butterflies was made in 20 different sampling stations on a seasonal basis to cover different stretches of the tiger reserve. Observations were made by transect method from 0700–0900 h at least to cover 5 km of every sampling station, and randomised sampling from 9-11am and 4-6pm during the years 2018-2021 (Table 1, Figure 1). Butterflies were observed using

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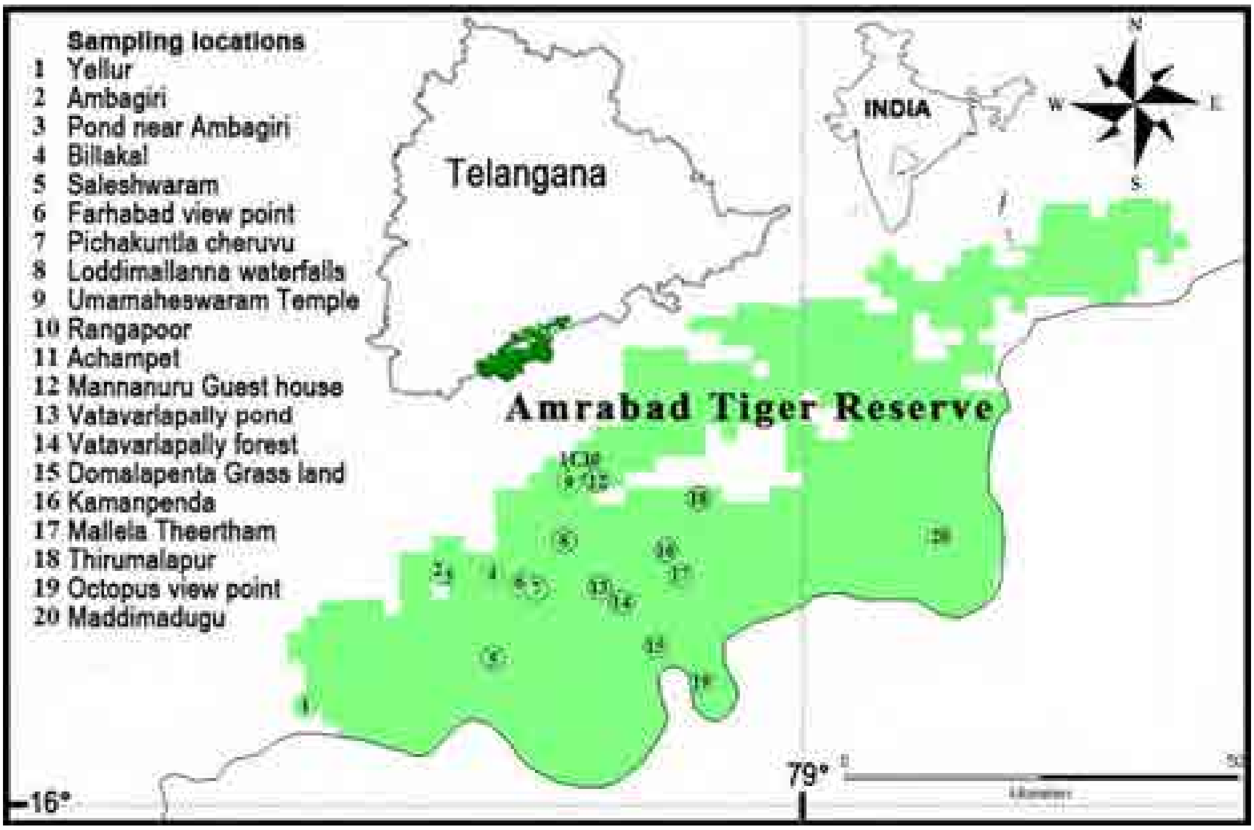

Figure 1. Map showing the sampling location of the Amrabad Tiger Reserve, Telangana.

Nikon binoculars and photographed by Nikon D500 DSLR camera. Collections were made with the help of a sweep net, samples were dry preserved and deposited in the museum collections of Zoological Survey of India, Freshwater Biology Regional Centre, Hyderabad. Species classification and nomenclature were after Kunte (2000), Kehimkar (2008), and Bhakare & Ogale (2018).

Results and Discussion

A total of 106 species of butterflies belonging to 68 genera, five families (Table 2, Image 1–106) were recorded from the Amrabad Tiger Reserve. Of these, specimens of 85 species have been collected and preserved. The remaining species were only photographed. Among the various families recorded, Nymphalidae with 36 species and 22 genera, showed high diversity followed by Lycaenidae (30 species) (Figure 2). Among these, 12 species belonged to the schedules I, II & IV of the Indian Wildlife Protection Act (1972). Four species namely, viz., Dark Glass Blue *Zizeeria karsandra*, Peacock Pansy *Junonia almana*, Yellow Pansy *Junonia hierta*, and Small Grass Yellow *Eurema brigitta* were common, and assessed as 'Least Concern' as per IUCN Red List.

The maximum number of species was observed from Umamaheswaram temple with 35 species, followed by Saleshwaram with 25 species, Pichakuntla cheruvu and Billakal with 21 species each. Most of the species are common, and seven were observed rarely, such as *Caprona ransonnettii* from Mallelatheertham waterfalls, *Neptis jumbah* from Domalapenta grassland, *Lethe europa, Phaedym columella, Spindasis schistacea* from Saleshwaram, *Polyura agrarian* from Umamaheswaram, *Colotis fausta* from Pichakuntla cheruvu, *Appias libythea* from Ambagiri and Kamanpenda.

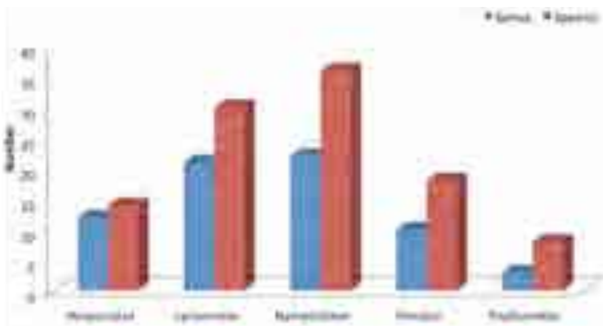

Figure 2. Family-wise species composition of butterflies of Amrabad Tiger Reserve.

Table 1. Sampling locations of Amrabad Tiger Reserve, Telangana.

	Locality	Longitude (E)	Latitude (N)
1	Achampet	78.7377	16.3930
2	Ambagiri	78.5792	16.2678
3	Thirumalapur	78.8775	16.3554
4	Billakal	78.6369	16.2678
5	Domalapenta Grass land	78.8264	16.1831
6	Farhabad view point	78.6714	16.2561
7	Kamanpenda	78.8391	16.2958
8	Loddimallanna waterfalls	78.7203	16.3061
9	Maddimadugu	79.1551	16.3115
10	Mallela Theertham Waterfalls	78.8558	16.2672
11	Mannanuru Guest house	78.7583	16.3758
12	Octopus view point	78.8800	16.1415
13	Pichakuntla cheruvu	78.6889	16.2506
14	Pond near Ambagiri	78.5792	16.2675
15	Rangapoor	78.7375	16.3939
16	Saleshwaram	78.6392	16.1689
17	Umamaheswaram Temple	78.7267	16.3728
18	Vatavarlapally forest	78.7881	16.2350
19	Vatavarlapally pond	78.7614	16.2514
20	Yellur	78.4217	16.1153

The 165 species of butterflies have been recorded from Telangana, and the species recorded in this study represent 64% of those reported from the state. Eighty-nine species were reported from NSTR and of these 20 were not observed in the present study. The present study documented 34 new additions to the list of butterfly species of Amrabad Tiger Reserve. Butterflies recorded in this study showed 69% similarity with species recorded in Rao et al. (2004), 50% with Goswami et al. (2018), 68% with Raju et al. (2003), and 62% with Venkataramana (2010). It shows that the northern and southern Eastern Ghats species distribution are approximately 45% dissimilar, it could be due to variation in habitat, host plant and climatic conditions.

The family Nymphalidae are dominant in the tropical region because most of them are polyphagous in nature and thus able to survive in all habitats. Additionally, many species of this family are strong, active fliers able to search for resources in large areas (Easwaran & Pramod 2005; Krishnakumar et al. 2008). The high proportion of nymphalidae observed might also be due to the availability of a variety of host plants in Amrabad Tiger Reserve. The predominance of Nymphalidae over other butterfly groups in the Western Ghats has earlier been

Table 2 List of Butterfly species recorded from Amrabad Tiger Reserve, Telangana

	Scientific name	Common name	IUCN Status	WPA Status
	Hesperiidae			
1	*Borbo cinnara* (Wallace, 1866)	Rice Swift		
2	*Caltoris kumara* (Moore, 1878)	Blank Swift		
3	*Caprona agama* (Moore, 1858)	Spotted Angle		
4	*Caprona ransonnettii* (R.Felder, 1868)	Golden Angle		
5	*Hasora chromus* (Cramer, 1780)	Common Banded Awl		
6	*Matapa aria* (Moore, 1866)	Common Red Eye		
7	*Lambrix salsala* (Moore, 1866)	Chestnut Bob		
8	*Parnara ganga* Evans, 1937	Continental Swift		
9	*Pelopidas mathias* (Fabricius, 1798)	Small-Branded Swift		
10	*Pelopidas subochracea* (Moore, 1878)	Large Banded Swift		
11	*Spialia galba* (Fabricius, 1793)	Indian Skipper		
12	*Suastus gremius* (Fabricius, 1798)	Indian Palm Bob		
13	*Telicota bambusae* (Moore, 1878)	Dark Palm Dart		
14	*Udaspes folus* (Cramer, 1775)	Grass Demon		
	Lycaenidae			
15	*Azanus jesous* (Guérin-Méneville, 1849)	African Babul Blue		
16	*Azanus ubaldus* (Stoll, 1782)	Bright Babul Blue		
17	*Azanus uranus* Butler, 1886	Dull Babul Blue		
18	*Caleta decidia* (Hewitson, 1876)	Angled Pierrot		
19	*Castalius rosimon* (Fabricius, 1775)	Common Pierrot		Schedule I Species
20	*Catochrysops panormus* (C.Felder, 1860)	Silver Forget-Me-Not		
21	*Catochrysops strabo* (Fabricius, 1793)	Forget-Me-Not		
22	*Chilades lajus* (Stoll, 1780)	Indian Lime blue		
23	*Chilades pandava* (Horsfield, 1829)	Plains Cupid		
24	*Chilades parrhasius* (Fabricius, 1793)	Small Cupid		
25	*Curetis thetis* (Drury, 1773)	Indian Sunbeam		
26	*Euchrysops cnejus* (Fabricius, 1798)	Gram Blue		Schedule II Species
27	*Everes lacturuns* (Godart, 1824)	Indian Cupid		
28	*Freyeria putli* (Kollar, 1844)	Small Grass Jewel		

	Scientific name	Common name	IUCN Status	WPA Status
29	*Jamides bochus* (Stoll, 1782)	Dark Cerulean		
30	*Jamides celeno* (Cramer 1775)	Common Cerulean		
31	*Lampides boeticus* (Linnaeus, 1767)	Pea Blue		Schedule II Species
32	*Leptotes plinius* (Fabricius, 1793)	Zebra Blue		
33	*Prosotas dubiosa indica* (Evans, 1925)	Tailless Line Blue		
34	*Prosotas nora* (C.Felder, 1860)	Common Line Blue		
35	*Rathinda amor* (Fabricius, 1775)	Monkey Puzzle		
36	*Spindasis ictis* (Hewitson, 1865)	Common Shot Silverline		
37	*Spindasis schistacea* (Moore, 1881)	Plumbeous Silverline		
38	*Spindasis vulcanus* (Fabricius, 1775)	Common Silverline		
39	*Talicada nyseus* (Guérin-Méneville, 1843)	Red Pierrot		
40	*Tarucus nara* (Kollar, 1848)	Striped Pierrot		
41	*Virachola isocrates* (Fabricius, 1793)	Common Guava blue		
42	*Zizeeria karsandra* (Moore, 1865)	Dark Grass Blue	Least Concern	
43	*Zizina otis* (Fabricius, 1787)	Lesser Grass Blue		
44	*Zizula hylax* (Fabricius, 1775)	Tiny Grass Blue		
	Nymphalidae			
45	*Acraca terpsicore* (Linnaeus, 1758)	Tawny Coster		
46	*Ariadne merione* (Cramer, 1777)	Common Castor		
47	*Ariadne ariadne* (Linnaeus, 1763)	Angled Castor		
48	*Byblia ilithyia* (Drury, 1773)	Joker		
49	*Charaxes solon* (Fabricius, 1793)	Black Rajah		Schedule II Species
50	*Danaus chrysippus* (Linnaeus, 1758)	Plain Tiger		
51	*Danaus genutia* (Cramer, 1779)	Striped Tiger		
52	*Euploea core* (Cramer, 1780)	Common Crow		
53	*Euploea sylvester* (Fabricius, 1793)	Double-Branded Crow		
54	*Euthalia aconthea* (Cramer, 1777)	Common Baron		Schedule II Species
55	*Hypolimnas bolina* (Linnaeus, 1758)	Great Eggfly		
56	*Hypolimnas misippus* (Linnaeus, 1764)	Danaid Eggfly		Schedule I Species
57	*Junonia almana* (Linnaeus, 1758)	Peacock Pansy	Least Concern	
58	*Junonia atlites* (Linnaeus, 1763)	Gray Pansy		
59	*Junonia hierta* (Fabricius, 1798)	Yellow Pansy	Least Concern	
60	*Junonia iphita* (Cramer, 1779)	Chocolate pansy		

	Scientific name	Common name	IUCN Status	WPA Status
61	*Junonia lemonias* (Linnaeus, 1758)	Lemon Pansy		
62	*Junonia orithya* (Linnaeus, 1758)	Blue Pansy		
63	*Lethe europa* (Fabricius, 1775)	Bamboo Tree Brown		
65	*Melanitis leda* (Linnaeus, 1758)	Common Evening Brown		
66	*Moduza procris* (Cramer, 1777)	Commander		
67	*Mycalesis mineus* (Linnaeus, 1758)	Dark Banded Bush Brown		Schedule II Species
67	*Mycalesis perseus* (Fabricius, 1775)	Common Bushbrown		
68	*Neptis hylas* (Linnaeus, 1758)	Common Sailer		
69	*Neptis jumbah* Moore, 1858	Chestnut Streaked Sailer		Schedule I Species
70	*Phaedyma columella* (Cramer, 1780)	Short Banded Sailer		
71	*Parantica aglea* (Stoll, 1782)	Glassy Tiger		
72	*Phalantha phalantha* (Drury, 1773)	Common Leopard		
73	*Polyura agraria* (Swinhoe, 1887)	Anomalous Nawab		
74	*Polyura athamas* (Drury, 1773)	Common Nawab		Schedule II Species
75	*Symphaedra nais* (Forster, 1771)	Baronet		
76	*Tirumala limniace* (Cramer, 1775)	Blue Tiger		
77	*Tirumala septentrionis* (Butler, 1874)	Dark Blue tiger		
78	*Vanessa cardui* (Linnaeus, 1758)	Painted Lady		
79	*Ypthima asterope* (Klug, 1832)	Common Three-Ring		
80	*Ypthima baldus* (Fabricius,1775)	Common Five Ring		
	Pieridae			
81	*Appias albina* (Boisoduval, 1836)	Common Albatross		
82	*Appias libythea* (Fabricius, 1775)	Striped Albatros		Schedule IV Species
83	*Belenois aurota* (Fabricius, 1793)	Pioneer		
84	*Catopsilia pyranthe* (Linnaeus, 1758)	Mottled Emigrant		
85	*Catospilia pomona* (Fabricius, 1775)	Common Emigrant		
86	*Cepora nerissa* (Fabricius, 1775)	Common Gull		Schedule II Species
87	*Colotis aurora* (Cramer, 1780)	Plain Orange Tip		
88	*Colotis danae* (Fabricius, 1775)	Crimson Tip		
89	*Colotis etrida* (Boisoduval, 1836)	Little Orange Tip		
90	*Colotis fausta* (Olivier, 1804)	Large Salmon Arab		
91	*Delias eucharis* (Drury, 1773)	Common Jezebel		
92	*Eurema brigitta* (Stoll, 1780)	Small Grass Yellow	Least Concern	

	Scientific name	Common name	IUCN Status	WPA Status
93	*Eurema hecabe* (Linnaeus, 1758)	Common Grass Yellow		
94	*Eurema laeta* (Boisduval, 1836)	Spotless Grass Yellow		
95	*Leptosia nina* (Fabricius, 1793)	Psyche		
96	*Ixias marianne* (Cramer, 1779)	White Orange Tip		
97	*Ixias pyrene* (Linnaeus, 1764)	Yellow Orange Tip		
98	*Pareronia hippia* (Fabricius, 1787)	Common Wanderer		
	Papilionidae			
99	*Graphium agamemnon* (Linnaeus, 1758)	Tailed Jay		
100	*Graphium doson* (C&R Felder, 1864)	Common Jay		
101	*Graphium nomius* (Esper, 1799)	Spot Swordtail		
102	*Pachliopta aristolochiae* (Fabricius, 1775)	Common Rose		
103	*Pachliopta hector* (Linnaeus, 1758)	Crimson Rose		Schedule I Species
104	*Papilio demoleus* Linnaeus, 1758	Lime Butterfly		
105	*Papilio polytes* Linnaeus, 1758	Common Mormon		
106	*Papilio crino* Fabricius, 1793	Common Banded Peacock		

WPA—Wildlife Protection Act | IUCN—International Union for Conservation of Nature.

reported by (Kunte 1997; Easwaran & Pramod 2005). Amrabad Tiger Reserve has mixed vegetation supporting rich species diversity. The increase in butterfly diversity may be due to favourable climatic conditions, availability of more number of host plants and vegetation cover of herbs, shrubs and trees for nectaring of butterflies (Tiple 2009). Since, the Amrabad Tiger Reserve hosts the scheduled and least concern species, conservation measures to ensure habitat protection in the tiger reserve are essential. However, further studies on ecology, threats and conservation of butterfly needs to be focused.

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Image 1–35. 1—*Borbo cinnara* | 2—*Caltoris kumara* | 3—*Caprona agama* | 4—*Caprona ransonnettii* | 5—*Hasora chromus* | 6—*Matapa aria* | 7—*Lambrix salsala* | 8—*Parnara ganga* | 9—*Pelopidas mathias* | 10—*Pelopidas subochracea* | 11—*Spialia galba* | 12—*Suastus gremius* | 13—*Telicota bambusae* | 14—*Udaspes folus* | 15—*Azanus jesous* | 16—*Azanus ubaldus* | 17—*Azanus uranus* | 18—*Calet decidia* | 19—*Castalius rosimon* | 20—*Catochrysops panormus* | 21—*Catochrysops strabo* | 22—*Chilades lajus* | 23—*Chilades pandava* | 24—*Chilades parrhasius* | 25—*Curetis thetis* | 26—*Euchrysops cnejus* | 27—*Everes lacturuns* | 28—*Freyeria putli* | 29—*Jamides bochus* | 30—*Jamides celeno* | 31—*Lampides boeticus* | 32—*Leptotes plinius* | 33—*Prosotas dubiosa indica* | 34—*Prosotas nora* | 35—*Rathinda amor*. © Authors

Image 36–70. 36—*Spindasis ictis* | 37—*Spindasis schistacea* | 38—*Spindasis vulcanus* | 39—*Talicada nyseus* | 40—*Tarucus nara* | 41—*Virachola isocrates* | 42—*Zizeeria karsandra* | 43—*Zizina otis* | 44—*Zizula hylax* | 45—*Acraca terpsicore* | 46—*Ariadne merione* | 47—*Ariadne ariadne* | 48—*Byblia ilithyia* | 49—*Charaxes solon* | 50—*Danaus chrysippus* | 51—*Danaus genutia* | 52—*Euploea core* | 53—*Euploea sylvester* | 54—*Euthalia aconthea* | 55—*Hypolimnas bolina* | 56—*Hypolimnas misippus* | 57—*Junonia almana* | 58—*Junonia atlites* | 59—*Junonia hierta* | 60—*Junonia iphita* | 61—*Junonia lemonias* | 62—*Junonia orithya* | 63—*Lethe europa* | 64—*Melanitis leda* | 65—*Moduza procris* | 66—*Mycalesis mineus* | 67—*Mycalesis perseus* | 68—*Neptis hylas* | 69—*Neptis jumbah* | 70—*Phaedyma columella.* © Authors

Image 71–106. 71—*Parantica aglea* | 72—*Phalantha phalantha* | 73—*Polyura agraria* | 74—*Polyura athamas* | 75—*Symphaedra nais* | 76—*Tirumala limniace* | 77—*Tirumala septentrionis* | 78—*Vanessa cardui* | 79—*Ypthima asterope* | 80—*Ypthima baldus* | 81—*Appias albina* | 82—*Appias libythea* | 83—*Belenois aurota* | 84—*Catopsilia pyranthe* | 85—*Catospilia Pomona* | 86—*Cepora nerissa* | 87—*Colotis aurora* | 88—*Colotis danae* | 89—*Colotis etrida* | 90—*Colotis fausta* | 91—*Delias eucharis* | 92—*Eurema brigitta* | 93—*Eurema hecabe* | 94—*Eurema laeta* | 95—*Leptosia nina* | 96—*Ixias marianne* | 97—*Ixias pyrene* | 98—*Pareronia hippia* | 99—*Graphium agamemnon* | 100—*Graphium doson* | 101—*Graphium nomius* | 102—*Pachliopta aristolochiae* | 103—*Pachliopta hector* | 104—*Papilio demoleus* | 105—*Papilio polytes* | 106—*Papilio crino*. © Authors

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SHORT COMMUNICATION

An enumeration of the flowering plants of Kyongnosla Alpine Sanctuary in eastern Sikkim, India

Sudhansu Sekhar Dash [1], Subhajit Lahiri [2] & Ashiho Asoshii Mao [3]

[1,3] Botanical Survey of India, III MSO Building, 5–6th Floor, CGO Complex, DF Block, Sector-1, Salt Lake, West Bengal 700064, India.
[2] Botanical Survey of India, Central National Herbarium, Howrah, Kolkata, West Bengal 711103, India.
[1] ssdash2002@gmail.com (corresponding author), [2] subhajitbsi@yahoo.com, [3] aamao2008@gmail.com

Abstract: The present paper is the outcome of an extensive floristic survey conducted in two phases by the authors in Kyongnosla Alpine Sanctuary, East Sikkim, India. During the study 411 taxa (400 species, 04 subspecies and 07 varieties) belonging to 173 genera and 54 families were recorded. The most dominating family was Asteraceae with 44 species followed by Ericaceae 28 species, Ranunculaceae 26 species, Polygonaceae 24 species and Rosaceae 20 species. These five families represent 34.13% of the total taxa recorded from the sanctuary. About 12 families were represented by only one species each. The most dominating genus was *Rhododendron* (18 species) followed by *Primula* (16 species), *Pedicularis* (15 species), *Gentiana* (11 species), and *Impatiens* (10 species). Among the different growth forms, herbs contributed the maximum (86.61 %) followed by shrubs (7.79%), trees (4.87%), climbers 0.49%, and epiphyte (0.24%).

Keywords: checklist, eastern Himalaya, floristic survey, growth form, Himalayan forest types.

Comprehensive documentation and identification of plant diversity is one of the targets of Global Strategy for Plant Conservation (GSPC). Being a signatory of the Convention on Plant Diversity (CBD), India is committed towards achieving a complete inventory of plant diversity of all the protected and nonprotected areas (Singh & Dash 2015). India is endowed with diverse ecosystems ranging from high altitude cold deserts to hot and humid coastlands which show rich floral diversity. Continuous survey and exploration in different habitats have facilitated an updated inventory of plants, which opens up different potential linkages among various sectors and implementation of appropriate action on management and sustainable conservation.

Kyongnosla Alpine Sanctuary (KAS) situated in the East district of Sikkim (Figure 1) between 27^{0}22'33"N latitude and 88^{0}44'13"E longitude covers an area of 31 km^2 between the elevation ranging from 3,000–4,500 m. In the initial notification 45/WL/83/625 dated 29.viii.84, the area demarcated was 4.5 km^2, however in the second and final notification 45/WL/F/92/1585/F&WL dated 12.v.92 the area of the sanctuary extended to 31 km^2. The vegetation of the KAS comprises different ecological zones depending upon the elevation, viz., mixed *Rhododendron* temperate forest, coniferous forest along open slopes and ridges and alpine scrubs on upper reaches. Though it encompasses a small area, the sanctuary supports a luxuriant temperate and alpine vegetation owing to its unique topography, variation of altitudes and high annual precipitation. All representative Himalayan forest types (Champion

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& Seth 1968; Dash & Singh 2010), such as northern montane wet temperate forests (dominated by Oaks Quercus, and Acer); Himalayan moist temperate forests (dominated by Rhododendron spp., *Tsuga dumosa, Picea spinulosa*, and *Abies densa*); Himalayan dry temperate forests (represented by gregarious growth of *Juniperus wallichiana*); sub-alpine forests (represented by *Rhododendron* spp., *Betula utilis, Sorbus* spp.) and alpine forests (gregarious patches of *Rhododendron* thickets, *Juniperus recurva*, and dense herbaceous growth) exist. The subalpine and alpine forests are present with climax formations, self-generating, resilience forest types. Nevertheless, this diversity is variously challenged by several driving forces such as over exploitation of medicinal plants, heavy grazing by yaks and developmental activities in the fringe areas. Extensive surveys of the study area were conducted to document the floristic composition in different altitudinal gradients of the KAS from July 2017–March 2020, being a part of our project work 'Biodiversity Assessment through Long-term Monitoring of Plots In the Indian Himalayan Landscape' under the National Mission of Himalayan Studies. In the paper we have enumerated 411 flowering plants occurring in the sanctuary with their correct accepted names.

Materials and Methods

The entire area of KAS was surveyed extensively in two phases. The first phase during 1998–2000 by the first author (SSD) and the second phase during 2017–2020 by the first two authors (SSD & SL). More than 1,300 plant specimens were collected and processed following standard protocols (Jain & Rao 1977). All the collected specimens were identified consulting available literature (Hooker 1872–1897; Grierson & Long 1983; Long 1984; Grierson 1984; Grierson 1987; Grierson & Long 1987; Hajra & Verma 1996; Srivastava 1998; Aitken 1999; Aitken, Grierson & Long 1999; Grierson & Springate 2001; Lucksom 2007; Gogoi et al. 2018; Maity et al. 2018; Mao et al. 2018; Lahiri et al. 2019; Dash et al. 2020; Lahiri & Dash 2020) and voucher specimens were deposited at BSHC and CAL for future reference. Earlier collections made from KAS by different collectors and available in different herbaria (ASSAM, BSHC, and CAL) were also taken into consideration while preparing the present enumeration. In the present inventory, families are arranged as per APG IV system of classification (Chase et al. 2016) and within the family, genera, and species are arranged alphabetically. For determination of current names, the World Flora Online (http://www.worldfloraonline.org) and Plants of the World

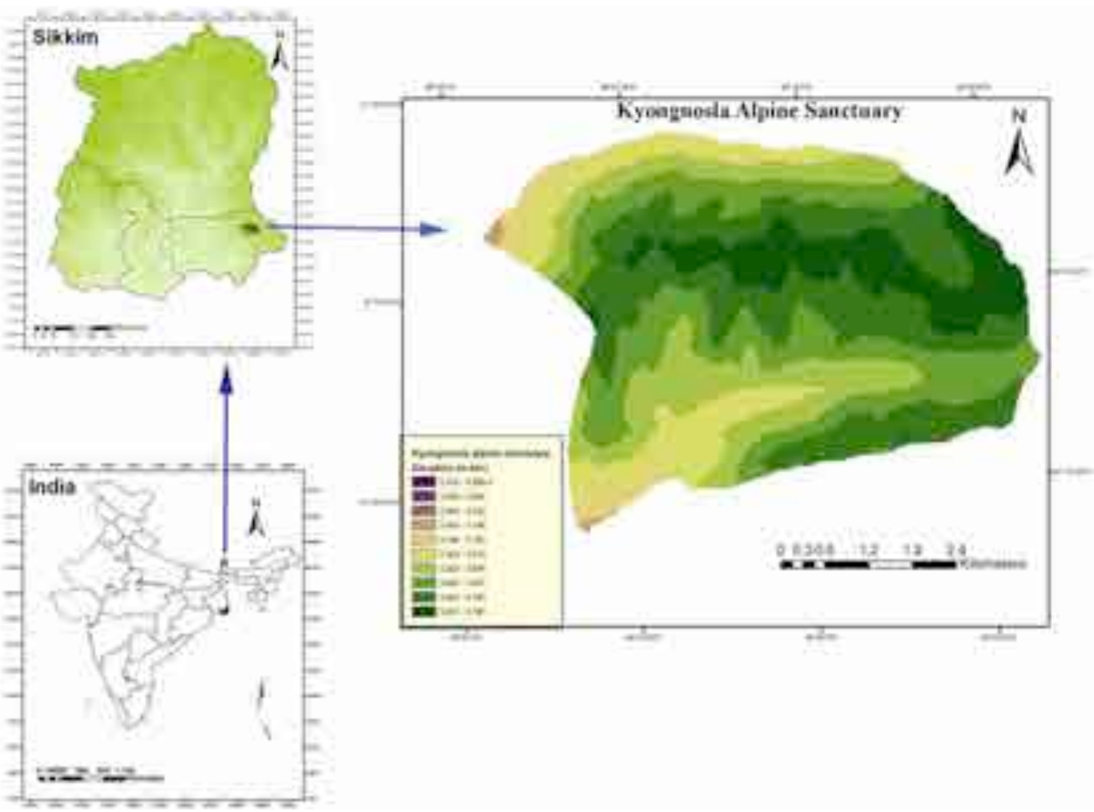

Figure 1. Location of Kyongnosla Alpine Sanctuary in eastern Sikkim.

Online (http://www.plantsoftheworldonline.org) were consulted. The enumeration comprises family names, correct scientific names followed by valid author citation, growth form, altitude ranges where they occur and collection details along with the field number and herbarium acronym in each of the columns. Range of distribution of a species has been determined taking into consideration the present collections and also earlier collections deposited in different herbaria.

Results and Discussion

The enumeration of the flowering plants of KAS includes 411 species belonging to 173 genera and 54 families (Table 2). The family Asteraceae with 44 species is the most dominant family, followed by Ericaceae (28 species), Ranunculaceae (26 species), Polygonaceae (24 species), and Rosaceae (20 species). These families represent 34.13% of the total species recorded from the sanctuary. Among the genera, *Rhododendron* is the most dominant genus represented by 18 species, followed by *Primula* (16 species), *Gentiana* (11 species), *Impatiens* (10 species), *Corydalis* (9 species), *Saxifraga* and *Rhodiola* (7 species each). Three families, i.e., Acanthaceae, Carlemanniaceae, and Euphorbiaceae are represented by only one species.

The plants present in the sanctuary show wider distribution in other parts of the Himalaya too, such as *Allium prattii*, *Cyananthus lobatus*, *Gaultheria trichophylla*, *Juniperus recurva*, *Nardostachys jatamansii*, *Rosa sericea*, and *Streptopus simplex*, which have a wider distribution from North-West Himalayas to China. The taxa showing eastward extension are *Cassiope selaginoides, Gentiana stylophora, Morina nepalensis, Panax pseudo-ginseng, Primula sikkimensis,* and *Ribes luridum*. Many species which are restricted only to eastern Himalaya are represented by *Abies densa, Meconopsis villosa, Rhododendron lanatum, Impatiens cymbifera, Codonopsis benthamii, Codonopsis subsimplex,* and *Primula kingii*.

The basal angiosperm is represented by only one species *Schisandra grandiflora* (Wall.) Hook.f. & Thomson, while eudicots are represented by 85.88% and monocots by 13.86% of total species in KAS (Table 1).

The sanctuary provides a suitable habitat both for temperate and alpine species and holds many endangered and endemic species, viz. *Aconitum ferox*, *Bhutanthera albomarginata, Ponerorchis puberula, Aconitum novoluridum, Codonopsis benthamii, Codonopsis subsimplex* etc. The present study also recorded some of little-known species viz. *Bhutanthera albomarginata*, *Ponerorchis puberula*, *Aconitum novoluridum*, *Codonopsis benthamii*, *Rubus lasiostylus*, *Sinopodophyllum hexandrum*, *Gentiana leucomelaena*, *Veratrilla burkilliana*, *Tibetoseris depressa*, and *Pedicularis porrecta*. The sanctuary has been facing a continuous challenge in its community structure due to various anthropogenic interferences and heavy grazing which need to be controlled.

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Table 1. Detailed analysis of floristic diversity under various taxonomic groups (values in parentheses are percent contribution of the total).

	Total Families			Total Genera			Total taxa		
	Basal angiosperms (Austrobaileyales Takht. ex Reveal)	Mono cots	Eudicots	Basal angiosperms (Austrobaileyales Takht. ex Reveal)	Monocots	Eudicots	Basal angiosperms (Austrobaileyales Takht. ex Reveal)	Mono cots	Eudicots
Angiosperms	01 (1.85%)	13 (24.07%)	40 (74.07%)	01 (0.57%)	30 (17.34%)	142 (82.08%)	01 (0.24%)	57 (13.86%)	353 (85.88%)
Total	54			173			411		

Table 2. Enumeration of the flowering plants of Kyongnosla Alpine Sanctuary.

Family	Scientific name of taxa	*Growth form	Altitude (m)	Collection number & Herbarium acronym
		Basal angiosperms		
Schisandraceae	*Schisandra grandiflora* (Wall.) Hook.f. & Thomson	C	3000–3600	S.S. Dash 24144 (BSHC)
		Monocots		
Araceae	*Arisaema erubescens* (Wall.) Schott	H	2000–3400	S.S. Dash 22712 (BSHC)
	Arisaema griffithii Schott	H	2400–3700	S.S. Dash 27028 (BSHC); S. Lahiri 95710 (CAL)
	Arisaema jacquemontii Blume	H	2300–4200	S.S. Dash 22782 (BSHC); S. Lahiri 86682 (CAL)
Tofieldiaceae	*Tofieldia himalaica* Baker	H	3000-4500	B. Krishna 2068 (BSHC)
Nartheciaceae	*Aletris glabra* Bureau & Franchet	H	2400–4200	S.S. Dash 27247 (BSHC); S. Lahiri 86690 (CAL)
	Aletris pauciflora (Klotzsch) Hand. –Mazz.	H	2200–4900	S.S. Dash 22734 (BSHC); S. Lahiri 85719 (CAL)
Smilacaceae	*Smilax menispermoidea* A.DC.	C	2800–3600	S.S. Dash 20995, 24010 (BSHC); S. Lahiri 86685(CAL)
Liliaceae	*Fritillaria cirrhosa* D.Don	H	3200–4500	S. Lahiri & S.S. Dash 86714, 64902, 86623 (CAL)
	Gagea flavonutans (H. Hara) Zarrei & Wilkin	H	3800–4500	S. Lahiri & S.S. Dash 85788 (CAL)
	Lilium nanum Klotzsch	H	3500–4500	S. Lahiri & S.S. Dash 85784 (CAL)
	Streptopus simplex D. Don	H	3200-4300	S.S. Dash 22270 (BSHC); S. Lahiri 85701 (CAL)
Orchidaceae	*Bhutanthera albomarginata* (King & Pant.) Renz	H	3800–4300	S. Lahiri & S.S. Dash 85753, 95737 (CAL)
	Galearis spathulata (Lindl.) P.F.Hunt	H	3000–4300	S. Lahiri & S.S. Dash 86661 (CAL)
	Gymnadenia orchidis Lindl.	H	2800–4100	S. Lahiri & S.S. Dash 85791 (CAL)
	Herminium macrophyllum (D.Don) Dandy	H	2400–4100	S.S. Dash 38383 (BSHC)
	Herminium monorchis (L.) R.Br	H	1200–4500	S. Lahiri & S.S. Dash 95720 (CAL)
	Platanthera exelliana Soó Hook.f	H	3300–4500	S. Lahiri & S.S. Dash 95721 (CAL).
	Platanthera leptocaulon (Hook.f.) Soó	H	3000–4000	S. Lahiri & S.S. Dash 85705, 86695 (CAL).
	Ponerorchis chusua (D.Don) Soó	H	2500–4500	S. Lahiri & S.S. Dash 86665, 85714(CAL)
	Ponerorchis puberula (King & Pantl.) Verm.	H	2700-3600	S. Lahiri & S.S. Dash 85702 (CAL)
	Satyrium nepalense D.Don	H	1800–4000	S. Lahiri & S.S. Dash 86731(CAL)
	Satyrium nepalense var. *ciliatum* (Lindl.) Hook.f.	H	2500–4000	S. Lahiri & S.S. Dash 86730, 86747(CAL)
Iridaceae	*Iris clarkei* Baker ex Hook.f.	H	3300–4200	S.S. Dash 22702 (BSHC); S. Lahiri 85727 (CAL)
Amaryllidaceae	*Allium prattii* C.H. Wright	H	2500–4400	S. Lahiri & S.S. Dash 85785, 95735 (CAL)
	Allium wallichii Kunth	H	3000–4500	S.S. Dash 24071, 24122, 27002 (BSHC); S. Lahiri 86737 (CAL)
Asparagaceae	*Maianthemum oleraceum* (Baker) LaFrankie	H	2700–3600	S. Lahiri & S.S. Dash 95729 (CAL)
	Maianthemum purpureum (Wall.) LaFrankie	H	2700–4000	S. Lahiri & S.S. Dash 86691, 86692 (CAL)
	Polygonatum brevistylum Baker	H	2000–3300	S.S. Dash 22710 (BSHC)
	Polygonatum cirrhifolium (Wall.) Royle	H	2200–4200	S.S. Dash 20992(a) (BSHC)
	Polygonatum verticillatum (L.) All.	H	2400–4300	S.S. Dash 20992, 22710 (BSHC); S. Lahiri 86694 (CAL)
Eriocaulaceae	*Eriocaulon alpestre* Hook.f. & Thomson ex Körn.	H	2400–3900	S. Lahiri & S.S. Dash 64907 (CAL)
Juncaceae	*Juncus benghalensis* Kunth	H	2200–4200	S.S. Dash 22728 (BSHC); S. Lahiri 86696 (CAL)
	Juncus bufonius L.	H	2700–4500	S. Lahiri & S.S. Dash 64934 (CAL)
	Juncus cephalostigma Sam.	H	3300–4500	S. Pradhan 6631 (BSHC)
	Juncus chrysocarpus Buchenau	H	3000–3600	D.C.S. Raju 3680 (BSHC)
	Juncus concinnus D.Don	H	2100–4300	S.S. Dash 27016 (BSHC)
	Juncus effusus L.	H	2000–3400	S.S. Dash 27286 (BSHC)
	Juncus grisebachii Buchenau	H	2500–5000	S. Lahiri & S.S. Dash 86745 (CAL)

Family	Scientific name of taxa	*Growth form	Altitude (m)	Collection number & Herbarium acronym
Juncaceae	*Juncus himalensis* Klotzsch	H	2400–4200	S.S. Dash 24123,24130 (BSHC); S. Lahiri 86657 (CAL)
	Juncus kingii Rendle	H	3700–4300	S.S. Dash 27231 (BSHC)
	Juncus sikkimensis Hook.f.	H	3600–4800	S.S. Dash 27289
	Juncus thomsonii Buchenau	H	3600–3900	S.S. Dash 22208 (BSHC); S. Lahiri 64923 (CAL)
	Luzula multiflora (Ehrh.) Lej.	H	3000–4500	S.S. Dash 20996 (BSHC); S. Lahiri (CAL)
Cyperaceae	*Carex gracilenta* Boott ex Boeckeler	H	3200–4300	S. Lahiri & S.S. Dash 64909 (CAL)
	Carex inanis Kunth	H	1400–3700	S. Lahiri & S.S. Dash 64929 (CAL)
	Kobresia curticeps (C.B.Clarke) Kük.	H	2500–4000	G.P. Sinha & D.G. Long 17748 (BSHC)
Poaceae	*Agrostis inaequiglumis* Griseb.	H	3000–4500	S.S. Dash 24046 (BSHC); S. Lahiri 64911 (CAL)
	Agrostis micrantha Steud.	H	1600–3500	P. Singh & S.K. Rai. 23784 (BSHC).
	Agrostis nervosa Nees ex Trinius	H	3300–4000	S.S. Dash 22789 (BSHC)
	Calamagrostis emodensis Griseb.	H	2200–4600	S.S. Dash 24068 (BSHC)
	Calamagrostis scabrescens Griseb.	H	2000–3800	S. Lahiri & S.S. Dash 64931 (CAL)
	Cyathopus sikkimensis Stapf	H	3600-4600	S.S. Dash 24105 (BSHC)
	Deschampsia cespitosa (L.) P.Beauv.	H	2700-4500	S.S. Dash 24104 (BSHC)
	Festuca rubra L.	H	3500–4200	S.S. Dash 27228 (BSHC)
	Festuca valesiaca Schleicher ex Gaudin	H	2500–3700	S.S. Dash 27044 (BSHC)
	Poa pagophila Bor	H	3600–5200	S.S. Dash 27035 (BSHC)
	Poa pratensis L.	H	3000–5000	S.S. Dash 24113 (BSHC)
		Eudicots		
Papaveraceae	*Corydalis cashmeriana* Royle	H	3000–5000	S. Lahiri & S.S. Dash 85773 (CAL)
	Corydalis filicina Prain	H	2500-3500	S.S. Dash 27250 (BSHC); S. Lahiri 85774 (CAL)
	Corydalis flaccida Hook.f. & Thomson	H	3300–4200	S.S. Dash 22738 (BSHC)
	Corydalis juncea Wall.	H	3600–4600	S.S. Dash 27226 (BSHC)
	Corydalis meifolia Wall.	H	3800–5200	S.S. Dash 27223 (BSHC); S. Lahiri 86612 (CAL)
	Corydalis polygalina Hook.f. & Thomson	H	4000–5100	D.C.S. Raju 3655 (BSHC)
	Corydalis pseudolongipes Lidén	H	3000–4000	S.S. Dash 24119,24018, 27276 (BSHC); S. Lahiri 86634 (CAL)
	Corydalis sikkimensis (Prain) Fedde	H	3000–4600	S.S. Dash 27006 (BSHC)
	Corydalis trifoliata Franch.	H	3600–4200	S.S. Dash 20977 (BSHC)
	Meconopsis paniculata (D. Don) Prain	H	3000–4200	S.S. Dash 22715 (BSHC); S. Lahiri 86659 (CAL)
	Meconopsis simplicifolia (D. Don) Walp.	H	3200–4500	S.S. Dash 20073 (BSHC); S. Lahiri 95705 (CAL)
	Meconopsis villosa (Hook.f.) G.Taylor	H	2700–4300	S.S. Dash 22703(BSHC); S. Lahiri 85723(CAL)
Berberidaceae	*Berberis angulosa* Wall. ex Hook.f. & Thomson	S	3000–4000	S.S. Dash 27008 (BSHC); S. Lahiri 85879, 86651 (CAL)
	Berberis griffithiana C.K.Schneid.	H	2500–3300	S.S. Dash 22776 (BSHC)
	Berberis macrosepala Hook.f & Thomson	H	3500–4400	S.S. Dash 22776(A) (BSHC)
	Sinopodophyllum hexandrum (Royle) T.S.Ying	H	2500–4500	S.S. Dash 27029 (BSHC).
Ranunculaceae	*Aconitum dissectum* D.Don	H	3200-4500	S. Lahiri & S.S. Dash 85739 (CAL)
	Aconitum ferox Wallich ex Sering	H	3000–5000	S.S. Dash 27225 (A) (BSHC); S. Lahiri 86754 (CAL)
	Aconitum heterophylloides (Brühl) Stapf	H	3300–4500	S. Lahiri & S.S. Dash 86784 (CAL)
	Aconitum novoluridum Munz	H	2000–3500	S.S. Dash 27225(BSHC); S. Lahiri 64905 (CAL)
	Aconitum palmatum D.Don	H	2500–4000	S. Lahiri & S.S. Dash 86795 (CAL)
	Aconitum spicatum (Bruelh) Stapf	H	3500–4000	S.S. Dash 27227 (BSHC); S. Lahiri 86783 (CAL)
	Anemone obtusiloba D.Don	H	2300–5300	S.S. Dash 22752 (BSHC)
	Anemone rupestris Wallich ex Hook.f.	H	2000–3500	S. Lahiri 95717 (CAL).

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Ranunculaceae	*Anemone trullifolia* Hook.f. & Thomson	H	2500–5000	S.S. Dash 27256 (BSHC)
	Caltha palustris L.	H	2000–3600	S.S. Dash 22721 (BSHC).
	Caltha scaposa Hook.f. & Thomson	H	2500–4500	S.S. Dash 27225 (BSHC); S. Lahiri 86649 (CAL)
	Clematis montana Buch. –Ham. ex DC.	H	2000–4000	S.S. Dash 22701 (BSHC); S. Lahiri 86788, 95712 (CAL)
	Delphinium candelabrum Ostenf.	H	4100–5300	S.S. Dash 24189 (BSHC)
	Oxygraphis polypetala (Raf.) Hook.f. & Thomson	H	3200–5300	S. Lahiri & S.S. Dash 73248 (CAL)
	Ranunculus brotherusii Freyn	H	3000–3300	S.S. Dash 22747 (BSHC)
	Ranunculus diffusus DC.	H	1100–3100	S.S. Dash 22741 (BSHC)
	Ranunculus ficariifolius Leveille & Veniot	H	1100–3200	S.S. Dash 27294 (BSHC)
	Ranunculus hirtellus Royle ex D.Don	H	3000–5000	Sinha & Shukla 20550 (BSHC)
	Ranunculus pulchellus C.A. Mey.	H	2300–3200	S.S. Dash 20993, 20973 (BSHC)
	Ranunculus trichophyllus Chaix	H	3200–4100	Sinha & Shukla 20550 (BSHC)
	Thalictrum alpinum L.	H	2800–5000	S.S. Dash 19289 (BSHC); S. Lahiri 64924 (CAL)
	Thalictrum chelidonii DC.	H	2300–3600	S.S. Dash 24197 (BSHC)
	Thalictrum elegans Wall. ex Royle	H	2700–4200	S.S. Dash 24048 (BSHC)
	Thalictrum javanicum Blume	H	1500–3800	S.S. Dash 24196 (BSHC)
	Thalictrum reniforme Wall.	H	2800–3700	S. Lahiri & S.S. Dash 85711 (CAL)
	Thalictrum rutifolium Hook.f. & Thomson	H	2300–4300	S.K. Rai 9455 (BSHC)
Grossulariaceae	*Ribes glaciale* Wall	S	2000–3500	S.S. Dash 27284 (BSHC)
	Ribes laciniatum Hook.f. & Thomson	S	2400–3900	S.S. Dash 27206 (BSHC)
	Ribes luridum Hook.f. & Thomson	S	2800–4200	S.S. Dash 24150 (BSHC)
	Ribes takare D.Don	S	2700–4200	S.S. Dash 22796, 22799 (BSHC)
Saxifragaceae	*Astilbe rivularis* Buch.-Ham. ex D. Don	H	2000–3600	S.S. Dash 20976, 24135 (BSHC); S. Lahiri 86662 (CAL)
	Bergenia ciliata (Haw.) Sternb.	H	2000–3500	S. Lahiri & S.S. Dash 95753 (CAL)
	Bergenia purpurascens (Hook.f. & Thomson) Engl.	H	3700–4800	S.S. Dash 27221 (BSHC); S. Lahiri 86718 (CAL)
	Saxifraga assamensis Wadhwa	H	3600–3900	S.S. Dash 24198 (BSHC)
	Saxifraga brachypoda D.Don	H	3000–5000	S.S. Dash 24198 (BSHC); S. Lahiri 86775, 85769 (CAL)
	Saxifraga cordigera Hook.f. & Thomson	H	3000–4600	S.S. Dash 27208 (BSHC) & S. Lahiri 86797 (CAL)
	Saxifraga melanocentra Franch.		3000–4900	Sinha & Shukla 20447 (BSHC)
	Saxifraga moorcroftiana (Ser.) Wall. ex Sternb.	H	2000–3500	S.S. Dash 24126, 27214 (BSHC); S. Lahiri 86776 (CAL)
	Saxifraga pallida Wall. ex Ser.	H	3000–5000	S. Lahiri & S.S. Dash 86617 (CAL)
	Saxifraga parnassifolia D.Don	H	2000–3500	S.S. Dash 24001 (BSHC); S. Lahiri 86786 (CAL)
Crassulaceae	*Rhodiola bupleuroides* (Wall. ex Hook.f. & Thomson) S.H.Fu	H	3400–5700	S.S. Dash 27274(BSHC); S. Lahiri 85730, 85757 (CAL)
	Rhodiola chrysanthemifolia (H. Lév.) S.H.Fu	H	3200–4200	S.S. Dash 19275 (BSHC)
	Rhodiola cretinii (Raymond–Hamet) H.Ohba	H	3700–4400	S. Lahiri & S.S. Dash 85752 (CAL)
	Rhodiola crenulata (Hook.f. & Thomson) H.Ohba	H	2800–5600	S.S. Dash 27248 (BSHC).
	Rhodiola fastigiata (Hook. f. & Thomson) S.H.Fu	H	3500–5400	S. Lahiri & S.S. Dash 74489 (CAL)
	Rhodiola himalensis (D. Don) S.H.Fu	H	3600–4200	S.S. Dash 6620, 85752 (BSHC); S. Lahiri 74416 (CAL).
	Rhodiola wallichiana (Hook.) S.H.Fu	H	3500–3800	S.S. Dash 27255, 24012; S. Lahiri 86715, 86748 (CAL)

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Fabaceae (= Leguminosae)	*Astragalus sikkimensis* Bunge	H	2600–4500	S. Lahiri & S.S. Dash 64922 (CAL)
	Parochetus communis D.Don	H	1800–3500	S. Lahiri & S.S. Dash 86654 (CAL)
Rosaceae	*Fragaria nubicola* (Lindl. ex Hook.f.) Lacaita	H	2500–3900	S.S. Dash 24045 (BSHC); S. Lahiri 86728 (CAL)
	Fragaria vesca L.	H	2000–3200	S. Singh 3398 (BSHC)
	Potentilla eriocarpa Wall. ex Lehm.	H	2700–5000	S.S. Dash 22753 (BSHC)
	Potentilla fruticosa var. *arbuscula* (D. Don) Maxim.	S	2600–4600	S. Lahiri & S.S. Dash 85742 (CAL)
	Potentilla leuconota D.Don	H	2200–4600	S. Lahiri & S.S. Dash 86640 (CAL)
	Potentilla peduncularis D.Don	H	3000–4800	S.S. Dash 22735 (BSHC); S. Lahiri 95754 (CAL)
	Potentilla polyphylla Wall. ex Lehm.	H	2500–4500	S.S. Dash 22707 (BSHC)
	Potentilla saundersiana Royle	H	2600–5200	S.S. Dash 22762 (BSHC)
	Prunus carmesina H.Hara	T	1900–3000	S.S. Dash & S. Lahiri 95760 (CAL)
	Prunus cornuata	T	2000–3200	S.S. Dash & S. Lahiri 95761 (CAL)
	Rosa sericea Wall. ex Lindl.	S	3000– 4000	S.S. Dash 222705, 24036, 27246, 27041 (BSHC); S. Lahiri 86627 (CAL)
	Rubus lasiostylus Focke	S	2700–3200	S. Lahiri & S.S. Dash 85717 (CAL)
	Rubus mesogaeus Focke	S	2700–3600	S.S. Dash 24194 (BSHC)
	Rubus pectinarioides H.Hara	S	2000–3500	D.C.S. Raju & S. Singh 3661 (BSHC)
	Rubus pedunculosus D.Don	S	2600–3700	S.S. Dash 22784 (BSHC)
	Rubus thomsonii Focke	S	2700–3400	A.K. Sahoo 3588 (BSHC)
	Sibbaldia parviflora Willd.	H	2000–3500	S. Lahiri & S.S. Dash 86723 (CAL)
	Sorbus foliolosa (Wall.) Spach	T	2500–4200	S.S. Dash 20987 (BSHC); S. Lahiri 86780 (CAL)
	Sorbus prattii Koehne	T	2000–4500	S.S. Dash 24133 (BSHC)
	Sorbus microphylla (Wall. ex Hook.f.) Wenz.	T	3200–4200	S.S. Dash 24038 (BSHC)
	Spiraea arcuata Hook.f.	S	2700–4000	S.S. Dash 22794 (BSHC)
	Spiraea canescens D.Don	S	2700–4000	S.S. Dash 24154 (BSHC); S. Lahiri 95739 (CAL)
Betulaceae	*Betula utilis* D.Don	T	2600–4200	S.S. Dash 22751, 24019 (BSHC)
Celastraceae	*Euonymus tingens* Wall	H	1300–3700	S.S. Dash 24049 (BSHC)
	Parnassia chinensis Franch.	H	2500–4400	S.S. Dash 27208 (BSHC); S. Lahiri 86733, 86632, 86638 (CAL)
	Parnassia cooperi W.E.Evans	H	3000–3500	S.S. Dash 22741(BSHC)
	Parnassia nubicola Wall. ex Royle	H	3200–4350	S.S. Dash 24131,27203 (BSHC); S. Lahiri 86733(CAL)
	Parnassia tenella Hook.f. & Thomson	H	2800–3400	S.S. Dash 22741(BSHC)
Oxalidaceae	*Oxalis leucolepis* Diels	H	2800–4000	S. Lahiri & S.S. Dash 86664 (CAL)
Hypericaceae	*Hypericum choisianum* Wall. ex N.Robson	H	2100–4000	S.S. Dash 20980 (BSHC)
	Hypericum hookerianum Wight & Arn.	H	1900–3400	S.S. Dash 24077 (BSHC); S. Lahiri 86724 (CAL)
	Hypericum petiolulatum Hook.f. & Thomson ex Dyer	H	1000–3100	S. Lahiri & S.S. Dash 86653 (CAL)
Violaceae	*Viola biflora* L.	H	2500–4300	S.S. Dash 22733 (BSHC); S. Lahiri 85772 (CAL)
Salicaceae	*Salix calyculata* Hook.f. ex Andersson	S	3400–4700	S.S. Dash 22749 (BSHC); S. Lahiri 74463 (CAL)
	Salix daltoniana Andersson	S	3000–4400	S.S. Dash 24013 (BSHC)
	Salix longiflora Wall. ex Andersson	S	500–4000	Sinha & Shukla 20470 (BSHC)
	Salix serpyllum Anderson	S	3200–4500	S.S. Dash 24050 (BSHC); S. Lahiri 85878 (CAL).
	Salix sikkimensis Andersson	S	3350–4000	S.S. Dash 27290 (BSHC); S. Lahiri 86631 (CAL)
Euphorbiaceae	*Euphorbia sikkimensis* Boiss.	H	2500–3500	S. Lahiri & S.S. Dash 85766 (CAL)

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Geraniaceae	*Geranium donianum* Sweet	H	2400–4800	S.S. Dash 24043 (BSHC); S. Lahiri 74455 (CAL)
	Geranium nepalense Sweet	H	1000–3600	S.S. Dash 24040, 22757 (BSHC); S. Lahiri 85721 (CAL)
	Geranium polyanthes Edgew. & Hook.f.	H	2900–4000	S.S. Dash 24065 (BSHC)
Onagraceae	*Circaea alpina* subsp. *imaicola* (Asch. & Magnus) Kitam.	H	2000–4000	B. Krishna 6431 (BSHC)
	Epilobium amurense Hausskn.	H	2100–4000	S. Lahiri & S.S. Dash 86633 (CAL)
	Epilobium sikkimense Hausskn.	H	2000–3750	S. Lahiri & S.S. Dash 85741 (CAL)
	Epilobium tibetanum Hausskn.	H	2000–4500	Sinha & Shukla 21598 (BSHC)
	Epilobium wallichianum Hausskn.	H	2200–4100	Sinha & Shukla 21594 (BSHC)
	Epilobium williamsii P.H.Raven	H	2300–4700	S. Lahiri & S.S. Dash 74422 (CAL).
Sapindaceae	*Acer acuminatum* Wall. ex D.Don	T	3300–4700	S. Lahiri & S.S. Dash 95744 (CAL)
	Acer campbellii Hook.f. & Thomson ex Hiern	T	2000–3500	S. Lahiri & S.S. Dash 85708 (CAL)
Brassicaceae (= Cruciferae)	*Arcyosperma primulifolium* (Thomson) O.E.Schulz	H	3000–4500	Sinha & Shukla 20539 (BSHC)
	Barbarea elata Hook.f. & Thomson	H	3200–3800	S.S. Dash 22749 (A) (BSHC)
	Barbarea intermedia Boreau	H	2800–4200	S.S. Dash 22779 (BSHC); S. Lahiri 95716 (CAL)
	Cardamine griffithi Hook.f., Thomson	H	2000–3800	S.S. Dash 22739 (BSHC)
	Cardamine macrophylla Willd.	H	2500–4200	S.S. Dash 22754, 27053 (BSHC); S. Lahiri 86628, 85877 (CAL)
	Cardamine pulchella (Hook.f. & Thomson) Al–Shehbaz & G.Yang	H	3000–4100	S.S. Dash 22766 (BSHC) S. Lahiri 85716 (CAL)
	Pegaeophyton minutum H.Hara	H	3700–4200	S. Lahiri 95749 (CAL)
	Thlaspi montanum L.	H	1500–3000	S. Pradhan 6608 (BSHC)
Polygonaceae	*Aconogonon campanulatum* (Hook.f.) H.Hara	H	3000–3600	S.S. Dash 20736, 24035, 86642 (BSHC); S. Lahiri 86642 (CAL)
	Aconogonon campanulatum var. *oblongum* (Meisn.) H.Hara	H	3000–3600	S.S. Dash 22717 (BSHC).
	Aconogonon molle (D. Don) H.Hara	H	2000–4000	S.S. Dash 24081 (BSHC); S. Lahiri 86620 (CAL)
	Aconogonon polystachyum (Wall. ex Meisn.) M.Král	H	2000–4000	S.S. Dash 20735, 27242, 24005 (BSHC); S. Lahiri 86742 (CAL)
	Aconogonon rude (Meisn.) S.S.Dash & P.Singh	H	2000–3300	S.S. Dash 24138 (BSHC)
	Bistorta affinis (D.Don) Greene	H	3500–5000	S.S. Dash 27293 (BSHC); S. Lahiri 74426 (CAL)
	Bistorta amplexicaulis (D.Don) Green	H	3000–4200	S.S. Dash 20999, 24002 (BSH); S. Lahiri 85713 (CAL)
	Bistorta emodi (Meisn.) H.Hara	H	3200–4000	S.S. Dash 27253 (BSHC); S. Lahiri 64935 (CAL)
	Bistorta macrophylla (D.Don) Soják	H	3500–4200	S.S. Dash 27251 (BSHC)
	Bistorta suffulta (Maximowicz) Greene ex. H.Gross	H	3000–4200	S. Kumar & P. Singh 11640 (BSHC)
	Bistorta vacciniifolia (Wall. ex Meisn.) Greene	H	2600–3900	S.S. Dash 24109 (BSHC); S. Lahiri 86758 (CAL)
	Bistorta vivipara (L) S.F.Gray	H	2200–3850	S.S. Dash 22719 (BSHC); S. Lahiri 86726, 85800 (CAL)
Polygonaceae	*Koenigia delicatula* (Meisn.) H.Hara	H	2600–5000	S.S. Dash 18593, 24060, 27240 (BSHC); S. Lahiri 74492, 85720 (CAL)
	Koenigia forrestii (Diels) Mesicek & Soják	H	2800–5200	D.G. Long et al. 18245 (BSHC)
	Koenigia nepalensis D.Don	H	2800–5000	S.S. Dash 27032 (BSHC); S. Lahiri 85720, 85738 (CAL)
	Koenigia nepalensis D.Don var. villosa	H	3000–4900	S.S. Dash 24041(BSHC)
	Koenigia pilosa Maxim.	H	3000–4500	Sinha & Shukla 21565 (BSHC)
	Oxyria digyna (L.) Hill	H	3000–5500	S.S. Dash 18532, 27283 (BSHC); S. Lahiri 86619 (CAL).
	Persicaria nepalensis (Meisn.) Miyabe	H	2500–3900	S.S. Dash 27032,24041(BSHC); S. Lahiri 86738, 86739, 85797 (CAL)
	Persicaria runcinata (Buch.-Ham. ex D.Don) H. Gross	H	1000–3800	S.S. Dash 24032 (BSHC); S. Lahiri 86735, 85710, 85711 (CAL)

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Polygonaceae	*Rheum acuminatum* Hook.f. & Thomson	H	3000–4100	S.S. Dash 18569 (BSHC); S. Lahiri 85735 (CAL).
	Rheum nobile Hook.f. & Thomson	H	3000–5200	S.S. Dash 24124 (BSHC).
	Rumex dentatus L.	H	2200–3800	S.S. Dash 20985 (BSHC)
	Rumex nepalensis Spreng.	H	1500–3600	S.S. Dash 22775, 24066, 27268 (BSHC)
Caryophyllaceae	*Arenaria debilis* Hook.f	H	3000–4900	S. Lahiri & S.S. Dash 85726 (CAL)
	Cerastium glomeratum Thuill.	H	1000–4200	S.S. Dash 27287 (BSHC); S. Lahiri 86625 (CAL)
	Gypsophila cerastoides D.Don	H	3000–4200	S.S. Dash 22763,22787 (BSHC); S. Lahiri 85764 (CAL)
	Silene caespitella F.Williams	H	2500–5100	S.S. Dash 24190 (A) (BSHC); S. Lahiri 86727 (CAL)
	Silene indica (Roxb.) Roxb. ex Otth	H	2500–5000	B. Krishna & B. Mitra 6414 (BSHC)
	Silene nigrescens (Edgew.) Majumdar	H	3000–4500	S. Lahiri & S.S. Dash 64903 (CAL)
	Stellaria subumbellata Edgew.	H	3500–5300	S.S. Dash 24118 (BSHC)
Balsaminaceae	*Impatiens bicornuta* Wall.	H	2400–3200	P.K. Hajra 514 (BSHC)
	Impatiens cymbifera Hook.f.	H	2100–3200	S. Lahiri & S.S. Dash 95746 (CAL)
	Impatiens falcifer Hook.f.	H	2400–3800	S. Lahiri & S.S. Dash 95747 (CAL)
	Impatiens jurpia Buch.-Ham.	H	2000–3000	S.S. Dash 20988 (BSHC)
	Impatiens kingii Hook.f.	H	2800–4000	S. Lahiri & S.S. Dash 86708 (CAL)
	Impatiens racemosa DC.	H	1500–3300	S.S. Dash 27207(BSHC); S. Lahiri 95748 (CAL)
	Impatiens radiata Hook.f.	H	2000–3600	S. Lahiri & S.S. Dash 86639, 86641(CAL)
	Impatiens serratifolia Hook.f.	H	2400–3300	S. Lahiri & S.S. Dash 85712, 86643 (CAL)
	Impatiens spirifer Hook.f. & Thomson	H	1200–3200	S.S. Dash 27257 (BSHC)
	Impatiens urticifolia Wall.	H	2300–3400	S. Lahiri & S.S. Dash 86707 (CAL)
Primulaceae	*Androsace croftii* Watt	H	3000–4000	S.S. Dash & S. Lahiri 95762 (CAL)
	Primula calderiana Balf.f. & Cooper	H	3500–4500	Sinha & Shukla 21589 (BSHC)
	Primula capitata Hook.f	H	3500–4500	S.S. Dash 24092 (BSHC); S. Lahiri 85775 (CAL)
	Primula drummondiana Craib	H	3000–4200	S. Lahiri & S.S. Dash 74545 (CAL)
	Primula elongata Watt	H	3800–4300	S.S. Dash & S. Lahiri 95759 (CAL)
	Primula glomerata Pax	H	3300–5700	S. Lahiri & S.S. Dash 85775 (CAL)
	Primula involucrata Wall. ex Duby	H	3000–4500	S. Lahiri & S.S. Dash 85750 (CAL)
	Primula kingii Watt	H	3500–4300	S. Lahiri & S.S. Dash 85728 (CAL)
	Primula minutissima Jacquem. ex Duby	H	3700–5200	S.S. Dash 27280 (BSHC)
	Primula obliqua W.W.Sm.	H	3500–4500	S. Lahiri & S.S. Dash 86614(CAL)
	Primula primulina (Spreng.) H.Hara	H	3400–5000	S. Lahiri & S.S. Dash 85780, 85781 (CAL)
	Primula reticulata Wall.	H	3000–4000	S. Pradhan 6603 (BSHC)
	Primula sapphirina Hook.f. & Thomson ex Watt	H	3500–4800	S. Lahiri & S.S. Dash 85796 (CAL)
	Primula scapigera (Hook.f.) Craib	H	2000–4000	S. Lahiri & S.S. Dash 73245 (BSHC)
	Primula sikkimensis Hook.f.	H	3200–4400	S.S. Dash 22722, 27212(BSHC); S. Lahiri 85707 (CAL)
	Primula vaginata Watt	H	2500–4500	S. Lahiri & S.S. Dash 95726 (CAL)
	Primula wattii King ex Watt	H	4000–4600	S. Lahiri & S.S. Dash 95704 (CAL)
Ericaceae	*Cassiope fastigiata* (Wall.) D.Don	H	3000–4500	S. Lahiri & S.S. Dash 85787 (CAL)
	Cassiope selaginoides Hook.f. & Thomson	H	3000–4200	S. S. Dash 24149 (BSHC); S. Lahiri 95715 (CAL)
	Enkianthus deflexus (Griff.) C.K. Schneid.	S	2000–3600	S. S. Dash 24142 (BSHC)
	Gaultheria griffithiana Wight	H	2100–4000	P. Singh & S.K. Rai 22692 (BSHC)
	Gaultheria nummularioides D.Don	H	1800–3500	S.S. Dash 24045(BSHC); S. Lahiri 86729 (CAL)
	Gaultheria semi–infera (C.B. Clarke) Airy Shaw	S	2100–3000	S.S. Dash 27208 (BSHC); S. Lahiri 85745 (CAL)

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Ericaceae	*Gaultheria trichophylla* Royle	H	3000–3900	S.S. Dash 27039, 22768, 27235, 24045 (BSHC); S. Lahiri 73247 (CAL)
	Lyonia ovalifolia (Wall.) Drude	T	1500–3400	S. Lahiri & S.S. Dash 64901, 85745 (CAL)
	Lyonia villosa (Wall. ex C.B.Clarke) Hand. – Mazz.	T	3000–3900	S.S. Dash 22746 (BSHC); S. Lahiri 64920 (CAL)
	Rhododendron anthopogon D.Don	S	2400–4900	S.S. Dash 27291 (BSHC); S. Lahiri 95751 (CAL)
	Rhododendron arboreum Sm.	T	1500–3800	S. Lahiri & S.S. Dash 73242 (CAL)
	Rhododendron baileyi Balf.f.	S	3000–4000	S. S. Dash 24151 (BSHC)
	Rhododendron camelliiflorum Hook.f.	S	2500–3700	S.S. Dash 24146 (BSHC)
	Rhododendron campanulatum D.Don	T	2800–4000	S. Lahiri & S.S. Dash 73244 (CAL)
	Rhododendron campanulatum subsp. *aeruginosum* (Hook. f.) D.F.Chamb.	T	3500–4600	S. S. Dash 24145 (BSHC); S. Lahiri 73249 (CAL)
	Rhododendron campylocarpum Hook.f.	T	3000–4600	S. Lahiri & S.S. Dash 95752 CAL)
	Rhododendron cinnabarinum Hook.f.	T	2400–4000	S.S. Dash 24147 (BSHC)
	Rhododendron fulgens Hook.f.	S	3700–4500	S.S. Dash 22723 (BSHC); S. Lahiri 73251(CAL)
	Rhododendron glaucophyllum Rehder	S	2700– 3700	S.S. Dash 24070, 24146 (BSHC); S. Lahiri 73240 (CAL).
	Rhododendron grande Wight	T	2500–3200	S.S. Dash 27219 (BSHC)
	Rhododendron griffithianum Wight	T	2000–3000	P.K. Hajra 2215 (BSHC)
	Rhododendron hodgsonii Hook.f.	T	3000–3600	S. Lahiri & S.S. Dash 73255 (CAL)
	Rhododendron lanatum Hook.f.	T	3000–4000	S.S. Dash 24143 (BSHC)
	Rhododendron lepidotum Wall. ex G.Don	S	3000–4500	S.S. Dash 24063, 22723 (BSHC); S. Lahiri 73252 (CAL)
	Rhododendron niveum Hook.f.	S	2900–3700	P. Singh & B.P. Uniyal 16228 (BSHC)
	Rhododendron setosum D.Don	S	3000–4500	P.K. Hajra 308 (BSHC); S. Lahiri & S.S. Dash 86711 CAL)
	Rhododendron thomsonii Hook.f.	T	3000– 4200	S.S. Dash 22785 (BSHC); S. Lahiri 73243 (CAL)
	Vaccinium nummularia Hook.f. & Thomson ex C.B.Clarke	E	2440–3200	P.K. Hajra 341, B. Krishna 6366 (BSHC)
Rubiaceae	*Galium acutum* Edgew.	H	2000–4100	S. Lahiri & S.S. Dash 74434 (CAL)
	Galium asperifolium Wall.	H	400–3500	S.S. Dash & S. Lahiri 95758 (CAL)
	Galium rebae R.R.Mill	H	2000–4000	S. Lahiri & S.S. Dash 86636 (CAL)
Gentianaceae	*Crawfurdia puberula* C.B.Clarke	H	2700–3200	S.S. Dash 24003 (BSHC)
	Gentiana bryoides Burkill	H	3000–4500	S. Lahiri & S.S. Dash 73253 (CAL)
	Gentiana capitata Buch.-Ham. ex D.Don	H	2000–3500	S.S. Dash 24030 (a) (BSHC)
	Gentiana crassuloides Bureau & Franch.	H	3600–4600	S.S. Dash 22771 (BSHC)
	Gentiana elwesii C.B.Clarke	H	3600–4500	S.S. Dash 27281 (BSHC); S. Lahiri 86716 (CAL)
	Gentiana leucomelaena Maxim.	H	3000–5000	S. Lahiri & S.S. Dash 85754 (CAL)
	Gentiana prolata Balf.f.	H	3000–4500	S. Lahiri & S.S. Dash 74402 (CAL)
	Gentiana recurvata C.B.Clarke	H	3000–4300	S. Lahiri & S.S. Dash 86676 (CAL)
	Gentiana recurvata subsp. *prainii* (Burkill) Halda	H	3000–4300	S. Lahiri & S.S. Dash 85718 (CAL)
	Gentiana sikkimensis C.B.Clarke	H	2700–5200	S.S. Dash 24067, 27949 (BSHC); S. Lahiri 86772 (CAL)
	Gentiana stylophora C.B.Clarke	H	3000–4500	S.S. Dash 27005, 6636 (BSHC); S. Lahiri 85760 (CAL)
	Gentiana tubiflora (G. Don) Griseb.	H	4000–5300	S.S. Dash 24029 (BSHC); S. Lahiri 86670, 86755, 86622 (CAL)
	Halenia elliptica D.Don	H	2000–4200	S.S. Dash 27271, 24030 (BSHC); S. Lahiri 86740, 86644 (CAL)
	Lomatogonium brachyantherum (C.B. Clarke) Fernald	H	3800–4300	S. Lahiri & S.S. Dash 86762 (CAL)

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Gentianaceae	*Omphalogramma elwesianum* (King ex Watt) Franch.	H	3300–4200	P.K. Hajra 344(BSHC).
	Swertia bimaculata (Siebold & Zucc.) Hook.f. & Thomson ex C.B.Clarke	H	2000–3500	S.S. Dash 24047 (BSHC); S. Lahiri 74453 (CAL)
	Swertia hookeri C.B.Clarke	H	3700–4500	S. Lahiri & S.S. Dash 85756, 95736 (CAL)
	Swertia multicaulis D.Don	H	3600–4700	S. Lahiri & S.S. Dash 74451 (CAL).
	Swertia teres (G.Don) J.Shah	H	3000–4500	S. Lahiri & S.S. Dash 74414, 86744 (CAL)
	Veratrilla burkilliana (W.W.Sm.) Harry Sm.	H	3200–4600	S. Lahiri & S. S. Dash 95702 (CAL).
Boraginaceae	*Cynoglossum wallichii* G.Don	H	1300–3600	S.S. Dash 27274 (BSHC); S. Lahiri 85715 (CAL)
	Cynoglossum wallichii var. *glochidiatum* (Wall. ex Benth.) Kazmi	H	1300–3600	S. Lahiri & S.S. Dash 85737 (CAL)
	Hackelia uncinata (Benth.) C.E.C.Fisch.	H	3300–4200	S.S. Dash 22758 (BSHC); S. Lahiri 86675 (CAL)
	Maharanga emodi (Wall.) A.DC.	H	2500–3300	S.S. Dash 22751, 24019 (BSHC); S. Lahiri 85732 (CAL)
Carlemanniaceae	*Carlemannia griffithii* Benth.	H	1000-2900	S.S. Dash 13892 (BSHC)
Calceolariaceae	*Calceolaria tripartita* Ruiz & Pav.	H	1900–5000	S. Lahiri & S.S. Dash 64936 (CAL)
Plantaginaceae	*Lagotis kunawurensis* Rupr.	H	2700–5600	S. Lahiri & S.S. Dash 85761 (CAL)
	Neopicrorhiza scrophulariiflora (Pennell) D.Y.Hong	H	3600–4400	S. Lahiri & S.S. Dash 86700 (BSHC)
	Plantago depressa Willd.	H	2600–3900	S. Lahiri & S.S. Dash 86725 (BSHC)
	Veronica cana Wall. ex Benth.	H	2743–4115	S.S. Dash 22736, 27043, 24089 (BSHC); S. Lahiri 86669 (CAL)
	Veronica szechuanica subsp. *sikkimensis* (Hook.f.) D.Y.Hong	H	2900–4200	S. Lahiri & S.S. Dash 86673 (CAL)
	Hemiphragma heterophyllum Wall.	H	2600–4100	S.S. Dash 24026 (BSHC); S. Lahiri 73249 (CAL).
Scrophulariaceae	*Scrophularia elatior* Wall. ex Benth.	H	2000–3200	S.S. Dash 22998 (BSHC)
	Euphrasia bhutanica Pugsley	H	3000–4200	S. Lahiri & S.S. Dash 64904, 85771 (CAL)
Acanthaceae	*Strobilanthes wallichii* Nees	H	2500–3700	S. Lahiri & S. S. Dash 85740, 86635 (CAL)
Lentibulariaceae.	*Utricularia brachiata* Oliver	H	2500–4200	S. Lahiri & S.S. Dash 86698 (CAL)
	Utricularia christopheri P.Taylor	H	2100–3900	S. Lahiri & S.S. Dash 86768 (CAL)
	Utricularia multicaulis Oliv.	H	3050–4115	S. Lahiri & S.S. Dash 85734 (CAL)
Lamiaceae	*Ajuga integrifolia* Buch.-Ham.	H	1200–2900	S.S. Dash 22785 (BSHC)
	Elsholtzia blanda (Benth.) Benth.	H	1000–3000	S.S. Dash 27233, 27288 (BSHC)
	Elsholtzia densa Benth.	H	2500–3600	S.S. Dash 24116 (BSHC)
	Elsholtzia strobilifera (Benth.) Benth.	H	2300–4000	S.S. Dash 24969 (BSHC); S. Lahiri 86759, 86756 (CAL)
	Paraphlomis brevifolia C.Y.Wu & H.W.Li	H	2000–3200	S. Lahiri & S.S. Dash 85706 (CAL)
	Phlomoides tibetica (C.Marquand & A.Shaw) Kamelin & Makhm.	H	2500–4700	S.S. Dash 22767(BSHC)
	Plectranthus mollis (Aiton) Spreng.	H	1000–2900	P.K. Hajra 518 (BSHC)
	Prunella vulgaris L.	H	2600–4200	S. Lahiri 86697 (CAL)
	Salvia campanulata Wall. ex Benth.	H	2200–4000	S.S. Dash 24102,24048 (BSHC); S. Lahiri 86674 (CAL).
	Salvia nubicola Wall. ex Sweet	H	2600–3700	S. Lahiri & S.S. Dash 95727 (CAL)
	Salvia roborowskii Maxim.	H	2500–3700	S. Lahiri & S.S. Dash 85767 (CAL)
Orobanchaceae	*Pedicularis denudata* Hook.f.	H	3500–4500	S. Lahiri & S.S. Dash 86717 (CAL)
	Pedicularis elwesii Hook.f.	H	3200–4600	S.S. Dash 27037 (BSHC)
	Pedicularis flexuosa Hook.f.	H	2800–4000	S. Lahiri & S.S. Dash 86712 (CAL)
	Pedicularis furfuracea Wall. ex Benth.	H	3500–4000	S.S. Dash 22783 (BSHC); S. Lahiri 85731 (CAL)
	Pedicularis gracilis subsp. *macrocarpa* (Prain) Tsoong	H	2900–3600	S. Lahiri & S.S. Dash 85724 (CAL).

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Orobanchaceae	*Pedicularis longiflora* var. *tubiformis* (Klotzsch) Tsoong	H	3000–5000	S.S. Dash 24017 (BSHC); S. Lahiri 86656 (CAL).
	Pedicularis megalantha D. Don	H	2800–5000	S.S. Dash 27210 (BSHC); S. Lahiri 86752 (CAL)
	Pedicularis microcalyx Hook.f.	H	3200–4500	S. Lahiri & S.S. Dash 85786 (CAL)
	Pedicularis mollis Wall. ex Benth.	H	2700–4200	S. Lahiri & S.S. Dash 85798 (CAL)
	Pedicularis porrecta Wall.	H	3300–5000	S. Lahiri & S.S. Dash 86630 (CAL)
	Pedicularis rhinanthoides Schrenk	H	2500–5500	S.S. Dash 22774 (BSHC)
	Pedicularis roylei Maxim.	H	3400–5500	S. Lahiri & S.S. Dash 85789 (CAL)
	Pedicularis siphonantha D.Don	H	3200–4500	S. Lahiri & S.S. Dash 86629 (CAL)
	Pedicularis tenuicaulis Prain	H	3500–4000	S.S. Dash 27249 (BSHC)
	Pedicularis wallichii Bunge	H	3600–5000	S. Lahiri & S.S. Dash 95734 (CAL)
Campanulaceae	*Campanula pallida* Wall.	H	1200–3500	S.S. Dash 24200 (BSHC)
	Codonopsis benthamii Hook.f. & Thomson	H	2100–4300	S. Lahiri & S.S. Dash 86684 (CAL)
	Codonopsis foetens Hook.f. & Thomson	H	3600–4500	S. Lahiri & S.S. Dash 85747 (CAL)
	Codonopsis subsimplex Hook.f. & Thomson	H	3000–4200	S. Lahiri & S.S. Dash 86751, 85743, 86637 (CAL)
	Codonopsis thalictrifolia Wall.	H	3400–5000	S. Lahiri & S.S. Dash 95750 (CAL)
	Cyananthus incanus Hook.f. & Thomson	H	3500–4600	S. Lahiri & S.S. Dash 86736 (CAL)
	Cyananthus inflatus Hook.f. & Thomson	H	2700–4800	S. Lahiri & S.S. Dash 86774 (CAL)
	Cyananthus lobatus Wall. ex Benth.	H	3300–4200	S. Lahiri & S.S. Dash 86777, 85755, 85799 (CAL)
	Cyananthus pedunculatus C.B.Clarke	H	3000–4500	S. Lahiri & S.S. Dash 86785 (CAL)
	Lobelia erectiuscula H.Hara	H	2200–4200	S. Lahiri & S.S. Dash 85709 (CAL)
Asteraceae (= Compositae)	*Ainsliaea aptera* DC.	H	3000–3600	S.S. Dash 24101 (BSHC)
	Anaphalis contorta (D. Don) Hook.f.	H	2000–5000	S. Lahiri & S.S. Dash 64921(CAL)
	Anaphalis margaritacea (L.) Benth. & Hook.f.	H	2000–4000	S. Lahiri & S.S. Dash 95743 (CAL)
	Anaphalis nepalensis (Spreng.) Hand. –Mazz. Var. *nepalensis*	H	2800–5200	S. Lahiri & S.S. Dash 86789 (CAL)
	Anaphalis nepalensis var. *monocephala* (DC.) Hand.-Mazz.	H	2800–5200	S. Lahiri & S.S. Dash 86770 (CAL)
	Anaphalis triplinervis (Sims) Sims ex C.B. Clarke	H	1500–4200	S.S. Dash 24020 (BSHC); S. Lahiri 86650, 86741, 86778 (CAL)
	Anaphalis triplinervis var. *monocephala* (DC.) Airy Shaw	H	1500–4200	S.S. Dash 22724,27273 (BSHC); S. Lahiri 85733, 86650 (CAL)
	Artemisia nilagirica (C.B.Clarke) Pamp.	H	1500–3300	S.S. Dash 24039 (BSHC)
	Aster flaccidus Bunge	H	3800–5000	S.S. Dash 20457 (BSHC); S. Lahiri (CAL)
	Aster himalaicus C.B.Clarke	H	2500–5000	S.S. Dash 27034, 24024 (BSHC); S. Lahiri 85748 (CAL)
	Aster tricephalus C.B.Clarke	H	3000–4000	S. Lahiri & S.S. Dash 86753 (CAL)
	Cacalia mortonii (C.B.Clarke) Kitam. ex H. Koyama	H	2500–3800	S. Lahiri & S.S. Dash 85759 (CAL)
	Carpesium cernuum L.	H	2900–3500	S.S. Dash & S.S. Lahiri 95757 (CAL).
	Chaetoseris cyanea (D.Don) C.Shih	H	2600–4000	S. Lahiri & S.S. Dash 85704 (CAL)
	Chaetoseris macrantha (C.B.Clarke) C.Shih	H	3000–5000	S.S. Dash 27267 (BSHC)
	Cirsium falconeri (Hook.f.) Petr.	H	3000–4200	S.S. Dash 20998, 24014 (BSHC); S. Lahiri 86767 (CAL)
	Cremanthodium oblongatum C.B.Clarke	H	3600–5300	S.S. Dash 27277 (BSHC); S. Lahiri 85783 (CAL)
	Cremanthodium reniforme (DC.) Benth.	H	3300–4500	S.S. Dash 27279 (BSHC); S. Lahiri 85765 (CAL)
	Dubyaea hispida (D.Don) DC.	H	3000–4500	S.S. Dash 24120 (BSHC); S. Lahiri 86648, 86734 (CAL)
	Himalaiella deltoidea (DC.) Raab–Straube	H	1000–3400	D.C.S. Raju, 5050 (BSHC)
	Jurinea cooperi J.Anthony	H	3500–4300	S.S. Dash 24112 (BSHC)

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Asteraceae (= Compositae)	*Jurinea dolomiaea* Boiss.	H	3500–4300	S.S. Dash 27285 (BSHC)
	Lactuca brunoniana (DC.) Wall. ex C.B.Clarke	H	3300–3800	S.S. Dash 24078 (BSHC)
	Lactuca lessertiana (Wall. ex DC.) Wall. ex C.B.Clarke	H	3400–4100	S.S. Dash 24125 (BSHC); S. Lahiri 86787 (CAL)
	Laphangium luteoalbum (L.) Tzvelev	H	2000–3800	S.S. Dash 27241(BSHC); S. Lahiri 74535 (CAL)
	Leontopodium nivale subsp. *alpinum* (Cass.) Greuter	H	3500–4500	S. Lahiri & S.S. Dash 85777 (CAL)
	Ligularia amplexicaulis DC.	H	3200–4400	S.S. Dash 24037 (BSHC); S. Lahiri 86671 (CAL)
	Ligularia fischeri (Ledeb.) Turcz.	H	2800–3600	S. Lahiri & S.S. Dash 85762 (CAL)
	Ligularia kingiana (W.W.Smith) R.Mathur	H	3500–4000	S.S. Dash 22062, 27030 (BSHC)
	Ligularia virgaurea (Maxim.) Mattf. ex Rehder & Kobuski	H	2400–4700	S. Lahiri & S.S. Dash 85768 (CAL)
	Myriactis nepalensis Less.	H	700–3700	S. Lahiri & S.S. Dash 64919 (CAL)
	Saussurea gossypiphora D.Don	H	3500–4500	S.S. Dash 27217 (BSHC)
	Saussurea nepalensis Spreng.	H	3200–5000	S.S. Dash 24110, 27262 (BSHC) S. Lahiri 86773, 86798, 85792 (CAL)
	Saussurea obvallata (DC.) Edgew.	H	3500–4500	S.S. Dash 27265(BSHC); S. Lahiri 85782(CAL)
	Saussurea roylei (DC.) Sch.-Bip	H	3500–4500	S.S. Dash 27261 (BSHC)
	Saussurea piptathera Edgew.	H	3200–4200	S. Lahiri & S.S. Dash 95745 (CAL)
	Saussurea sughoo C.B. Clarke	H	3500–4800	B. Krishna & S. Singh 3100 (BSHC)
	Saussurea uniflora (DC.) Wall. ex Sch.Bip.	H	3000–4700	S. Lahiri & S.S. Dash 86771 (CAL)
	Senecio graciliflorus (Wall.) DC.	H	3500-4600	S.S. Dash 24111, 27031(a) (BSHC); S. Lahiri 85776 (CAL)
	Senecio raphanifolius Wallich ex DC.	H	2800–4400	S.S. Dash 22714,24016,27042 (BSHC); S. Lahiri 86699, 85703 (CAL)
	Synotis alata C.Jeffrey & Y.L.Chen	H	2000–4000	S. Lahiri & S.S. Dash 86681, 64932 (CAL)
	Tanacetum atkinsonii (C.B.Clarke) Kitam	H	2000–4200	S. Lahiri & S.S. Dash 85794 (CAL)
	Taraxacum eriopodum (D.Don) DC.	H	2000–4500	S. Lahiri & S.S. Dash 86647, 86750, 64918 (CAL)
	Tibetoseris depressa (Hook.f. & Thomson) Sennikov	H	3600–5000	S. Lahiri & S.S. Dash 86779 (CAL)
Caprifoliaceae	*Dipsacus atratus* Hook.f. & Thomson ex C.B.Clarke	H	3000–4000	S. Lahiri & S.S. Dash 86757 (BSHC)
	Lonicera lanceolata Wall.	S	2440–3880	S.S. Dash 20986,24134 (BSHC)
	Morina nepalensis D.Don	H	3000–4800	S. Lahiri & S.S. Dash 86618 (CAL)
	Nardostachys jatamansi (D.Don) DC.	H	2800–5000	S. Lahiri & S.S. Dash 85880, 85750 (CAL)
	Triplostegia glandulifera Wall. ex DC.	H	2000–4000	S. Lahiri & S.S. Dash 86763 (CAL)
	Valeriana hardwickii Wall.	H	1200–3800	S. Lahiri & S.S. Dash 64926, 85790 (CAL)
	Viburnum erubescens Wall.	S	2500–3500	S. Lahiri & S.S. Dash 86800 (CAL)
Araliaceae	*Aralia apioides* Hand.-Mazz.	H	2700–3600	S. Lahiri & S.S. Dash 86679 (CAL)
	Aralia tibetana G.Hoo	H	3200–3500	S.S. Dash 20990,24052,24192 (BSHC)
	Panax bipinnatifidus Seem.	H	2500–3500	S.S. Dash 22727 (BSHC)
	Panax pseudoginseng Wall.	H	1500–3600	S. Lahiri & S.S. Dash 86644, 86764, 64925 (CAL)
Apiaceae	*Angelica cyclocarpa* (C.Norman) M.Hiroe	S	2800–4000	S. Lahiri & S.S. Dash 86613 (CAL)
	Bupleurum candollei Wall. ex DC.	H	2000–3500	S.S. Dash 27010 (BSHC)
	Bupleurum dalhousianum (C.B.Clarke) Koso-Pol.	H	2000–4800	S.S. Dash 22780 (BSHC); S. Lahiri 95728 (CAL)
	Cortiella hookeri (C.B.Clarke) C.Norman	H	4000–5000	S.S. Dash 27274 (BSHC)
	Heracleum wallichii DC.	H	3000–3700	S.S. Dash 27245 (BSHC)
	Oenanthe thomsonii C.B.Clarke	H	1500–3200	S.S. Dash 24051 (BSHC); S. Lahiri 95744 (CAL)
	Pleurospermum apiolens C.B.Clarke	H	3200–5000	S. Lahiri & S.S. Dash 86621 (CAL)

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Apiaceae	*Pleurospermum hookeri* C.B.Clarke	H	3500–4200	S.S. Dash & S.S. Lahiri 95756 (CAL)
	Pleurospermopsis sikkimensis (C.B.Clarke) C.Norman	H	3700–4500	S.S. Dash 27001 (BSHC); S. Lahiri 86782 (CAL)
	Sanicula elata Buch.-Ham. ex D.Don	H	1000–3200	S.S. Dash 24100 (BSHC)
	Selinum wallichianum (DC.) Raizada & H.O.Saxena	H	3400–4000	S.S. Dash 27269 (BSHC); S. Lahiri, 85729 (CAL)
	Vicatia coniifolia Wall. ex DC.	H	3500–4200	S.S. Dash 27011 (BSHC); S. Lahiri 86672 (CAL)
Gymnosperm				
Cupressaceae	*Juniperus recurva* Buch.-Ham. ex D.Don	T	1800–3900	S.S. Dash 24004, 22769 (BSHC); S. Lahiri 86693 (CAL)
	Juniperus squamata f. wilsonii Rehder	S	1600–4500	S. Lahiri & S.S. Dash 74471 (CAL)
Pinaceae	*Abies densa* Griff.	T	2800–3700	S.S. Dash 24034,16210 (A) (BSHC); S. Lahiri 86615 (CAL)
	Larix griffithii Hook.f.	T	3000–4100	S.S. Dash 24148 (BSHC)
	Picea spinulosa (Griff.) A.Henry	T	2900–3600	S.S. Dash 24152 (BSHC)

*—Growth form | C—Climber | E—Epiphyte | H—Herb | S—Shrub | T—Tree.

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Image 1. a—Post monsoon view of Ek gote area at 3,300 m | b—*Rhododendron-Abies* forest at 3,600 m | c—*Rhododendron* woodland at Panch gote area at 3,800 m | d—Riverine habitat near Ek gote area at 3,300 m | e—View of Kyangnosla village in the sanctuary | f—Jor Pokhari Lake at Nakchok at 4,100 m | g—Gregarious growth of *Iris clarkei* at 4,122 m | h—Snow covered slope at Namnang (3,800 m) during autumn. © Subhajit Lahiri.

Image 2. a—*Senecio raphanifolius* Wall. ex DC. | b—*Cacalia mortonii* (C.B. Clarke) Kitam. ex H. Koyama | c—*Cirsium falconeri* (Hook.f.) Petrd. | d—*Chaetoseris cyanea* (D. Don) C. Shih | e—*Senecio graciliflorus* (Wall.) DC. | f—*Saussurea obvallata* (DC.) Edgew. | g—*Saussurea piptathera* Edgew | h—*Saussurea nepalensis* Spreng. © Subhajit Lahiri.

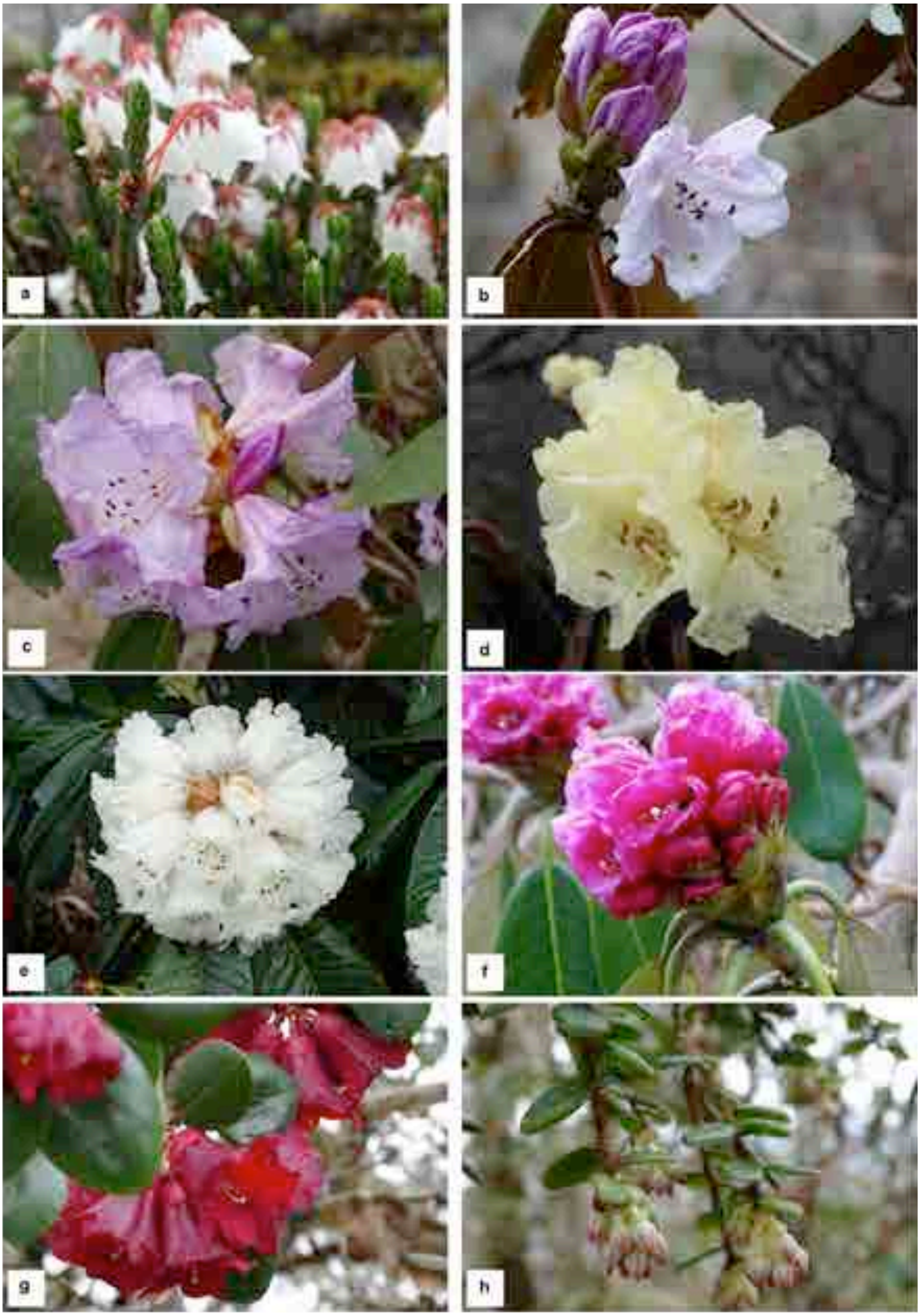

Image 3. a—*Cassiope fastigiata* (Wall.) D.Don | b—*Rhododendron campanulatum* D. Don | c—*Rhododendron campanulatum* subsp. *aeruginosum* (Hook.f.) D.F.Chamb. | d—*Rhododendron campylocarpum* Hook.f. | e—*Rhododendron grande* Wight | f—*Rhododendron hodgsonii* Hook.f. | g.—*Rhododendron thomsonii* Hook.f. | h—*Vaccinium nummularia* Hook.f. & Thomson ex C.B. Clarke. © Subhajit Lahiri.

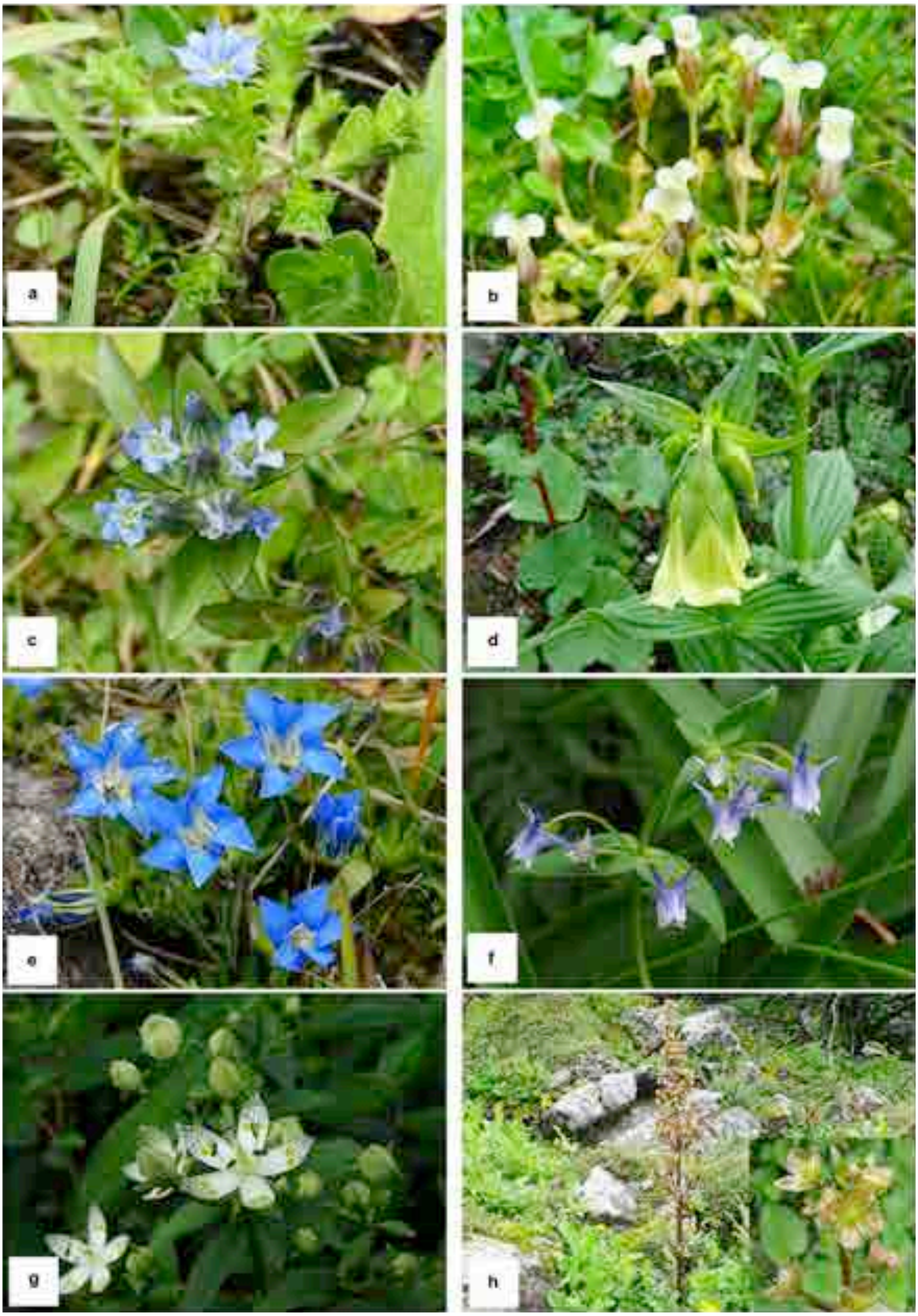

Image 4. a—*Gentiana recurvata* C.B.Clarke | b—*Gentiana recurvata* subsp. *prainii* (Burkill) Halda | c—*Gentiana sikkimensis* C.B.Clarke | d—*Gentiana stylophora* C.B.Clarke | e—*Gentiana tubiflora* (G.Don) Griseb | f—*Halenia elliptica* D.Don | g—*Swertia bimaculata* (Siebold & Zucc.) Hook.f. & Thomson ex C.B. Clarke | h—*Swertia hookeri* C.B. Clarke. © Subhajit Lahiri.

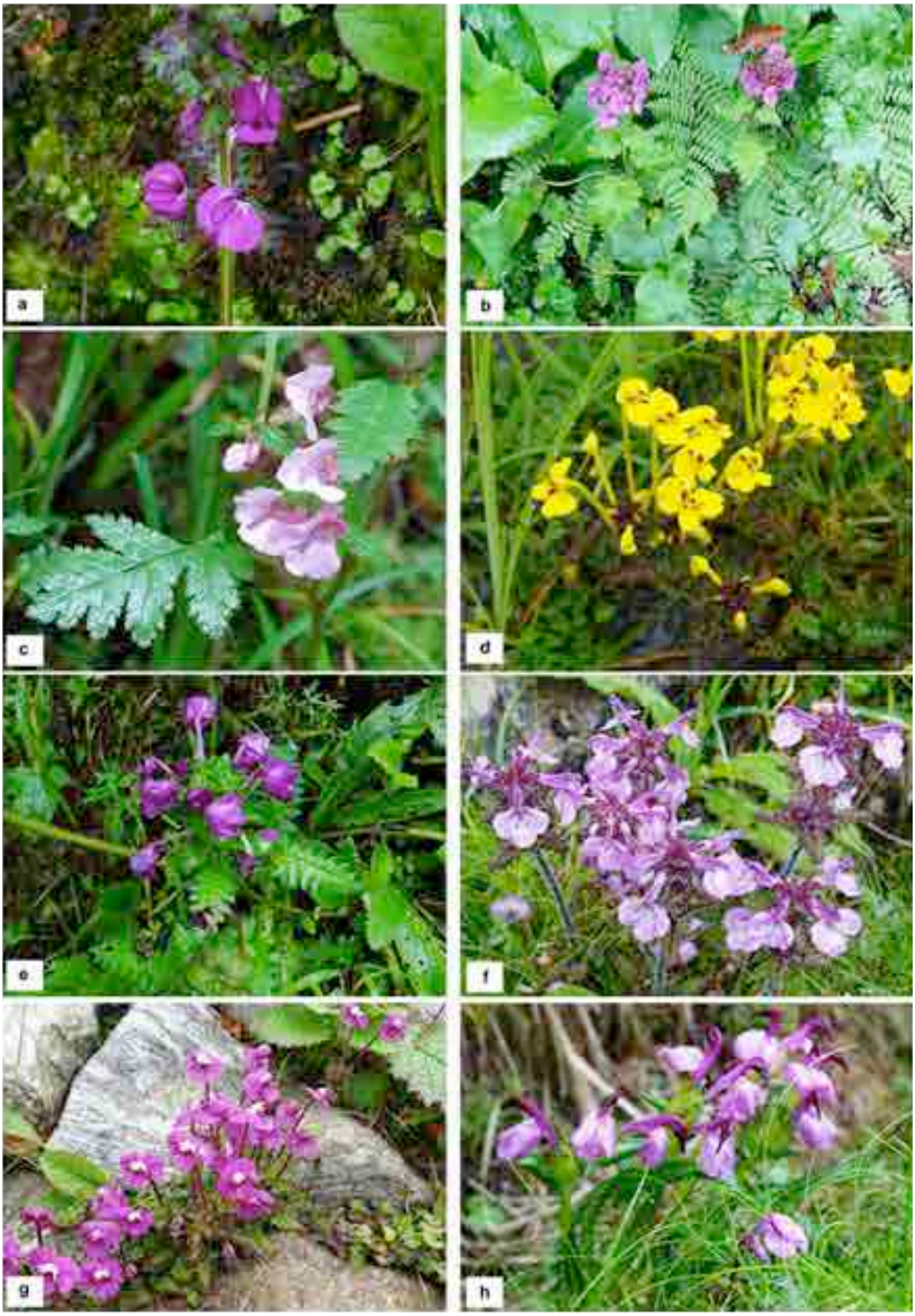

Image 5. a—*Pedicularis flexuosa* Hook.f | b—*Pedicularis furfuracea* Wall | c—*Pedicularis gracilis* subsp. *macrocarpa* (Prain) Tsoong | d—*Pedicularis longiflora* var. *tubiformis* (Klotzsch) Tsoong | e—*Pedicularis megalantha* D.Don | f—*Pedicularis roylei* Maxim | g—*Pedicularis siphonantha* D.Don | h—*Pedicularis wallichii* Bunge. © Subhajit Lahiri.

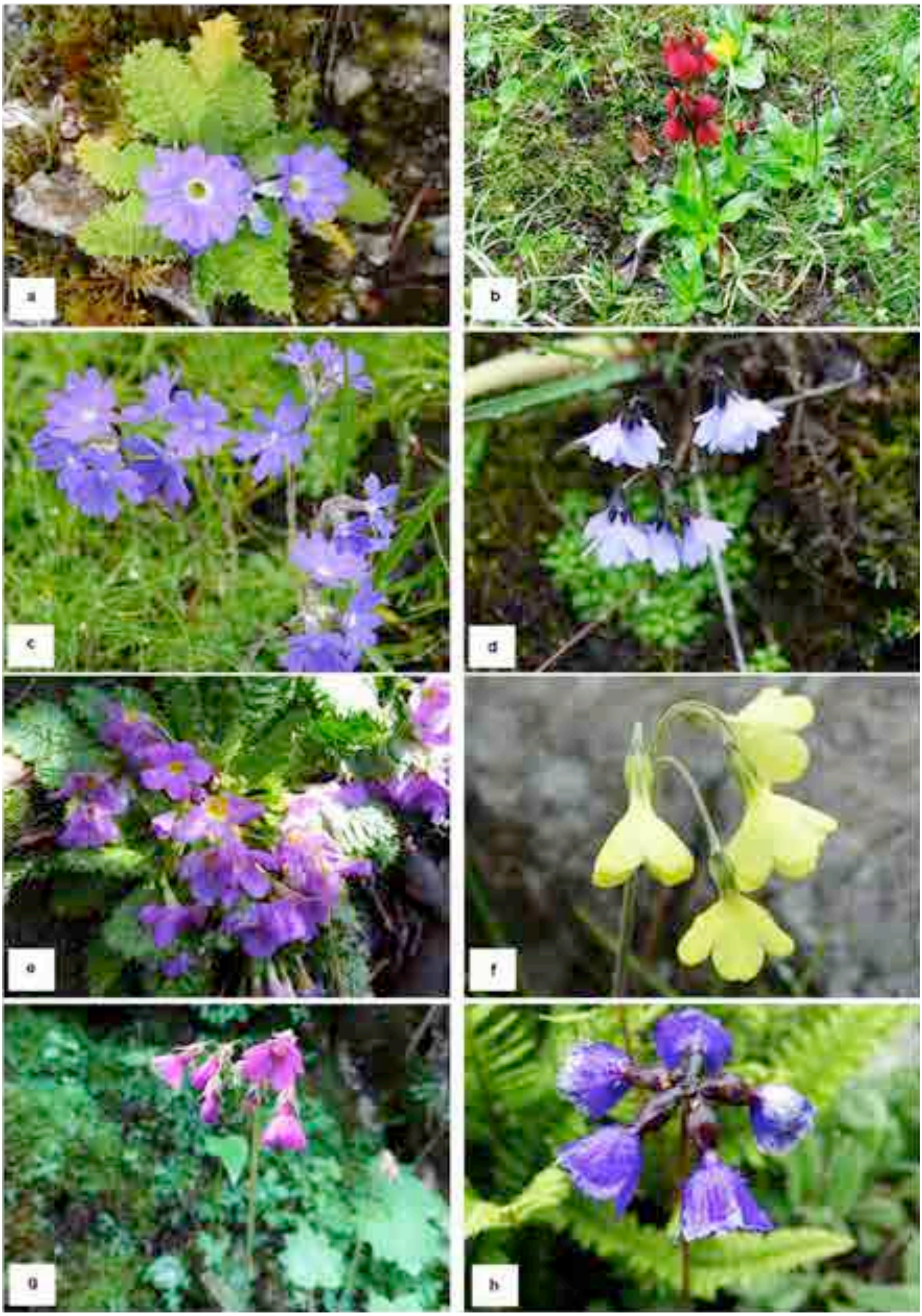

Image 6. a—*Primula drummondiana* Craib | b—*Primula kingii* Watt | c—*Primula primulina* (Spreng.) H.Hara | d—*Primula sapphirina* Hook.f. & Thomson | e—*Primula scapigera* (Hook.f.) Craib | f—*Primula sikkimensis* Hook.f | g—*Primula vaginata* Watt | h—*Primula wattii* King ex Watt. © Subhajit Lahiri.

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SHORT COMMUNICATION

A new record of psychrotrophic *Paecilomyces formosus* (Eurotiales: Ascomycota) from India: morphological and molecular characterization

Skarma Nonzom [1] & **Geeta Sumbali** [2]

[1,2] Department of Botany, University of Jammu, B.R. Ambedkar Road, Jammu, Jammu & Kashmir 180006, India.
[1] skarmanunzom@yahoo.com (corresponding author), [2] geetasumbalippl@yahoo.co.in

Abstract: A filamentous fungus *Paecilomyces formosus* (Eurotiales, Ascomycota) was detected for the first time from the region while surveying fungal diversity of a cold arid high-altitude pass (4,000 msl) located in Kargil district (Ladakh), India. The fungal isolate was characterized morphologically with camera lucida drawings and microphotographs, and identified using internal transcribed spacer (ITS) ribosomal DNA sequences. *P. formosus* has not been reported from India, or from arid/semi-arid/cold regions before, thus this represents a new record of Indian hot/cold desert mycoflora that is psychrotrophic in contrast to the more common thermophilic fungi.

Keywords: Fungal diversity, Kargil district, Indian mycoflora, internal transcribed spacer, new record, taxonomy.

The genus *Paecilomyces* (Eurotiales, Ascomycota) was first described by Bainier in 1907, and established as closely related to the genus *Penicillium*. Nevertheless, these genera differ in many aspects, such as colony and spore colour (green in *Penicillium,* white, pink, buff or other colours besides green in *Paecilomyces*), phialide shape and form of conidiophores. Later, based on morphological characters, Brown & Smith (1957) and Samson (1974) provided comprehensive monographs of *Paecilomyces* with a number of additions including the sexual stages of several species. Luangsa-ard & Hywel-Jones (2004) used molecular approaches with 18S rDNA sequencing in phylogenetic studies of *Paecilomyces* sensu lato. Similarly, Samson et al. (2009) combined data from the internal transcribed spacer (ITS) region and β-tubulin and calmodulin genes and extrolite profiles, and provided detailed taxonomy and comprehensive description of nine accepted taxa (five sexual morphs and four asexual morphs).

Sapi La (34.371^{0}N, 76.197^{0}E) is a high altitude pass (4,000 m) between two villages located in Kargil district in the trans-Himalayan region that is well known for the Sapi glacier (34.352^{0}N, 76.076^{0}E) and lake (34.352^{0}N 76.076^{0}E; Image 1 a–d). During a mycological survey of this barren pass, which experiences continual strong winds, low temperatures (below 20 ºC during summer and 0 to -35 ^{o}C in winter) and high UV radiation throughout the year, more than 30 psychrotolerant fungi were recovered. Of these, a rare microfungus belonging to the genus *Paecilomyces* (*P. formosus* syn. *P. maximus*) was detected, which is being reported for the first time from India. In this report, we describe the characteristics of this cold desert isolate.

Materials and Methods

Isolation of fungal isolates

For fungal isolation, soil samples were collected by scraping the superficial layer, not exceeding 3–5cm

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Competing interests: The authors declare no competing interests.

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Image 1. A—Study area Sapi La (34.371^{0}N, 76.197^{0}E) | b—Sapi Valley (34.352^{0}N, 76.134^{0}E) | c—Sapi glacier (34.352^{0}N, 76.076^{0}E) | d—Sapi Lake (34.352^{0}N, 76.076^{0}E). © Skarma Nonzom.

in depth, with sterilized spatulas in pre-sterilised polythene bags, and brought to the laboratory within 18 hours. Prior to fungal isolation the samples were stored in refrigerator at -4 ^{o}C for 24–48 hours. Fungal isolation was performed using the dilution pour plate method with modified Czapek Dox Agar (CDA) supplemented with Rose Bengal (0.1mg/100ml) and streptomycin sulphate (5mg/100mL). The plates were incubated at 25 ^{o}C for 7–14 days in a BOD incubator. The morphologically different fungal isolates were further plated on potato dextrose agar (PDA) and malt extract agar (MEA) plates, and then incubated for 3–7 days at 25°C. The pure fungal isolates of DI1A (Desert Isolate 1A) were preserved and maintained on PDA slants at 4 °C for further use.

Morphological characterization

The fungal isolate described was cultured on MEA and PDA plates for three to four days at 25 °C. For microscopic observations, the fungal cultures were either teased directly by using dissecting needles and mounted on glass slides using lactophenol cotton blue/lactophenol, or by using a transparent adhesive tape. Microscopic line drawings were made with the aid of camera lucida (Erma, Japan) at 400x and 1000x magnifications. Dimensions (average of at least 20 measurements) were determined for conidiophores, phialides and conidia using an ocular micrometer. Microphotography was done using Sony N50 camera attached to an Olympus CH 20i binocular microscope.

The isolate was identified morphologically by following the description given by Samson et al. (2009).

Molecular characterization

DNA extraction and sequencing was carried out at the sequencing facility of the National Centre for Microbial Resource (NCMR), National Centre for Cell Science, Pune, India. Genomic DNA was isolated by the standard phenol/chloroform extraction method of Sambrook et al. (1989). This was followed by PCR amplification of the ITS regions using universal primers ITS1 [5'-TCC GTA GGT GAA CCT GCG G -3'] and ITS4 [5'-TCC TCC GCT TAT TGA TAT GC-3'] (White et al. 1990). The amplified PCR product was purified by PEG-NaCl precipitation and directly sequenced on an ABI® 3730XL automated DNA sequencer (Applied Biosystems, Inc., Foster City, CA) sequencing was carried out from both ends so that each position was read at least twice. Assembly was carried out using Lasergene package followed by NCBI BLAST against sequences from type material for tentative identification (Boratyn et al. 2013). The confirmed sequences were submitted to Genbank, National Centre for Biotechnology Information (NCBI), Maryland, USA to obtain GenBank accession number-MK255020.

The construction of phylogenetic trees was accomplished by maximum-likelihood method implemented in the program MEGA version 6 with 500 bootstrap replicates (Figure 1). Sequences were retrieved from GenBank based on their closest related species showing maximum identity.

Colonization index of the recovered fungal species

Percentage colonization frequency (CF%), A/F ratio, abundance and cfu /g were calculated for the isolated fungal species using formulae given in Table 1.

Table 1. Formulae used.

	Reference
$CF(\%) = \frac{\text{Number of soil samples colonized by a specific fungus}}{\text{Total number of samples studied}} \times 100$ A/F ratio = Abundance/Colonization frequency where, $\text{abundance} = \frac{\text{Total number of colonies of a specific fungus}}{\text{Number of soil samples colonized by a specific fungus}}$ A/F ratios describe the distribution pattern of each fungal species into one of the following three categories: A/F ratio of <0.025 depicts that the fungal species has regular distribution. A/F ratio between 0.025 & 0.05 depicts that fungal species has random distribution. A/F ratio of >0.05 depicts that the fungal species has contagious distribution.	Raunkiaer 1934
CFU/g = a×d/s where, a = average number of colonies on the petriplate; d= dilution factor (10,000) & s= dry weight of the soil sample	Parikh & Shah 2006

Results and Discussion

Taxonomic notes

Paecilomyces formosus Sakag., May. Inoue & Tada ex Houbraken & Samson, in Samson, Houbraken, Varga & Frisvad, Persoonia 22: 21 (2009)

Ecology and distribution of the species: Tropical soil, subtropical soil, sponge, wood, air and pot plant soil in Denmark (Samson et al. 2009); current isolate examined: India, trans-Himalaya, Kargil district, Sapi La, isolated from a high altitude extreme habitat, July 2017

Characteristics of the cold desert isolate- Asexual stage; sexual stage-not observed

Morphological identification

Colony characters

Colony characters of the fungal isolate *Paecilomyces formosus* desert isolate 1 (DI1A) are depicted in Image 2a. Colonies on PDA show fast growth, initially light buff, plane, later turning golden yellow to dark yellow, becoming powdery as spores are produced, reaching a diameter of 25 to 30 mm within 3–4 days at 25 ^{o}C; reverse pale buff.

Micromorphology

Hyphae branched, hyaline, 2.8–5.6 µm in width; conidiophores simple to irregularly branched, *Penicillum*-like, arising from simple or funiculose hyphae; metulae 7.0–8.4 × 4–2.8 µm; phialides cylindrical, slightly swollen at the base with a long tapering narrow zone, sometimes tapering slightly at the extreme apex, measuring 9.8–21 × 2.5–2.8 µm (Image 2b–e); conidia variable in shape and size, ovate to fusoid, hyaline and small when young; large, yellow, mostly with pointed to rounded apex and truncate base when mature, measuring 4.9–9.1 × 2.1–4.2 µm, smooth-walled, in exceedingly long chains (Image 2b–e, shown in arrows).

Table 2. CF%, cfu/g calculated for *P. formosus* DI1A

Number of soil samples analysed= 25				
Number of samples detected positive	CF (%)	Abundance	A/F ratio	cfu/g
3	12	1.00	0.083	0.3×10^3

Molecular identification

Blast analysis of the ITS region (700 bp) showed its closest similarity to the type material *Paecilomyces formosus* Samson et al. (2009) (GenBank: NR_149329.1; E-value 0; identity: 96.36% and coverage: 100%). Phylogenetic analysis of the sequences of the current isolate DI1A (GenBank: MK255020) based on combined sequences of 15 selected isolates of closest type strains confirmed that our isolate forms a strongly supported clade (99% bootstrap value) with *P. formosus* (Figure 1). *Aspergillus* was used as outgroup.

Discussions and Recommendation

During a mycological survey of a high altitude pass located in the trans-Himalayan region, a psychrotrophic *Paecilomyces* isolate DI1A was recovered which represents a new record to Indian and desert fungi. *P. fusisporus* was detected earlier from cold desert in Himachal Pradesh by Sagar et al. (2007). Similarly, Kotwal & Sumbali (2011) reported three species of *Paecilomyces*, viz., *P. lilacinus, P. marquandii* and *P. variotii* from a similar high altitude pass (5,359 m) located in Ladakh. From Sapi La high-altitude region, Nonzom & Sumbali (2019) have also reported another microfungus, *Geosmithia rufescens*, of rare occurrence.

This identified *Paecilomyces* species, described by Samson et al. (2009) as *Paecilomyces formosus* (Sakag., May. Inoue & Tada) Houbraken & Samson, comb. nov., wherein they illustrated and revised many sexual and

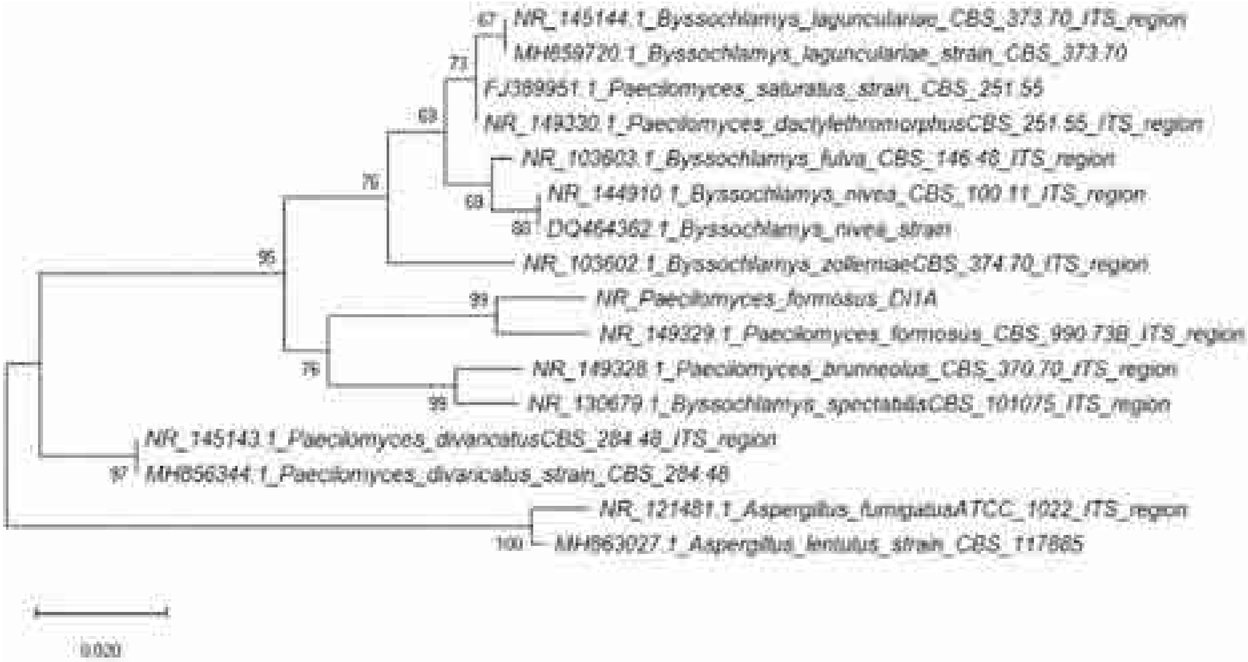

Figure 1. Phylogenetic tree based on maximum likelihood analysis of ITS data for *Paecilomyces* (DI1A) related to the isolate obtained in this study. Bootstrap values of >70% are indicated at the nodes. Scale bar represents the number of substitutions per site.

asexual morphs of *Byssochlamys* and *Paecilomyces*, respectively. Previously, the genus constituted a single species, *P*. *variotii* (Bainer, 1907). However, later a number of species were added to this genus with some revisions and reshufflings (Brown & Smith 1957; Samson 1974; Houbraken et al. 2006; Samson et al. 2009). As such, *P*. *variotii* is considered as a variable species, which has been described under diverse names from the beginning. As discussed earlier, Samson et al. (2009) presented an elaborated description of *Paecilomyces* and *Byssochlamys*, the latter comprising of five species with known sexual morphs, i.e., *B. fulva, B. nivea, B. spectabilis, B. zollerniae*, and *B. lagunculariae*, while the former included four species with only asexual morph known, i.e., *P. divaricatus*, *P. formosus*, *P*. *saturatus*, and *P. brunneolus*. Further, based on the ITS sequences and partial β-tubulin genes, they suggested that, *P*. *formosus* may constitute three distinct species, viz., *P*. *formosus*, *P*. *lecythidis*, and *P*. *maximus*. However, these three taxa appear morphologically similar and could not be identified on the basis of microscopic and analysis of extrolites, whereas molecular phylogeny data can prove helpful. One of the distinguishing feature observed by Samson et al. (2009) for the *P*. *maximus* clade and the other members of this diverse group was the rapid growth of this species at 37˚C than at 30 ˚C and based on their study they proposed *P*. *lecythidis* and *P*. *maximus* as synonyms of *P. formosus*.

As observed by Samson et al. (2009), on growth tests on PDA and MEA, colonies of the current isolate were also fast growing, reaching a diameter of 15–25 mm within 3–4 days of incubation. Morphologically, the conidia were resembling the isolate described by Samson et al. (2009) in terms of truncate shape (dominant), length, size range (3–10 µm) and variable shapes exhibited. However, the isolate from this study had larger conidia and were exhibiting slightly more diameter (up to 4.2 µm) compared to the results of Samson et al. (2009) (up to 3.5 µm) and in contrast to the formation of chlamydospores that were observed to be produced on short stalks, no such structures were observed in the current desert isolate DI1A. In other related asexual *Paecilomyces* morphs, Samson et al. (2009) observed the presence of chlamydospores (*P. brunneolus* and *P. saturatus*) but their absence in *P*. *divaricatus.*

Formerly, *P. maximus* was described to be associated with tropical and subtropical soils, wood and human bone marrow (Samson et al. 2009). Later, this species was found to be plant pathogenic in Iran causing dieback diseases in oak and Pistachio (Heidarian et al. 2018; Sabernasab et al. 2019). So far, there are no reports on the incidence of this isolate from arid or semi-arid regions and particularly from cold arid soils. Moreover, *Paecilomyces* species are usually considered thermophilic (Samson et al. 2009; Houbraken et al. 2010; Heidarian et al. 2018). However, in contrast,

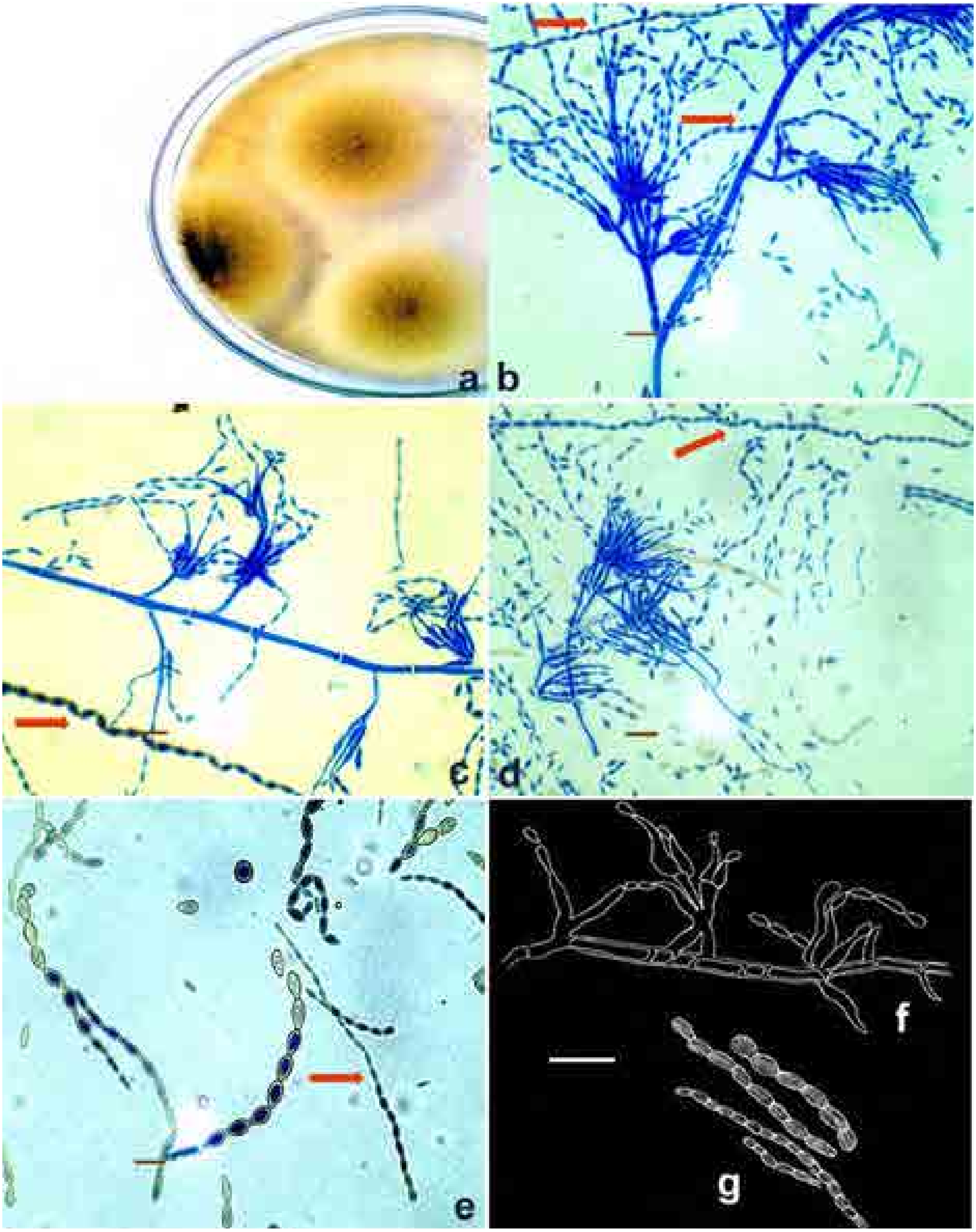

Image 2. ***Paecilomyces formosus*: a—Colonies growing on PDA | b—Conidiophores with conidia | c. d, e—conidia of variable size, conidia in very long chains indicated by arrows | f,g—camera lucida drawings of conidiophores and conidia. Bars a–e= 10 µm | f–g= 14 µm. © Skarma Nonzom.**

the current *Paecilomyces* isolate is a psychrotolerant or psychrotrophic with the capability to survive and surmount extremely low temperatures (up to -35°C) along with other harsh conditions such as intense UV radiation (4,000 m altitude), strong wind currents, low oxygen concentration, and oligotrophic environments. Therefore, through the present investigation we report that *Paecilomyces* can thrive and sustain their activities at temperature ranging from -35°C to 50°C. This indicates that further research in extreme habitats may unveil the diversity and distribution of described and undescribed fungal species.

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NOTE

Study on incidence and pathology of gastrointestinal parasitic infections in Nilgai *Boselaphus tragocamelus* in Hisar, Haryana, India

Maneesh Sharma [1], B.L. Jangir [2], D. Lather [3], G.A. Chandratre [4], V. Nehra [5], K.K. Jakhar [6] & G. Narang [7]

[1] Department of Veterinary Clinical Complex, [2–7] Department of Veterinary Pathology,
College of Veterinary Sciences, Lala Lajpat Rai University of Veterinary and Animal Sciences (LUVAS) Hisar, Haryana 125004, India.
[1] drmaneeshvet@gmail.com (corresponding author), [2] drbabu.jangir@gmail.com, [3] deepikalather@yahoo.co.in,
[4] drgaurichandratre@gmail.com, [5] drvikasnehra@gmail.com, [6] kk_hau@rediffmail.com, [7] gulshan.narang@gmail.com

India has a diverse population of domestic and wildlife animals that are either kept in captivity or in free range. Among them, Blue Bull, commonly called Nilgai in India, is one of the most commonly observed wild animals in agriculture dominated landscapes in central and northern India (Meena et al. 2014). The main threat for the existence of this species is the loss of their habitat due to human population growth, encroachment of forests and emergence of wildlife diseases. Several studies of wild life diseases especially parasitic diseases have been carried out in wild animals including nilgai species (Banerjee et al. 2005) and a number of helminths, arthropods and protozoan parasites were reported. In wild conditions, animals have some natural resistance against parasitic diseases and there is a state of equilibrium between the parasite and the host and it seldom led to harmful infection unless stressed (Gaur et al. 1979; Mir et al. 2016). In India, studies to assess helminth fauna of wild animals under captivity were carried out in a systematic way but the literature on the parasitic infections of free ranging wild animals is very scanty because of the difficulty in collection of fresh samples from these free ranging wild animals. The samples collected during postmortem cases may contribute in a better understanding of parasitic load as well as pathology caused by them to formulate different strategies in the control of different parasitic diseases.

Study area: The present study was conducted in the Department of Veterinary Pathology, Lala Lajpat Rai University of Veterinary and Animal Sciences (LUVAS), Hisar. The Hisar district of Haryana is located between 29.151 latitude, 75.721 longitude and 215.5m altitude. The climate of Hisar region is continental and it lies at the outer margins of the monsoon region, 1,600 km away from the ocean. The average maximum and minimum temperature during the month of March is 31.5°C and 16.4°C. The average annual rainfall in the district is 455 mm(Central Ground Water Board 2017).

Collection and processing of the samples: A total of 20 carcasses of Nilgai were brought to the Department

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Competing interests: The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this present article.

Ethical approval: In the present article, samples are taken from the dead carcasses of Nilgai brought to Veterinary Pathology for complete postmortem examination. Hence, it does not need any ethical approval and is not under consideration elsewhere and none of the paper's contents have been previously published.

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of Veterinary Pathology for necropsy by Wild Life Department, Hisar, from Hisar district and surrounding areas. Intestinal contents and faecal samples were collected in sterile polythene bags, properly sealed, labelled and processed for detailed routine parasitological analysis for the presence of parasitic eggs/oocysts by direct smear method and standard flotation technique using a saturated salt solution and sedimentation method.

Pathological studies: The detailed gross pathological examination was carried out and lesions were recorded. For histopathology, the representative tissue samples of intestine were collected in 10% neutral buffered formalin. After proper fixation, tissue samples were processed for histopathological examination. The tissues were properly trimmed, washed in running tap water over night, then dehydrated in ascending grades of ethanol, cleared in xylene and then embedded in paraffin wax. Sections of 4–5 µm thickness were cut using a semi-automatic rotary microtome. Thereafter, the sections were stained with haematoxylin and eosin (H&E) as per standard procedure (Luna 1968).

Results: During necropsy, the external examination of most of the carcasses showed varying degrees of traumatic injuries (9), external wounds and haemorrhages (5) along with putrefactive changes (6). Grossly, intestines revealed reddish discoloration, thickened mucosa and the presence of catarrhal exudate (Image 1). All 20 faecal samples were screened for the presence of gastrointestinal helminthsand protozoan infections. Overall the incidence of parasitic gastrointestinal tract infection was 40% (8/20). All eight cases revealed the presence of coccidian oocysts (Image 2), along with mixed infection with one or more types of helminthic eggs in two samples. All coccidian infections were found to be caused by *Eimeria* species by using sporulation technique. Among helminthic infections, *Strongyle*, *Moneizia* and *Trichuris* spp. were observed. Faecal samples showed unsporulated oocysts of *Eimeria* spp., thin double walled, smooth colourless eggs of *Strongyle* spp. containing blastomere (Image 2), eggs of *Moneizia* spp. containing a distinct pyriform apparatus (Image 3) and yellowish-brown, barrel shaped thick walled eggs of *Trichuris* spp. (Image 4) possessing a pair of polar plugs at both ends and egg mass identified by morphological characteristics. The results of faecal sample examination are presented in Table 1 and 2. Microscopic examination of intestine revealed congested mucosal and submucosal blood vessels, fusion of villi and desquamation of mucosal epithelium in focal areas (Image 5). Intestinal mucosa also revealed moderate infiltration of mononuclear cells mainly lymphocytes in the lamina propria along with different developmental stages of coccidian oocysts (Image 6).

Table 1.Incidence of parasitic infection in Blue Bull / Nilgai (N=20 faecal samples).

Oocysts/ Eggs of parasites observed	Number of samples
Coccidian oocysts (*Eimeria* spp.)	06
Mixed infection (*Eimeria*spp. + *Moneizia* spp. +*Strongyle* spp.)	01
Mixed infection (*Eimeria*spp. + *Strongyle* spp. + *Trichuris* spp.)	01
No parasitic infection	12
Total	**20**

Table 2. Semi quantitative load of parasitic eggs/oocysts in Nilgai.

	Sample	Parasitic load			
		Eimeria spp.	*Moneizia* spp.	*Strongyle* spp.	*Trichuris* spp.
1	N1	-	-	-	-
2	N2	-	-	-	-
3	N3	-	-	-	-
4	N4	-	-	-	-
5	N5	-	-	-	-
6	N6	++	++	+++	-
7	N7	-	-	-	-
8	N8	+++	-	++	+
9	N9	-	-	-	-
10	N10	-	-	-	-
11	N11	++	-	-	-
12	N12	++	-	-	-
13	N13	++	-	-	-
14	N14	+++	-	-	-
15	N15	++	-	-	-
16	N16	+	-	-	-
17	N17	-	-	-	-
18	N18	-	-	-	-
19	N19	-	-	-	-
20	N20	-	-	-	-

-—No egg/oocyst | +—Mild load | ++—Moderate load | +++—Heavy load.

Discussion: Wild animals are important reservoirs and amplifiers of emerging human and domestic animal pathogens including parasitic infections. In addition to their well-recognized zoonoses of public health significance, wildlife has gained considerable attention in recent years. Parasitic infections are quite common in wild ruminants across India (Banerjee et al. 2005). These

Image 1. Gross examination of intestine revealed congestion, haemorrhages, thickened mucosa and presence of catarrhal exudates.

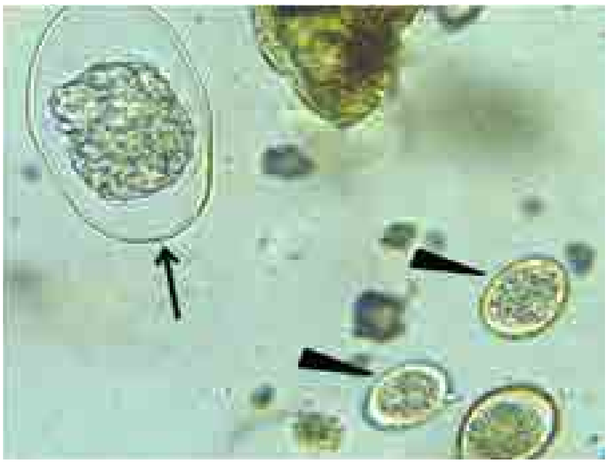

Image 2. Faecal sample showing thin double walled, smooth colourless barrel shaped egg of Strongyle spp. containing blastomere (arrow) and unsporulated oocysts of Eimeriaspp. (arrow heads). X 400.

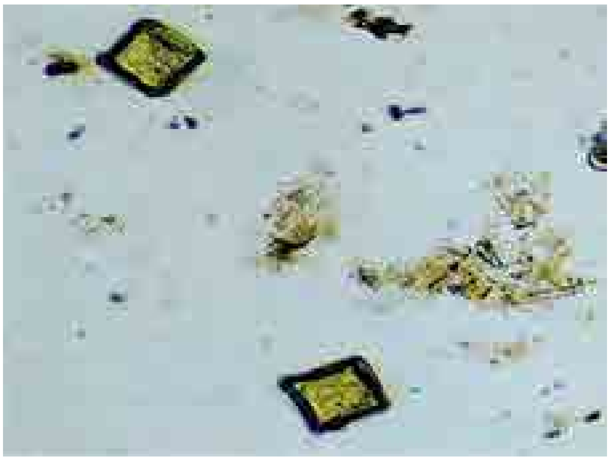

Image 3. Faecal sample showing square eggs of Moneizia spp. containing a distinct pyriform apparatus. X 400.

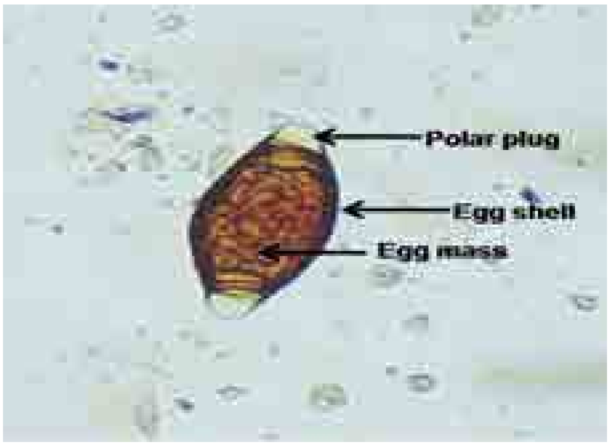

Image 4. Faecal sample showing barrel shaped thick walled eggs of Trichuris spp. possessing a pair of polar plugs at both ends and egg mass. X 400

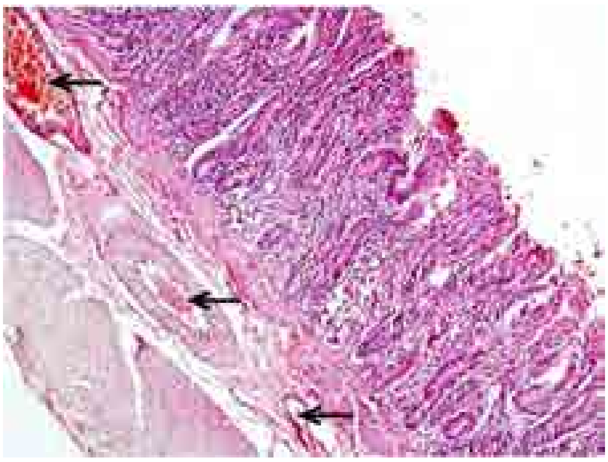

Image 5. Section of intestine showing congestion (arrows), fused villi, desquamated mucosal epithelium in focal areas and infiltration of mononuclear cells mainly lymphocytes. H&E X 100

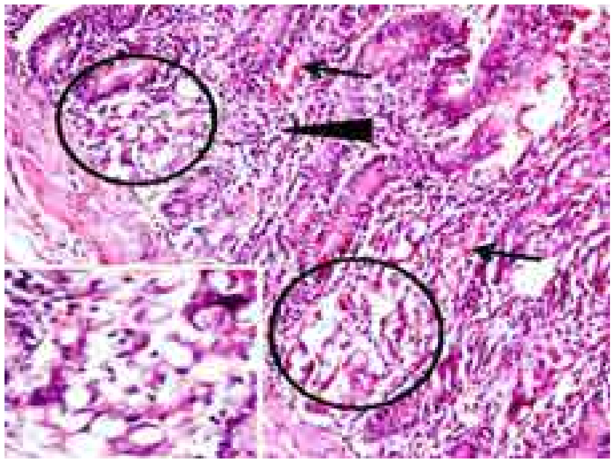

Image 6. Section of intestine showing congestion (arrow) of intestinal mucosa revealed moderate infiltration of mononuclear cells mainly lymphocytes (arrow) and different stages of developmental stages of coccidian oocysts (encircled). H&E X 400.

animals may acquire large quantums of infection while grazing that are mostly subclinical. However, sometimes the infections turn fatal for the infected animal. In the present study, most of the carcasses of Nilgai examined showed varying degrees of traumatic injuries, external wounds and haemorrhages and putrefactive changes. The main reason for the death of the animals is due to accidental injuries from vehicles on the roads and the use of barbed wires by farmers for fencing to protect agricultural land. However, this can be minimized by use of alternative methods of fencing to protect crop damage (Meena et al. 2014). The extent of injuries varied from bruises, lacerations and single to multiple fractures cases. Similar finding of varying degrees of more or less traumatic injuries caused by bullets/gunshots, infighting, automobile/train accidents, jumping/falling leading to haemorrhagic shock was also reported by Sharma et al. (2014).

As regard to parasitic infections, the morphological characteristics of the eggs of *Strongyle* spp., *Moneizia* spp., *Trichuris* spp., and coccidian oocysts was confirmed as per Soulsby (1982). Various studies of single and mixed parasitic infections in wild animals has also been reported by earlier researchers (Abhishek et al. 2011; Jaiswal et al. 2014). In Uttaranchal, India, 41.6% of 161 faecal samples from Nilgai were positive for single or mixed infections of *Amphistomes*, *Strongyles*, *Trichuris*, *Fasciola*, and *coccidians* (Banerjee et al. 2005). Endoparasitic fauna in wild animals and consequent detection of infection in these wild animals suggests close interactions with domestic animals (Holsback et al. 2013). Sharing of the same pasture land and water bodies like ponds by wild and domestic animals might be a potential source of infection for domestic animals. Histopathologically, intestines revealed circulatory disturbances such as congestion, enteritis and different developmental stages particularly in coccidian infected cases. Similar findings were also observed in Nilgai by other researchers (Sharma et al. 2012). In the present study, different types of mixed parasitic infections in free ranging nilgai with gross and microscopic changes in the intestinal tracts indicate that the increase in parasitic load might be due to the secondary infestation by opportunistic parasites due to decreased immune response because of stressful environmental conditions or injuries. Further, more detailed studies will be required as wild herbivores not only come into close contact with different domestic animals, but share the same pasture for grazing that might cause potential threat of interspecies transmission. This will also be of great importance for species conservation.

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NOTE

An unusual vocalization of Brown Hawk-Owl *Ninox scutulata* (Raffles, 1822) (Aves: Strigiformes: Strigidae) recorded from Kerala, India

Riju P. Nair [1] & **Shine Raj Tholkudiyil** [2]

[1,2] Wildlife Biology department, Kerala Forest Research Institute, Peechi, Kerala 680653, India..
[1] rijupnair2009@gmail.com, [2] shineraj263@gmail.com (corresponding author)

The distribution of the Brown Hawk-Owl ranges from the Himalayan foothills of northern India to the Western Ghats of southern India and in Sri Lanka (Ali & Ripley 1974; Grimmet et al. 1998). The species has a viable population in most of the protected areas of Kerala located along the southern Western Ghats, and its encounter rate is reported to be significantly higher in mid-altitude and moist deciduous forest (Jayson & Sivaram 2009). On 08 May 2020, at 2235h, we heard a very distinct and unusual call in the campus of Kerala Forest Research Institute (KFRI), Peechi, Thrissur. The campus (10.526N & 76.350E) is located on a slope of a hill ridge covered with a secondary moist deciduous forest patch near Peechi-Vazhani Wildlife Sanctuary. The call was of one-minute duration comprising of five repetitive 'kuh-hoo' phrases. Since the call was unfamiliar we recorded the call using a mobile phone.

After a gap of one month we heard a very similar call on 10 July 2020 at 2310h,this time the call was intense and more frequent than last time. We followed the call and to our surprise it was found to be produced by a pair of Brown Hawk-Owls. Since then, we heard the distinctive continuous calls of the species for the subsequent 15 days, mostly after 2230 h and more frequently during 2315h to 2345h. We photographed the vocalising bird on 11 July using a Sony DSC-HX400V camera (Image 1).

Spectrograms and measurements of the recorded calls were made using Raven Pro v. 1.6. Each phrase in a call bout comprised of about 8–11 notes (Image 2b) spanning about 0.5 seconds. The centre frequency was c. 3kHz (Image 2b). The recorded call has been deposited in the Xeno-canto foundation (shineraj, XC643715 (Audio 1); shineraj, XC660215 (Audio 2))

The pair of Hawk-Owls were seen in the area at multiple times roosting in a big, old tree (*Grewia tiliifolia*), personal observation by the author before the incident. The tree being old and because of its proximity to the road it was removed on concerns of public safety. We suspect that the unusual call from the owls happened as a result of the felling of the *Grewia tiliifolia* tree which might have been their nesting site and the sudden loss of it may have caused this unusual behaviour.

The studies which focussed on the vocalization of Brown Hawk-Owl in India and other Oriental regions (Neelakantan 1979; Hutchinson et al. 2006; Babu & Jayson 2007; Jayson & Sivaram 2009; Rasmussen et al. 2012) and the information available in the public domain such as eBird and xeno-canto did not describe

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Image 1. Brown Hawk-Owl *Ninox scutulata* at KFRI campus, Thrissur district, Kerala.

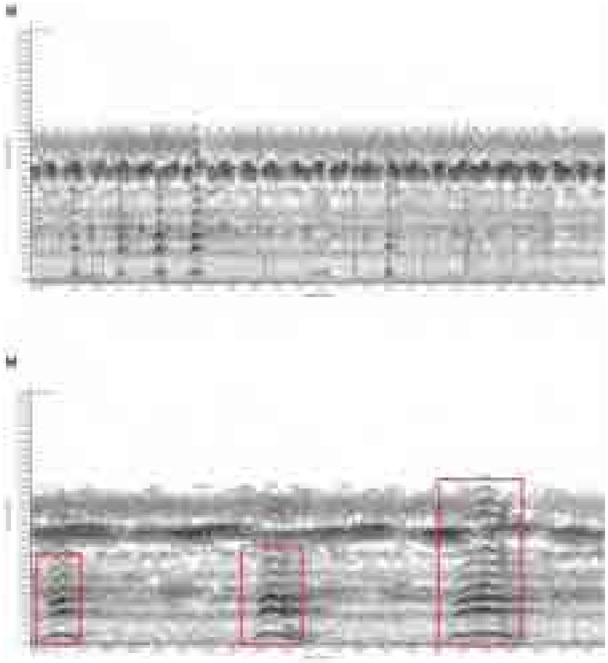

Image 2. Spectrograms of the unusual call of Brown Hawk-Owl recorded at Kerala Forest Research Institute, Peechi: a—25 seconds spectrogram showing the frequency of the call phrases | b—7 seconds spectrograms of the call with three phrases, each marked by a red box.

the peculiar vocalisation illustrated here which seems to be a new addition to the existing recorded vocalisation of the species.

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Xeno-canto Foundation: shineraj, XC660215. Accessible at www.xeno-canto.org/643715

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NOTE

New distribution data on the genus *Maripanthus* Maddison, 2020 (Araneae: Salticidae) from southern India

A. Asima [1], John T.D. Caleb [2], Dhruv A. Prajapati [3] & G. Prasad [4]

[1,4] Department of Zoology, University of Kerala, Kariavatom, Thiruvananthapuram, Kerala 695581, India.
[2] Division of Biodiversity, Entomology Research Institute, Loyola College (Autonomous), Chennai 600034, Tamil Nadu, India.
[3] GEER Foundation, Indroda Nature Park, Gandhinagar, Gujarat 382007, India.
[1] asimaashrafkh15@gmail.com, [2]caleb87woodgate@gmail.com, [3]dhruvspidy215@gmail.com
[4] probios1@gmail.com (corresponding author)

Jumping spiders belonging to the tribe Baviini Simon, 1901 are confined to the Asian tropics. They are arboreal and are characterized by their elongate bodies (Maddison 2015; Maddison et al. 2020). The tribe Baviini in India is represented by four genera (*Indopadilla* Caleb & Sankaran, 2019; *Maripanthus* Maddison, 2020; *Padillothorax* Simon, 1901; *Piranthus* Thorell, 1895) and eight species (Maddison et al. 2020; Caleb et al. 2021, World Spider Catalog 2021). The genus *Maripanthus* was recently established by Maddison (Maddison et al. 2020) with six species from the Oriental region, of which two species *Maripanthus gloria* Caleb, 2021 and *M. jubatus* Maddison, 2020 are known from India (Caleb & Sankaran 2021; World Spider Catalog 2021). The present paper deals with the additional distributional records of *M. gloria* and *M. jubatus* from southern India.

Materials and Methods: Specimens were hand collected and preserved in 70% alcohol. They were later examined and photographed by the Leica S8APO stereomicroscope. All images were then processed with the aid of Leica version 4.2 software. The female epigyne was dissected, cleared in 10% KOH and mounted on a temporary slide and observed under an Olympus CX31 compound microscope. Male left palp was removed and photographed. The studied specimens are deposited in the reference section of museum of the Department of Zoology, University of Kerala, Kariavattom, India (KUDZEN) and GEER Foundation, Indroda Nature Park, Gandhinagar, Gujarat, India (GEER).

Species account

***Maripanthus* Maddison, 2020**

Type species: *Maripanthus draconis* Maddison, 2020

Comments: Currently the distribution of the genus in India seems to be restricted to the southwestern part. Upon systematic sampling more species may be expected.

***Maripanthus gloria* Caleb, 2021**

Images 1–2, 4–7

Maripanthus gloria Caleb, in Caleb, Francis & Bhat, 2021: 201, figs. 1-20

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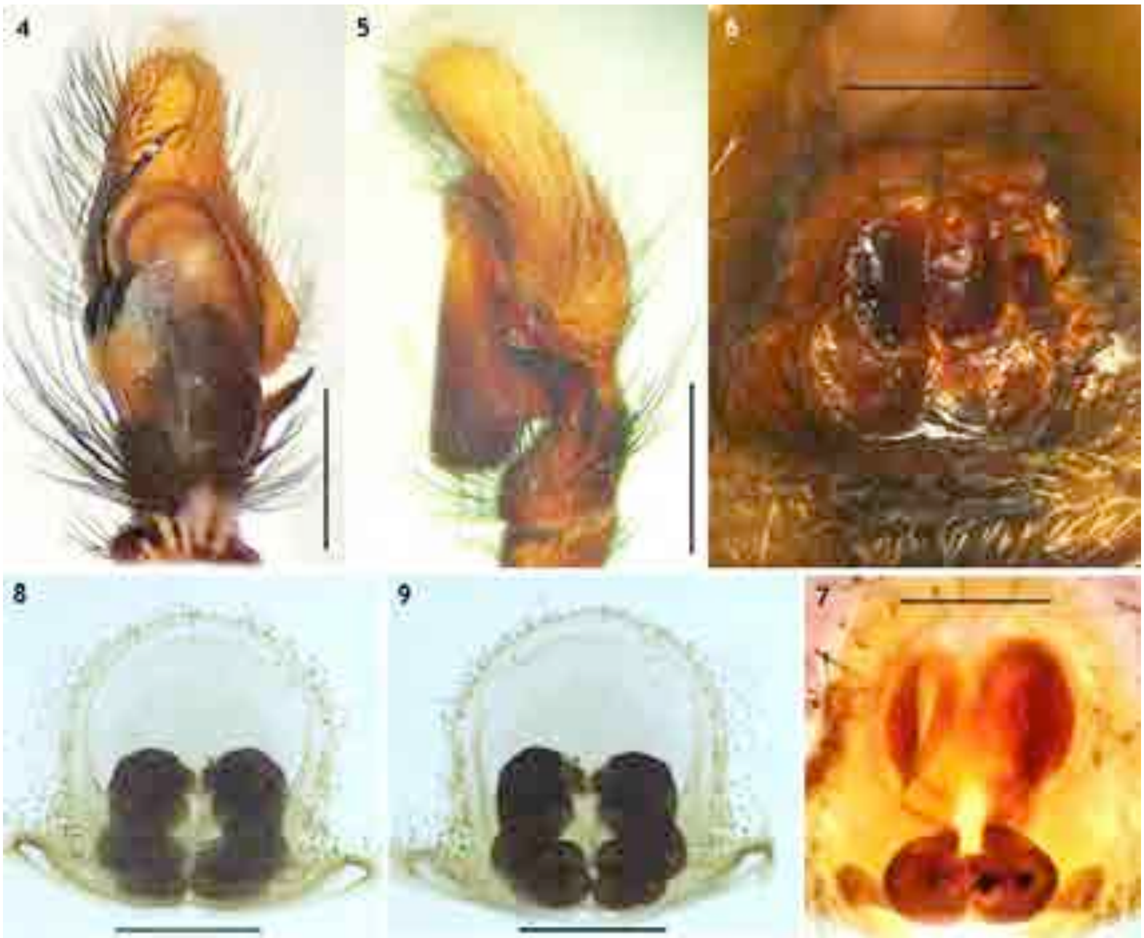
Images 1–3. General habitus of *Maripanthus* species: 1—*M. gloria* male, dorsal view (KUDZEN2021.I.04a) | 2—*M. gloria*, female, dorsal view (KUDZEN2021.I.04b) | 3—*M. jubatus* female, dorsal view (GEER98315A). Scale bars: 2mm (1–3). © 1,2—A. Asima; 3—Dhruv Prajapati.



Images 4–9. Copulatory organs of *Maripanthus* species: 4—*M. gloria* male left palp, ventral view (KUDZEN2021.I.04a) | 5—same, retrolateral view | 6—female epigyne, ventral view (KUDZEN2021.I.04b) | 7—same, dorsal view | 8—*M. jubatus* (GEER98315A) female epigyne, ventral view | 9—same, dorsal view. Scale bars: 0.2mm (7), 0.4mm (6), 0.5mm (4, 5, 8, 9). © 4–7—A. Asima); 8– 9—D. Prajapati.

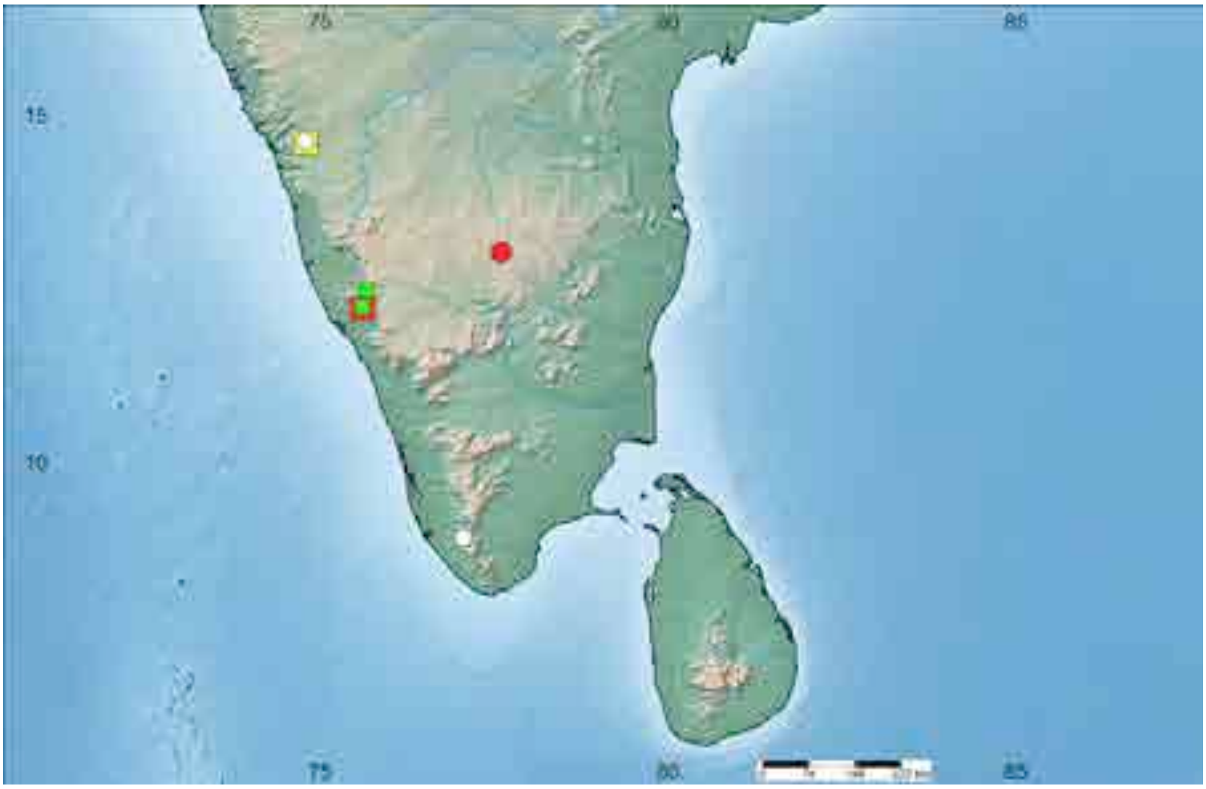


Image 10. Distribution records of *Maripanthus* species from India. Red circle indicates type locality of *M. gloria* and white circles indicate new records. Red square indicates type locality of *M. jubatus*, green squares indicate other records and yellow square indicates new record.

Material examined: 1 male (KUDZEN2021.I.04a) & 1 female (KUDZEN2021.I.04b) India, Kerala, Kulathoopuzha, Kattilappara (Myristica swamp) (8.915^{0}N, 77.102^{0}E, 149.96 m), 29.vi.2021, coll. A. Asima; 1 female (GEER98315B), India, Karnataka, Uttar Kannada, Sirsi (14.628^{0}N, 74.830^{0}E, 588 m), 21.vii.2015, coll. Prajapati D.A.

Diagnosis**:** Males of *M. gloria* are similar to those of *M. draconis* Maddison, 2020 but can be distinguished with palp having a relatively short embolus and the RTA with a broad base (Images 4, 5). Females are similar to those of *M. jubatus*, but can be distinguished in having short, simple copulatory ducts and globular spermathecae (Image 7).

Distribution: Karnataka (Caleb *et al.* 2021; present study) and Kerala (new record) (Image 10).

Maripanthus jubatus Maddison, 2020
Images 3, 8–9

Maripanthus jubatus Maddison, in Maddison et al., 2020: 76, figs. 11, 204–214

Material examined: 1 female (GEER98315A), India, Karnataka, Uttar Kannada, 16.vii.2015, Sirsi (14.611^{0}N, 74.833^{0}E, 588 m), coll. Prashanthakumara, S.M.

Diagnosis: Females of *M. jubatus* are similar to that of *M. draconis*, but can be differentiated with ECP split into a pocket on each side (Images 8, 9).

Distribution: India: Karnataka (Maddison et al. 2020; present study) (Image 10).

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NOTE

On the IUCN status of *Boesenbergia albolutea* and *B. rubrolutea* (Zingiberaceae) and typification of *B. rubrolutea*

K. Aishwarya [1] & M. Sabu [2]

[1] Department of Botany, University of Calicut, Kerala 673635, India.
[2] Malabar Botanical Garden and the Institute for Plant Sciences, Kozhikode, Kerala 673014, India.
[1] aishwaryakizhakethil12@gmail.com, [2] msabu9@gmail.com (corresponding author)

Boesenbergia albolutea (Baker) Schltr. and *B. rubrolutea* (Baker) Kuntze belong to the genus *Boesenbergia* Kuntze of the family Zingiberaceae. The genus is characterized by the two-ranked arrangement of the bracts of the inflorescence, and was originally described under the genus *Gastrochilus* Wall. But, finding *Gastrochilus* as a later homonym for an orchidaceous genus *Gastrochilus* Don (Don 1825), Kuntze (1891) proposed the new name *Boesenbergia*. Subsequently, the genus was treated by various authors, viz., Baker (1890) for British India, Schumann (1904) for Borneo and Sumatra, Gagnepain (1908) for Indochina, Valeton (1918) for Java and Malaysia, Ridley (1907, 1924) and Holttum (1950) for the Malay Peninsula, Das & Sikdar (1982) for India and Sirirugsa (1992) for Thailand. In India, the genus is represented by 10 species (Aishwarya 2017) including a new species (*B. meghalayensis* Aishwarya & M.Sabu) recently described (Aishwarya et al. 2015).

B. albolutea and B. rubrolutea are less explored species of the genus *Boesenbergia*. They were originally described under *Gastrochilus*, as *G. albolutens* (Baker 1894) and *G. rubrolutea* (Baker 1890), respectively. Later, once the genus *Boesenbergia* was established, Schlechter (1913) and Kuntze (1891) brought the new combinations of these two species as *B. albolutea* and *B. rubrolutea*, respectively.

Relevant literature and herbaria related to the species under study were thoroughly studied. The various herbaria consulted in India include CAL, MH, ASSAM, BSHC, CAL, CALI & DD (Thiers (2020 continuously updated)). In addition, digital database of world herbaria like BM, E, K, KEP, LINN, LIV, MO, NY, PBL, SING & W (Thiers (2020 continuously updated)) were also accessed.

The IUCN statuses of these species have been evaluated against IUCN Red List Categories and Criteria Version 14 (IUCN 2019) based on repeated field visits for the past 30 years and herbaria reference.

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Competing interests: The authors declare no competing interests.

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A revision on the genus shows that the species *B. albolutea* and *B. rubrolutea* are extinct in the wild (IUCN 2019). This is based on the observation that there has been no report of these species after type collection [*B. albolutea* from England (originally from Andaman; flowering condition from England) and *B. rubrolutea* from Meghalaya]. Besides, the field explorations conducted by the senior author over 30 years throughout India including Andaman & Nicobar Islands as part of the taxonomic revision of the family Zingiberaceae in India, could not spot even a single specimen of these species in the field. A thorough search of various herbaria also could not find any specimen added after the type collection.

Moreover, Jain & Prakash (1995) reported the species, *B. rubrolutea* as endemic to Meghalaya and as endangered by commenting on the endangered species of Zingiberaceae as "confined to very small areas of one state and facing immediate danger of extinction, these species need urgent conservation." The present study also tried to locate further collections of these species, however failed to find any. Based on all these, the present study recommends assigning these species under the IUCN Red List category, 'Extinct in the Wild' (EW) (IUCN 2019).

The study also shows that the type *B. rubrolutea* is not yet designated. Consequently, after studying the literature and herbaria deposition of the species in detail, the lectotype is being designated here.

Taxonomic Treatment

1. *Boesenbergia albolutea* (Baker) Schltr., Repert. Spec. Nov. Regni Veg. 12: 315. 1913; C.R. Das & Sikdar, Bull. Bot. Soc. Bengal 36: 41. 1982. ≡*Gastrochilus albolutens* Baker, Gard. Chron. 2: 34. 1894.

Type: England, London, Kew Gardens, 26 June 1894, s.c. s.n. (holotype, K; K000640518 image!).

(Image 1A)

Notes: In the protologue, Baker (1894), while describing the species, noted that the plant was to be collected by Mr. Mann from Andamans and sent to Kew in 1889, where it flowered and was identified and described as a new species. As this is the only specimen mentioned in the protologue of the species, it is the holotype.

Distribution: Endemic to Andaman Islands.

Recommended IUCN Red List Status: Extinct in the wild (EW) (IUCN 2019).

2. *Boesenbergia rubrolutea* (Baker) Kuntze, Rev. Gen. Pl. 2:685. 1891; Schltr., Repert. Spec. Nov. Regni Veg.12: 316. 1913; C.R. Das & Sikdar, Bull. Bot. Soc. Bengal 36: 44. 1982. ≡*Gastrochilus rubrolutea* Baker in Hook.f., Fl. Brit. India 6: 218. 1890.

Type: India, Meghalaya, Khasi Hills, Thera, 10 October 1886, C.B. Clarke 44985 A (lecto, K; K000640511image! designated here); ibid., C.B. Clarke 44985 B (isolecto, K; K000640512!). (Image 1B)

Notes: In the protologue, the specimen/specimens mentioned by Baker (1890) is the collection/collections by 'J.D.H. & T.T., Clarke' from Khasi Hills. Herbarium sheets of two specimens that were collected by C.B. Clarke are now housed at K (Thiers (2020 continuously updated)), viz., 44985 A & 44985 B. Out of these, following Articles 9.3, 9.12 and 9A.3 of ICN (Turland et al. 2018), 44985 A' is selected here as the lectotype of B. rubrolutea because this sheet depicts the details of the species, especially the spike, with better clarity compared to the other. Moreover, the herbarium label in it bears a sketch and a brief description of the anther, labellum and corolla segments of the species. No other collection of this species could be located anywhere else.

Distribution**:** *B. rubrolutea* is endemic to Meghalaya. Das & Sikdar (1982) noted that *B. rubrolutea* is not represented even by a single specimen at CAL. They added, "on the basis of two localities mentioned in Meghalaya, it is assumed that this species is restricted to Meghalaya, and therefore may be taken as endemic".

Recommended IUCN Red List status: Extinct in the wild (EW).

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NOTE

New records of mass seeding *Cephalostachyum latifolium* Munro (Poaceae) along the mid-elevation broadleaved forest of Sarpang district, Bhutan

Jigme Tenzin [1], Sangay Nidup [2] & Dago Dorji [3]

[1] Research and Information Unit, Divisional Forest Office, Sarpang, Department of Forests and Park Services, Ministry of Agriculture & Forests, 31002, Bhutan.

[2,3] Gelephu Forest Range Office, Divisional Forest Office, Sarpang, Department of Forests and Park Services, Ministry of Agriculture & Forests, 31101, Bhutan.

[1] jigmetenzin16@gmail.com (corresponding author), [2] sanzellsom@gmail.com, [3] ddorjee@moaf.gov.bt

Bamboo are plietesial plants which can typically grow as even-aged cohort for some time and in their final year of life, flower gregariously, set seed, and then die (Wright et al. 2014). According to Vorontsova et al. (2016), there are over 1,642 species of bamboo that belongs to about 88 genera of woody bamboos in the world. Out of that, Bhutan has recorded 15 genera and 31 species of bamboo (Noltie 2000), currently 32 species after the new record of *Bambusa pallida* by Dorjee et al. (2020). Among them, 17 species belonging to nine genera are found within the broadleaved forest of Sarpang district (Tenzin 2015). In fact, bamboo species flower once in their life and die after mass seeding (Wright et al. 2014). Flowering can be categorized into three major groups: annual, sporadic or irregular and gregarious flowering (Brandis 1899). This event appears in a cyclic pattern within the interval of 10 to 120 years (Ramanayake 2006) or 20 to 120 years (Thapliyal et al. 2015) depending on the species and genera.

According to Namgyel (2017), first oral account of sub-tropical bamboo flowered in Bhutan was recorded around 1963 in Kerabari, Woma & Sama villages in Kalikhola under Dagana district by Mr. Chenkyab Dorji (Forest Ranger at that time), former Minister of Planning Commission in Bhutan. Later, Samtse district has recorded mass seeding of *Dendrocalamus sikkimensis* in 1985 to 1986 and *Melocanna baccifera* in 2007 (Wright et al. 2014). While, temperate bamboo species such as *Sinarundinaria falcata*, *Thamnocalamus falconeri*, and *Thamnocalamus spathiflora* were also seeded around 2001 & 2002 and 2004 & 2005 in western part of the Bhutan (Wright et al. 2014). In sub-alpine region, similar mass seeding has been reported for *Borinda grossa* at Sakteng under Trashigang district in 2005; *Thamnocalamus spathiflorus* along Pelela-Yotongla passes in 2008 and *Yushania microphylla* at Lawala under Wangdue districts in 2011 (Wangda et al. 2011; Namgyel 2017). Likewise, mast seeding of *Melecanna beccifera* were also been reported in the lowland forest of Bajali in Indo-Burma hotspot region in 2008 (Sarma et al. 2010)

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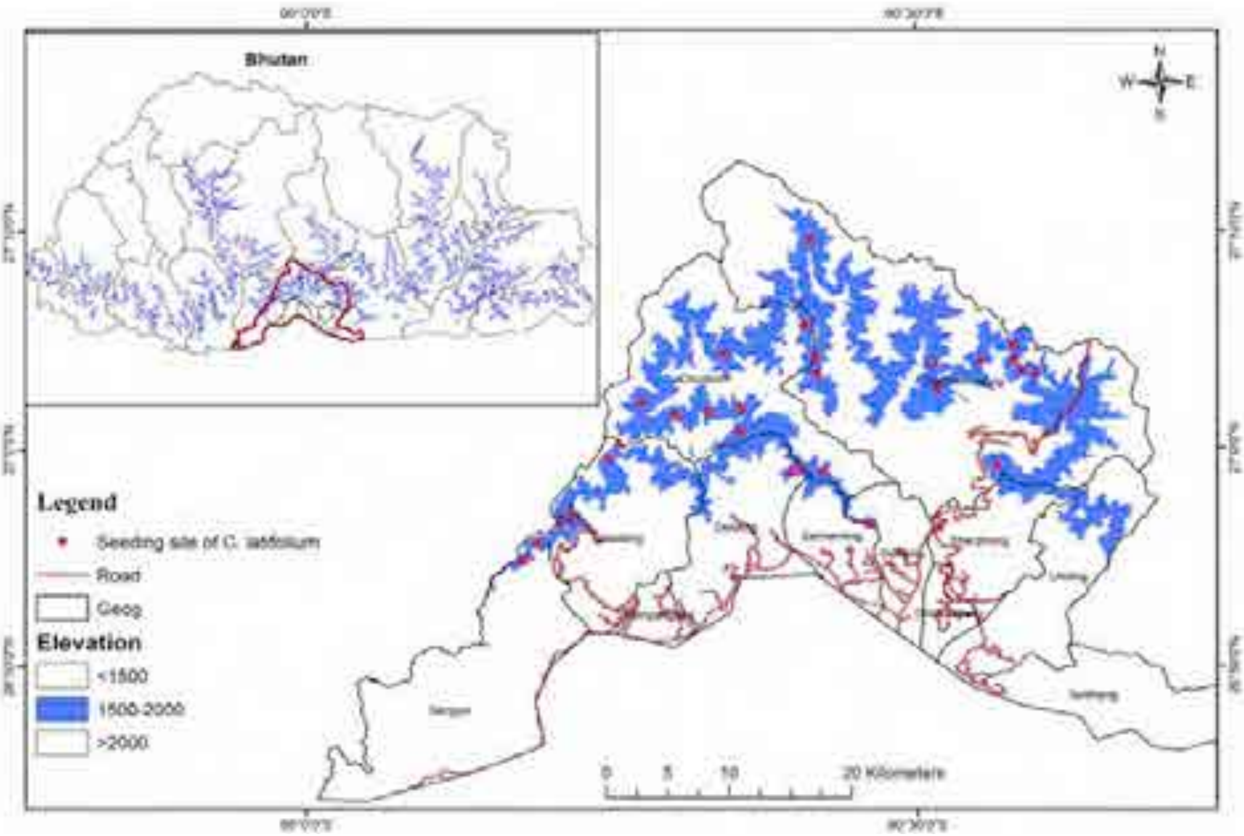

Figure 1. Mass seeding of *Cephalostachyum latifolium* under Sarpang District, Bhutan.

and neighboring northeastern India and Bangladesh in 2010 (Belmain et al. 2010; Wright et al. 2014). Till date, *Melecanna bambusoides* was the first bamboo species been recorded to be flowered in Mizoram under North east state, India in 1815 (Thapliyal et al. 2015). Perhaps this could be the first starting milestone ever tracked by the scientific literature till date within the range countries. Meanwhile, recent record of gregarious and mass seeding of *Cephalostachyum latifolium* bamboo species from the mid-elevation broadleaved forest of Sarpang district in Bhutan has added another new records to bamboo science in the February of 2017 (Image 1).

C. latifolium is locally known as 'Jhi' (Dzongkha), 'Pishima' (Kengkha), and 'Ghopi bans' (Nepali) that belongs to *Cephalostachyum* genera (Image 1). Globally, it is distributed across Bangladesh, China, India, Myanmar, and Nepal including Bhutan. However, Bhutan till date has recorded only two *Cephalostachyum* species (*C. latifolium & C. capitatum*) (Noltie 2000). *C. latifolium* is distributed along Phuntsholing and Gelephu under Chukha and Sarpang within the elevation range of 1,500 to 2,000 m (Noltie 2000). Taxonomically, Noltie (2000) reported that it is a broadleaved bamboo, which can grow up to 15 m height with the diameter of 5 cm. Culm sheaths has 50 cm with ridges, edges membranous, and raised shoulders. While, leaf sheath shoulder are raised, oral setae long, long ligules with glabrous and blade broad ranging 7 x 35 cm. Inflorescence are compounded with unilateral and becoming sub-globular with orange cylindrical shape spikelet.

In Bhutan, gregarious flowering of *C. latifolium* has been recorded from Dorokha in Samtse towards the extreme west, Gedu regions in Chukha and Narphung in Samdrup Jongkhar district including Sarpang (Sangay Dorjee, Samdrup Jongkhar Forest Division, DoFPS, pers. comm.) within the mid-elevation of 1,500–2,000 m (Figure 1). While, in case of Sarpang district, gregarious flowering and seeding were recorded from the different areas under five gewogs (sub-district administration): Darachu and Pathiwara in Gakidling; Dawnidhap and ridges of Sherubling under Chudzom; Ranibagan top in Dekiling; Labarbotry top in Sengye; and Ashiney, Samkhara top, Ghopidara and Lampokhari in Jigmecholing gewog (Figure 1). Dorjee (2019) has also recorded gregarious and mass seeding of same bamboo

Image 1. A—Clump of *Cephalostachyum latifolium* species |B—Flowers | C—Seeds. © Jigme Tenzin.

species in 2017 from undulated patches of Lemtsorong and Shekpashing at 26.950°N & 91.546°E extending towards 26.952°N & 91.958°E in Narphung under Samdrup Jongkhar Forest Division (eastern Bhutan). This suggested that the entire *C. latifolium* species which were grown within these elevation ranges (1,500–2,000 m) might have flowered and seeded across Bhutan. With this bamboo species, Bhutan has recorded a total of eight bamboo species have flowered till date (until 2020), while, 35 bamboo species have been reported to be flowered till 2015 in India ever since the early 19th century (Thapliyal et al. 2015).

According to Wang et al. (2016), gregarious and mast seeding explodes rodent population and induces food scarcity. Exactly in these gregarious years, Bhutan Broadcasting Services (BBS) and Kuensel both reported the ravages of maize by rodents in Largyab gewog in Dagana & Patsaling in Tsirang district (16 October 2018 in BBS) and paddy in Chudzom and Gongduegang in Jigmecholing gewog under Sarpang district in Bhutan (10 November 2018 in Kuensel). Similar ecological havoc (famine and food security issues) has been widely reported aftermath of gregarious flowering in northeastern states of India in 1929 and 1959, particularly in Mizoram, India (Goraya et al. 2003; Namgyel 2017). Nonetheless, gregarious and mass seeding of bamboo plants means that local people lose their raw materials for building, fencing, and other economic uses (Wangda et al. 2011). Further, studies also report that mass seeding leads to the explosion of numerous bird species and rodents in cases of India (Wright et el. 2014), while wild pigs, rats, squirrel, and bears in case of Bhutan (Namgyel 2017) that induced famine and human-wildlife interactions. Therefore, gregarious and mass seeding has immense social, economic, and ecological implications to the communities. Thus, research associated to ecology of gregarious flowered bamboo species, bamboo phenology, and socio-economic implication of gregarious flowering of bamboo species requires in-depth study in context to Bhutan by the research institute (UWICER) under Department of Forests and Park Services (DoFPS) in collaboration with Department of Agriculture (DoA) to manage and mitigate the future ecological havoc related gregarious flowering in Bhutan.

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RESPONSE

If habitat heterogeneity is effective for conservation of butterflies in urban landscapes of Delhi, India?' Unethical publication based on data manipulation

Sanjay Keshari Das [1] & Rita Singh [2]

[1,2] University School of Environment Management, Guru Gobind Singh Indraprastha University, Sector-16C, Dwarka, New Delhi 110078, India.
[1] skdasipu@gmail.com (corresponding author), [2] ritasingh@ipu.ac.in

Paul & Sultana (2021) published a paper on effectiveness of habitat heterogeneity for conservation of butterflies in urban landscapes of Delhi based on field sampling carried out in 2015–2017. Though the work presented in the paper is part of the Ph.D. Thesis work of the first author supervised by Das, S.K. and Singh, R. (Paul 2019), we found serious data manipulation of the data embodied in the Thesis (after award of the degree) to bring out the publication. Since our University name is tagged with the publication and the original work is from our lab only, we highlight them in the following paragraphs pointwise.

1. Paul & Sultana (2021) have distorted perception of the subject to build and test false theory with data forgery. Because, they have mentioned they have carried out sampling/assessment of nine different habitats in different urban landscapes and determined diversity indices across these habitats (Table 4) to test the hypothesis, is habitat heterogeneity effective for conservation of butterflies in urban landscapes of Delhi? In the original work these habitats were not sampled, rather transects laid across six different urban landscapes comprising sets of microhabitats were sampled (Section 3.2.4., Paul 2019) and the authors have referred those microhabitats as habitats in the paper (Section 4.2.2.1., Paul 2019). The original work is already published with another title (Paul & Sultana 2020). Hence, how they calculated diversity indices across different microhabitats (referred as habitats in the paper) for which sample size and sampling time for each microhabitat compared in the paper was not fixed?.

2. Paul & Sultana (2021) have very wisely changed the actual data collection methodology. In the original work data collection was made both from 'Pollard Walk' method between 1000 h and 1600 h (during which butterfly species, their microhabitat, and activities were recorded in selected transects) and opportunistic search (at few instances to include microhabitat information of Common Evening Brown *Melanitis leda* which were mostly sighted during dusk) (Section 3.2.4., Paul 2019), but in the paper authors have mentioned data was collected in selected transects between 1000 h and 1600 h using 'Pollard walk' method only. Moreover, in the original work 1 km transect was covered in one hour during 'Pollard walk' (Section 3.2.4., Paul 2019), but in the paper authors have mentioned 0.5–1 km transect was covered in one hour for the said sampling. Again, how they calculated diversity indices across different microhabitats (referred as habitats) based on data collected from both 'Pollard Walk' and 'opportunistic search' methods in which the later method was also not standardised across different landscapes sampled in terms of sample size and sampling time? Further, if they have sampled the nine microhabitats (referred as habitats) by Pollard walk method as mentioned in the paper, which area of Delhi they selected transect of 0.5–1 km of bird droppings? and which area of Delhi they selected transect of 0.5–1 km of artificial light in the day time between 1000 h and 1600 h? They have also misused different statistics (Shapiro-Wilk test,

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Kolmogorov-Smirnov test, ANOVA) to test these data and hypothesis (Table 5).

3. Keeping in mind 'artificial light' is not a microhabitat, in the thesis it was replaced by actual site of sighting (only a single such sighting was recorded) and hence, 'house wall' was inserted to replace artificial light. Unfortunately, even after the final editing of the thesis, by mistake 'artificial light' still continues along with 'house wall' for description of nine microhabitats (referred as habitats in the paper) of butterflies sampled during the study (Section 4.2.2.1., Paul 2019). However, in the Venn diagram for microhabitats in the thesis 'house wall' rather than 'artificial light' was mentioned (Figure 12, Paul 2019) as given below. This figure is also tampered by the authors in the paper (Figure 2).

4. Paul & Sultanas' (2021) data in Figure 2 is duplicated in Table 2 with wrong headings as second heading of Table 2 should be 'Number of butterfly species exclusively found or shared' instead of 'Number of butterfly species' because the actual number of butterfly species recorded in 'flowerbeds' and 'grass' were 31 and 19 (Table 1) instead of 6 and 4, respectively (Table 2). Further, from the data presented in Table 2, the authors have inferred that the generalists can exploit a greater number of microhabitats (referred as habitats) compared to specialists found only at selected sites without clear mentioning about which species were generalists or specialists. If they have considered that exclusively found species in particular microhabitats (referred as habitats in the paper) like 'flowerbeds' and 'grass' as specialists, then it is their misinterpretation of data from ecological point of view as 'grass' was present in all and 'flowerbeds' in 50% of urban landscapes (Table 3) in which they have laid transects for sampling. Also, the authors in third paragraph, Results section of the paper have mentioned that flowerbeds alone carry 15% of the total microhabitat (referred as habitats) share (Table 2), followed by grasses with 10%, while 2.5% was observed overlapping among various microhabitats. What is the actual % overlapping among various microhabitats (referred as habitats)? In the following lines, the authors have further mentioned *Melanitis leda* (rice crop pest) is the single candidate for the artificial light source, having 2.5% of the independent share, which accidentally got noticed during another type of field study at dusk. How they calculated % independent share of this species and what was another type of field study?

5. The authors have not included the microhabitat (referred as habitats) preference of butterflies discussed in the original study (Section 4.2.2.1., 5.2.2.1., Paul 2019) in the paper (Paul & Sultana 2021). In the thesis it is clearly mentioned that 31% sightings was for flowerbeds followed by hedges/crops/bushes (29%) and grasses (13%) that reflects microhabitat preference in terms of number of sightings rather than number of species. Further, the authors in second paragraph, Discussion section of the paper have mentioned that Northern ridge being a city forest also share the similar kind of environment as of Aravalli Biodiversity Park but due to human encroachment and trespassing, flowerbeds were missing (Paul & Sultana 2021). Such statements are confusing as a particular microhabitat (referred as habitat) may be missed out in a randomly selected transect in a particular urban landscape, but it does not mean it is absent in that entire landscape. In the same paragraph they have also mentioned two important statements related to COVID-19. First, with the outbreak of COVID-19, as the sky and air are getting unadulterated by the automobile pollutants, there are chances for the more specialist species to cope with the changing environment. Second, with further division of COVID-19 hotspot zones into red, orange, and green zones the chances of reviving city butterfly increases manifold. If the statements are a mere speculation by the authors or there is any scientific base on which authors have stated this?.

The above mentioned comments on the paper (Paul & Sultana 2021) clearly indicates academic misconduct by the authors in the form of data manipulation and fabrication. Also, unethical publication destroying academic integrity. The first author of the paper has carried out Ph.D. work under our supervision using our lab facilities and funding by our University, for which we had spent valuable time of our life for the entire period of her Ph.D. research work starting from conceptualization of work, research design, arranging necessary outside facilities including official permission from IARI to help in the research work, data analysis, interpretation of result, evaluating every six monthly progress report, assistance in drafting, writing, proof-reading, editing, and finalization of the thesis. Though the student has acknowledged the contribution of the guides in the Acknowledgement section of the thesis (Paul 2019), but after award of the degree she has published papers (Paul & Sultana 2020, 2021) from her Ph.D. work not only without the names of her supervisors, but also without acknowledging them in those papers for their contribution. Further, though the hard copy of the thesis submitted by the student bears the copy right of Guru Gobind Singh Indraprastha University, the student has given second authorship to a project scientist of another reputed University in the said publications

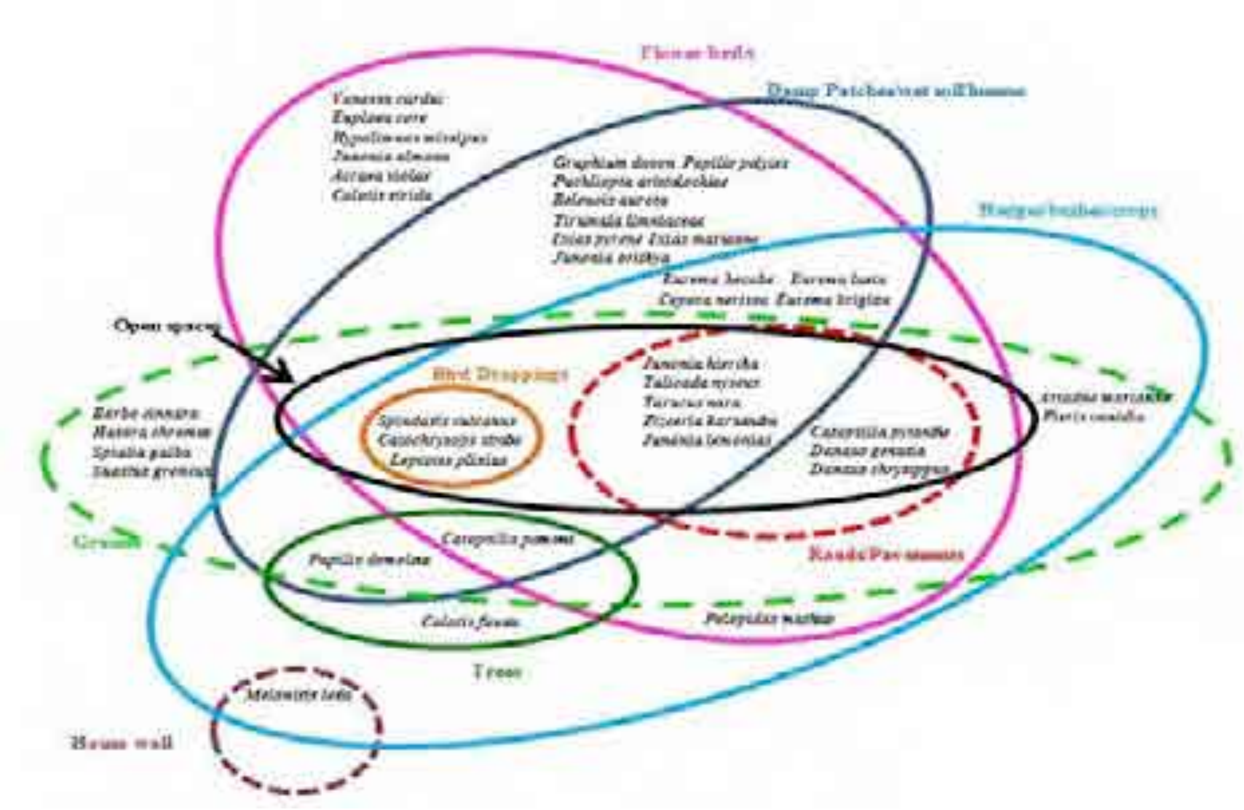

Figure 1. Microhabitats recorded for butterflies (Source: Figure 12, Paul 2019)

without permission from the University. As per our knowledge no help was taken from the second author for the Ph.D. work, except for official permission from the scientist-in-charge, Aravalli Biodiversity Park to carry out sampling in that Park, where the second author works. We want to know, in what capacity the second author was associated with the Ph.D. research work of the first author? And how has the second author really conceptualized the work, assisted in data analysis, and interpretation of result in the publication as mentioned in author contribution of Paul & Sultana (2021)?

According to guidance document prescribed by UGC for good academic research practices (Patwardhan et al. 2020), while it is vital to maintain high research quality, it is also important that research is conducted in a culture that supports honesty and integrity to ensure the highest standards of ethical practice and behaviour. Since, in the publication by Paul & Sultana (2021) our University name is tagged, we are herewith just expecting honest reply from the authors on the above mentioned comments.

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ravi@threatenedtaxa.org

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