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Cover: *Pipistrellus tenuis* recorded during the small mammalian fauna study, Manipur, India. © Uttam Saikia.

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ARTICLE

Diversity, distribution, and abundance status of small mammalian fauna (Chiroptera: Rodentia: Eulipotyphla) of Manipur, India

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Abstract: The three mammalian orders Chiroptera, Rodentia, and Eulipotyphla constitute the bulk of small mammalian species. In spite of their diversity, numerical preponderance, and widespread distribution, they are the least explored mammals with serious information gap on the diversity and distribution especially in the context of northeastern India. To partially fill this crucial information gap, we conducted two extensive field surveys covering nine districts of Manipur state during 2019 and 2021 resulting in the collection of 62 examples of these groups. Besides, 12 additional examples of bats and shrews from Manipur deposited at the North Eastern Regional Centre (NERC) of ZSI, Shillong and two specimens of rodents deposited in Manipur University in recent times were also examined. Based on these voucher records and field evidences, we report the presence of 38 species of small mammals from the state including 27 species of bats, 10 species of rodents and one species of shrew. Out of these, 12 species of bats have been recorded for the first time from the state. It is expected that the present inventory will expand with further surveys as fossorial rodents and shrews were not adequately sampled during the present studies.

Keywords: Bats, conservation, inventory, mammal, new records, rodents.

Manipuri: [illegible](Chiroptera), [illegible](Rodentia) [illegible](Eulipotyphla) [illegible] (Z.S.I) [illegible](Rodent) [illegible](Shrew) [illegible]

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Author details: Uttam Saikia is a scientist-D whose research interest lies in the systematics of the bat fauna of India with special reference to northeastern India. A.B. Meetei is working as assistant zoologist who is interested in the diversity and distribution of reptilian fauna in the northeastern region of India.

Author contributions: US and ABM conducted the field surveys. US identified the specimens, catalogued and wrote the manuscript. Both have finalized and approved the manuscript.

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INTRODUCTION

Small mammals are a group of mammals with 'small' body size and comprise about 90 percent of the living global mammal species (Lidicker 2011). Although there is no accepted definition of the term 'small mammal', it generally denotes the relatively smaller sized mammalian species comprising the orders Chiroptera, Rodentia, Eulipotyphla, Scandentia, and smaller members of the order Carnivora. For example, the mean body mass of all rodents, shrews and tree shrews are less than 1,000 g (https://small-mammals.org) while over 70 percent of the extant bat species weigh less than 30 g (Giannini et al. 2012). Commensurate with their overwhelming dominance, numerical preponderance, and cosmopolitan distribution, small mammals exert very significant influence on ecology and human economy in the form of sustaining a prey base for higher carnivores, seed dispersal, pollination services, seed predation, and energy & nutrient cycling. For example, more than 500 species of tropical plants are pollinated by nectar and pollen eating bats (Fleming et al. 2009). Similarly, rodents are found to provide important intermediate ecosystem services, but also disservices in agricultural landscapes (Tschumi et al. 2018).

However, small mammals as a group are lesser studied compared to their more charismatic larger cousins. This is also reflected from the fact that lesser numbers of studies pertaining to small mammalian fauna were published in leading global conservation journals especially from the Oriental region (Amori & Gippoliti 2000). Their diminutive appearance, often nocturnal and cryptic nature does not attract much attention of zoologists. This is especially true in the context of northeastern India where the vital diversity and distribution information for this group is scant at best. Except for the order Chiroptera which has been relatively well documented in Meghalaya state (Saikia et al. 2018, 2021), information is largely inadequate for all other northeastern states. Predictably, Manipur is one such state where there is no recent information on the diversity and abundance of small mammalian fauna. The latest documentation on the mammalian fauna of Manipur enlists at least 42 species belonging to the small mammalian orders, e.g., Rodentia, Eulipotyphla, and Chiroptera (Mandal et al. 2005). However, a majority of these species records were based on past reports and no recent field surveys have been conducted. Such information gap has also significant conservation implication as it critically undermines our efforts in biodiversity conservation. In this backdrop, the present work was undertaken to generate fresh data on the selected groups of small mammalian fauna of the state.

Review of literature

Most of the publications pertaining to the small mammalian fauna of Manipur state are old and new studies on this group in the state is far and few. One of the most important faunal works on this group from Manipur belongs to Roonwal (1950) who reported all the murid rodent species known from Manipur at that time. Some of the other notable works on this group includes Mandal et al. (1993, 1994). In their compilation on the mammalian fauna of the state, Mandal et al. (2005) mentioned at least 42 species under the three small mammalian orders albeit mostly based on secondary information. Singh et al. (2011) provided some morphometric data and distribution records of *Berylmys manipulus*, *Bandicota bengalensis gracilis*, and *Rattus rattus* in the state. In recent times, two species of rats *Rattus norvegicus* and *R. tanezumi* were added to the rodent fauna of the state (Chingangbam et al. 2014). As part of the present study, several new records of bats from Manipur were reported (Saikia et al. 2019); however the record of *Kerivoula picta* therein was later found to be a misidentified specimen of *Myotis formosus*. Therefore, this species should be deleted from the faunal list of Manipur. Barring these aforementioned scattered literature, no recent studies exist on the diversity and status of small mammalian fauna of Manipur.

MATERIALS AND METHODS

Study area

The state of Manipur spreads between 23.83^0 to 25.68^0 N and 92.96^0 to 94.78^0 E covering an area of 22,327 km^2. The state is bordered by Nagaland to the north, Mizoram to the south, Assam to the west, and shares international border with Myanmar to the east. Geographically, the state has been divided in to a hill range running north-south abridging the Patkai and Lushai Hill range and central Imphal valley covering about 1,500 km^2. The valley also holds Loktak Lake, the largest freshwater lake in northeastern India. Major rivers like Barak, Imphal, Thoubal flows from north to south. As per the State Forest Report (2017), the state has a forest cover of over 77 percent. The state has two national parks and seven wildlife sanctuaries. Climate of the state is largely influenced by the topography of the region. The eastern lowlands along the Indo-Burma border and the western Assam Manipur border lowlands

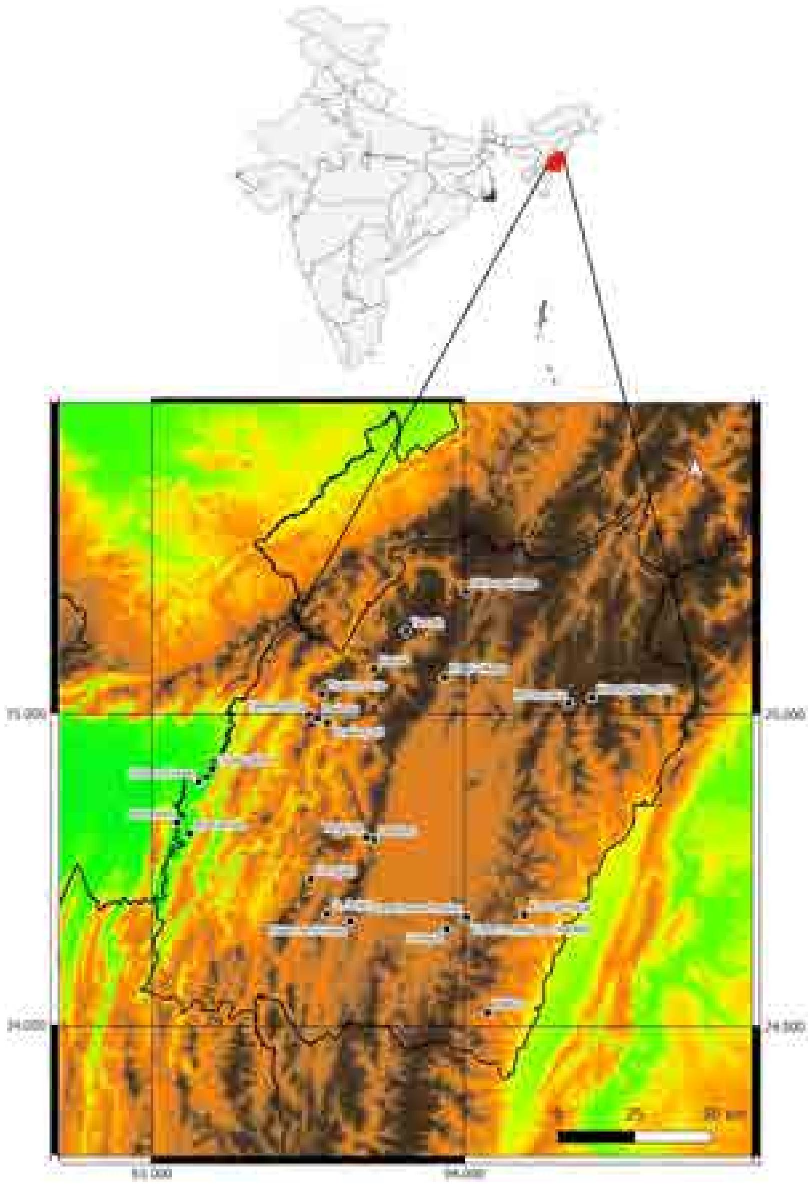

Image 1. Map of Manipur showing the survey localities (black dots).

fall between elevations 30–100 m and thus reigned by a tropical climate. The Manipur Valley at a height of 780–800 m has sub-tropical climate while the higher reaches of the mountains surrounding the valley have a temperate climate. Rainfall in this region is caused by the south westerly monsoon picking up moisture from the Bay of Bengal and heading towards the eastern Himalaya ranges (MASTEC 2022).

Field sampling

Two surveys were conducted covering nine districts in the state between 30 September 2019–18 October 2019 and 11 October 2021–26 October 2021. Due to the Covid-19 pandemic induced situation, the scheduled survey in 2020 could not be undertaken. Twenty-four localities representing a mix of dry deciduous forest, semi-evergreen forests, subtropical pine forest, caves and caverns and around human habitations were surveyed (Image 1,2; Table 1). For collecting bat samples, mist nets and a two bank harp trap was utilized whereas for rodents and shrews, several foldable Sherman traps were used. Opportunistic collections were also made inside a few of the prominent caves and from human dwellings using a collapsible butterfly net. Besides, as part of a faunal survey programme, the junior author also visited Zeilad Wildlife Sanctuary in Tamenglong district in October 2018 and collected a few bat specimens.

A total of 62 specimens of the target animal groups were collected during the aforementioned surveys. Additionally, 12 specimens of small mammals collected

Image 2. Survey localities covering various habitat types. A—Tharon Cave | B—Khangkhui Cave | C—Mixed coniferous forest at Lamdan | D—Riparian habitat at Babughat | E—Coniferous forest at Wailou | F—Semi-evergreen forest and Rice paddy at Tamah. © Uttam Saikia.

in recent times and deposited in the collections of NERC, Shillong are also included in this study. Besides, data on two specimens of rodents from Manipur identified by the first author and now deposited in the Department of Zoology, Manipur University have also been incorporated. Photographic evidence of eight species of small mammals (dead specimens or field photograph) obtained during the aforementioned surveys were also included in the study. Bat species were identified following Bates & Harrison (1997), Srinivasulu et al. (2010) except mentioned otherwise. Rodent specimens and photographs were identified following descriptions and measurements in Agrawal (2000) and Menon (2014) while the sole insectivore species was identified following Corbet & Hill (1992). The acronyms for chiropteran measurements are: Ear length (E); Tragus length (TR); Hindfoot length, including claw (HF c.u.); Forearm length (FA); Tibia length (TB); Greatest length

Table 1. List of surveyed localities in Manipur and their habitat characteristics.

	Survey locality	Habitat type
1	Borobekra, Jiribam District, (24.65333 N, 93.08108 E, 40 m)	Tropical semi-evergreen forest on the bank of river Jiri.
2	Sabughat Jiribam District, (24.82526 N, 93.1942 E, 36 m)	Tropical semi-evergreen forest on the bank of river Jiri
3	Forest adjacent to DFO Office, Jiribam District, (24.78305 N, 93.150466 E, 45m)	Deciduous forest dominated by Teak plantations.
4	Buangmun, Pherzawl District, (27.61851 N, 93.12028 E, 33 m)	Human habitation surrounded by bamboo and semi-evergreen forest.
5	Tamenglong, Tamenglong District (24.9985N, 93.50246E, 1,278 m)	Human habitation
6	Tharon cave, Tamenglong District (25.06445 N, 93.54346 E, 1,190 m)	Large limestone cave with multiple passageways.
7	Dialong village, Tamenglong District (24.98781 N, 93.52946 E, 1,350 m);	Lamtuai Kai Cave along roadside with a small watercourse inside.
8	Phalong III, Tamenglong District (24.97249 N, 93.56166 E, 1,090 m)	Human habitation dominated by bamboo forest and Jhum fields.
9	Tamei, Tamenglong District (25.14472 N, 93.70972 E, 1,100 m)	Rocky riverbank inside semi-evergreen forest.
10	Tamah, Tamenglong District (25.26499 N, 93.81305 E, 1,100 m)	Human habitation
11	Oklong village, Senapati District (25.39295 N; 94.00534 E, 1,100 m)	Human habitation
12	Haipi village, Kangpokpi district (24.96888 N, 93.49946 E, 1,150 m)	Human habitation
13	Khangkhui cave, Ukhrul District (25.05281 N, 94.40716 E, 1,690 m)	Limestone cave
14	Mova cave, Ukhrul District (25.03375 N, 94.33363 E, 1,307 m)	Limestone cave along river Lungshang.
15	Forest Complex, Chandel, Chandel District (24.34027 N, 94.00833 E, 900 m)	A forest patch dominated by *Pinus kesiya.*
16	Forest near Paralon, Chandel District (24.35111 N, 94.00500 E, 920 m)	Moist deciduous forest patch with some Pine and bamboo associations.
17	Unopat, Chandel District (24.31361 N, 93.94222 E, 1,078 m)	*Pinus kesiya* dominated forest.
18	Wailou village, Chandel District (24.04388 N, 94.07472 E, 650 m)	Deep sinkhole situated amidst semi-evergreen forest.
19	Henglep, Churchandpur District (24.47111 N, 93.50861 E, 1,200 m)	Small cave along roadside surrounded by semi-evergreen forest.
20	Lamdan, Churchandpur District (24.59916 N, 93.70777 E, 1,260 m)	Mixed Oak and conifers forest
21	Mata Lambulan, Churchandpur District (24.33805 N, 93.63555 E, 1,200 m)	Jhum field
22	Molphai, Churchandpur District (24.60583 N, 93.68527 E, 990 m)	Semi-evergreen forest
23	S. Sejol, Churchandpur District (24.36166 N, 93.56111 E, 1,080 m).	Semi-evergreen forest
24	Khongkgang, Tengnoupal District (24.35750 N, 94.19194 E, 560 m)	Semi-evergreen forest

of skull including incisors (GTLi); Condylocanine length (CCL); Maxillary toothrow length (CM^3); Width across third molars (M^3M^3); Zygomatic breadth (ZB); Postorbital constriction (POC); Breadth of braincase (BB); Length of mandible including incisors (MLi); Mandibular toothrow length (CM_3); Coronoid height (COH).

RESULTS

Based on examination of voucher specimens, 28 species of small mammals mostly bats could be recorded from the study area. Besides, another 10 species of rodents and bats were also recorded based on other evidences, i.e., field sightings, photographs of hunted animals, and field and laboratory examination of carcass (Table 2).

Species account:

Order: Chiroptera

Family: Pteropodidae

1. *Cynopterus sphinx* (Vahl, 1797)

(Greater Short-nosed Fruit bat)

Material examined: 1 male, 1 female, 07.x.2018, Zeilad WLS, Tamenglong district; 1 male, 1 male, 02.x.2019, Jiribam, Jiribam district; 1 female, 1 female, 22.x.2021, Henglep, 1 female, (released) 15.x.2021, Lamdan, Chrurchandpur district; 1 female (released), Paralon, 20.x.2021, 1 female (released), 19.x.2021, Chandel Town (Chandel district)

Locality records: Churchandpur town (940 m), Henglep (1,200 m), Lamdan (1,260 m), Churchandpur district; Uchathal (175 m), Jiribam (30 m), Jiribam district; Zeilad WS (260 m), Tamenglong town (1,280 m), Tamenglong district; Paralon (920 m), Chandel Town (900 m), Chandel district (Sinha 1999; Mandal et al. 2005; present study).

Remarks: Apparently widespread and a very common

Table 2. List of species recorded during the present study (species with asterisk indicate new records for Manipur state).

	Species	No of examples	Registration Number(s)/ remarks
Chiroptera: Pteropodidae			
1	*Cynopterus sphinx* Vahl	6	V/M/ERS/500, 501, 584, 585, 667, 675
2	*Eonycteris spelaea* (Dobson)	1	V/M/ERS/674
3	*Pteropus medius* (Temminck)	-	Field photograph
4	*Rousettus leschenaulti* (Desmarest)	-	Field photograph
Chiroptera: Hipposideridae			
5	*Hipposideros armiger* Hodgson	10	V/M/ERS/589-595, 669-671
6	**Hipposideros cineraceus* Blyth	1	V/M/ERS/672
7	**Hipposideros gentilis* Andersen	1	V/M/ERS/677
8	*Hipposideros lankadiva* Kelaart	2	V/M/ERS/432, 666
Chiroptera: Rhinolophidae			
9	**Rhinolophus affinis* Horsfield	1	V/M/ERS/610
10	**Rhinolophus lepidus* Blyth	1	V/M/ERS/613
11	**Rhinolophus perniger* Hodgson	1	V/M/ERS/581
12	**Rhinolophus macrotis* Blyth	1	V/M/ERS/614
13	*Rhinolophus sinicus* Andersen	3	V/M/ERS/453, 588, 596
14	*Rhinolophus yunanensis* Dobson	2	V/M/ERS/423, 587
Chiroptera:Megadermatidae			
15	**Lyroderma lyra* E. Geoffroy	3	V/M/ERS/573, 574, 673
Chiroptera: Vespertilionidae			
16	**Myotis annectans* (Dobson)	3	V/M/ERS/572, 582, 679
17	**Myotis formosus* Hodgson	1	V/M/ERS/502
18	*Myotis muricola* (Gray)	3	V/M/ERS/450, 583, 616
19	*Pipistrellus coromandra* (Gray)	4	V/M/ERS/503-506
20	*Pipistrellus javanicus* (Gray)	4	V/M/ERS/611, 612, 668, 681
21	*Pipistrellus tenuis* (Temminck)	11	V/M/ERS/665, 678, 680, 688-96
22	**Murina huttonii* (Peters)	1	V/M/ERS/586
23	**Murina cyclotis* Dobson	2	V/M/ERS/663, 664
24	**Mirostrellus joffrei* (Thomas)	1	V/M/ERS/676
25	*Scotophilus heathii* Horsfield	3	V/M/ERS/575-577
26	*Tylonycteris fulvida* (Blyth)	2	V/M/ERS/451, 615
Chiroptera: Miniopteridae			
27	*Miniopterus magnater* Sanborn	4	V/M/ERS/431, 578-580
Rodentia: Sciuridae			
28	*Callosciurus erythraeus* (Pallas)	-	Photograph of dead specimen
29	*Tamiops macclellandi* (Horsfield)	-	Field sightings
30	*Ratufa bicolor* (Sparrman)	-	Field sighting
Rodentia: Muruidae			
31	*Berylmys mackenziei* (Thomas)	1	Unregistered specimen deposited in Manipur University
32	*Rattus nitidus* (Hodgson)	1	Unregistered specimen deposited in Manipur University
33	*Niviventer fulvescens* (Gray)		Crushed specimen examined in the field
34	*Rattus rattus tistae* Hinton	1	V/M/ERS/696
35	*Cannomys badius* (Hodgson)	-	Photograph of dead specimen
Rodentia: Hytricidae			
36	*Hystrix brachyura* Linnaeus	-	Photograph of dead specimen
37	*Atherurus macrourus* Linnaeus	-	Photograph of dead specimen
Soricomorpha: Soricidae			
38	*Anourosorex squamipes* Milne Edwards	1	V/M/ERS/409

species throughout the state. It was mist netted both inside moist deciduous and mixed coniferous forest and also near human habitations. Most of the individuals caught during October 2021 were lactating.

2. *Eonycteris spelaea* (Dobson, 1871)

(Dawn Bat)

Material examined: 1 male, 18.x.2021, Forest Complex, Chandel, Chandel district

Locality records: Imphal (c.780 m), Imphal district; forest complex, Chandel (900 m), Chandel district (Sinha 1994; present study).

Remarks: Apparently uncommon in the state with a single record obtained in the present study. The male individual was caught in a mist net among *Pinus kesiya* forest on the way back from a foraging trip around 1830 h (seeds still in the mouth). Mandal et al. (2005) could not obtain any specimen from the state.

3. *Pteropus medius* (Temminck, 1825)

(Indian Flying Fox)

Material examined: Nil, field photograph from near Bishnupur, Bishnupur district.

Locality records: Imphal Town (780 m), Imphal district (Mandal et al. 2005); near Bishnupur town (806 m), Bishnupur district (present study).

Remarks: Unlike in many other parts of the country, this large pteropodid appears to be uncommon in the state. Previous records indicate only one locality (Imphal city) from the state. We observed a colony of >150 individuals of this species roosting in three large *Eucalyptus camaldulensis* trees along NH 2 near Bishnupur town.

4. *Rousettus leschenaulti* (Desmarest, 1820)
(Fulvous Fruit Bat)

Material examined: Nil, field photograph from Zeilad WS, Tamenglong district

Locality records: No particular locality, Imphal district; Zeilad WS (260 m), Tamenglong district; 4–5 km from S. Sejol towards Henglep (1,160 m) (Mandal et al. 2005; present study)

Remarks: Based on the lighter colour coat of the photographic specimen (as against darker grey brown in *R. amplexicaudatus*), it was provisionally identified as belonging to fulvous fruit bat. A few carcasses apparently of this species were observed entangled in nylon nets between S. Sejol and Henglep which are being used by villagers to catch wild birds.

Family: Hipposideridae

5. *Hipposideros armiger* (Hodgson, 1835)
(Great Roundleaf Bat)

Material examined: female, 05.x.2019, Dialong cave, 3 male, 1 female, 08.x.2019, Cave near Tamei, 1 male, 04.x.2019, Tharon cave (Tamenglong district); 1 female, 13.x.2019, Khangkhui cave (Ukhrul district); 3 male, 14.x.2021, Cave at S. Sejol (Churchandpur district).

Locality records: Dialong cave (1350 m), Cave near Tamei (1300 m), Tharon cave (1190 m), Tamenglong district; Khangkhui cave (1750 m), Ukhrul district; Cave at S. Sejol (1080 m), Churchandpur district; Wailou 650 (m) (Mandal et al 2005, present study)

Remarks: A widespread species especially in the hilly areas. Mostly caught inside caves and also in rocky caverns. In a rock fissure along a hill near S. Sejol village, a small group of about 10–12 individuals was found roosting with smaller populations of *Lyroderma lyra*, *Hipposideros cineraceus* and *H. gentilis*. A photographic specimen was obtained from Wailou village in Chandel district. It was caught form a deep sinkhole inside a forest and the villagers informed that a large colony of this species roost there during the drier period.

6. *Hipposideros cineraceus* Blyth, 1853
(Ashy Roundleaf Bat)

Material examined: 1 male, 14.x.2021, Cave at S. Sejol (Churchandpur district).

Locality records: Cave at S. Sejol (1080 m), Churchandpur district (present study)

Remarks: A small group of <10 were observed roosting inside a rock fissure and sharing roosting space with *H. armiger, H. gentilis* and *L. lyra*. This is the first record of this species from Manipur.

7. *Hipposideros gentilis* Andersen, 1918
(Andersen's Roundleaf Bat)

Material examined: 1 male, 14.x.2021, Cave at S. Sejol (Churchandpur district).

Locality records: Cave at S. Sejol (1080 m), Churchandpur district (present study). This is the first record of this species from Manipur.

8. *Hipposideros lankadiva* Kelaart, 1850
(Indian Roundleaf Bat)

Material examined: 1 female, 23.vi.2017, Dialong cave, Tamenglong district; male, 22.x.2021, Henglep, Churchandpur district

Locality records: Dialong cave (1350 m), Tamenglong district and Henglep (1200 m), Churchandpur district (present study)

Remarks: One specimen was collected from a shallow cave in near Dialong village which it shared with a few rhinolophids. In Henglep, several individuals were seen roosting in an underground tunnel amidst semi-evergreen forest.

Family: Rhinolophidae

9. *Rhinolophus affinis* Horsfield, 1823
(Intermediate Horseshoe Bat)

Material examined: 1 male, 05.x.2019, Dialong cave, Tamenglong district;

Locality records: Cave at Dialong (1350 m), Tamenglong district (present study).

Remarks: In a small cave along a hillside, a small colony of this species was observed with a few individuals of *R. macrotis*. This is the first record of this species from the state.

10. *Rhinolophus lepidus* Blyth, 1844
(Blyth's Horseshoe Bat)

Material examined: 1 male, 13.x.2019, Khangkhui cave, Ukhrul district

Locality records: Khangkhui cave (1690 m), Ukhrul district (present study)

Remarks: The specimen was identified based on bacular morphology following Csorba et al. (2003). The bacula is 2.9 mm length and 0.83 mm wide at the basal

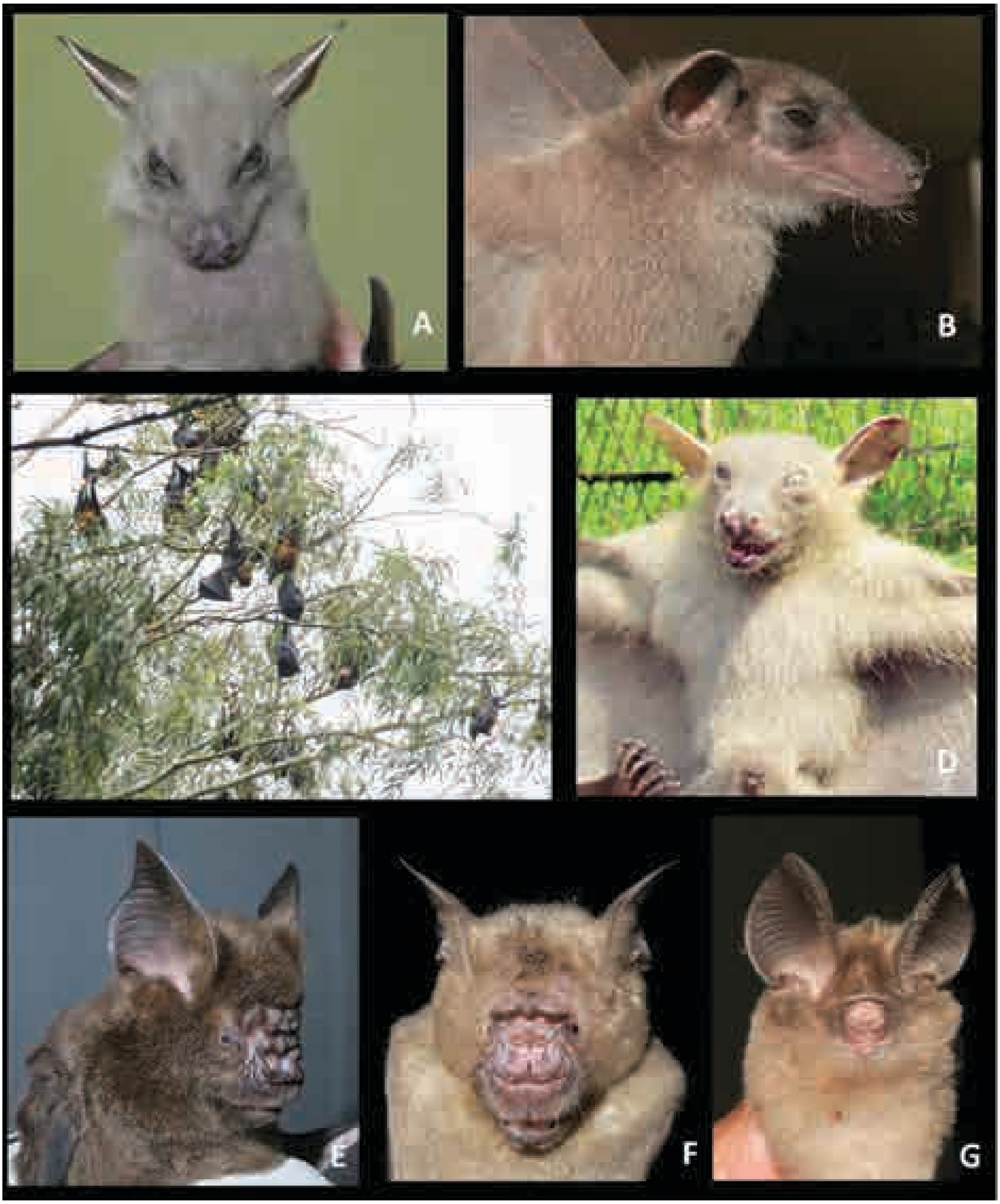

Image 3. Bat species recorded during the present study (not to scale): A—*Cynopterus sphinx* | B—*Eonycteris spelaea* | C—*Pteropus medius* | D—*Rousettus leschenaulti* | E—*Hipposideros armiger* | F—*Hipposideros lankadiva* | G—*Hipposideros gentilis*. © Uttam Saikia.

cone. In side profile, it is almost straight with a dorsal bend near the basal cone and a vetral bend near the tip. The basal cone has a wide and deep indentation on the dorsal surface.

Khangkhui is a large cave system with multiple passageways. Three species of bats were located in this cave albeit in smaller numbers, *R. perniger, R. lepidus* and *H. lankadiva*. This cave is a popular tourist destination in Ukhrul district and according to some villagers, until recent times, the cave harbored a large population of bats which were exterminated by the local authorities to make the cave tourist 'friendly'! This is the first record of *R. lepidus* from the state.

11. *Rhinolophus* cf *macrotis* Blyth, 1844
(Blyth's Horseshoe Bat)

Material examined: 1 female, 05.x.2019, cave at Dialong, Tamenglong district

Locality records: Dialong (1350 m), Tamenglong district.

Remarks: The specimen was collected from inside a small cave along the hillside and was roosting singly. The female individual was not showing any apparent sign of breeding or lactation. This is the first record of this species from Manipur.

12. *Rhinolophus perniger* Hodgson, 1843
(Northern Wooly Horseshoe Bat)

Material examined: 1 male, 13.x.2019, Khangkhui cave, Ukhrul district

Locality records: Khangkhui cave (1690 m), Ukhrul district (present study)

Remarks: One individual was shot from an inner chamber of the cave by a villager. About 10 individuals of this species were observed in the cave. This is a new record for the state.

13. *Rhinolophus sinicus* Andersen, 1905
(Chinese Horseshoe Bat)

Material examined: 1 female, 07.vi.2017, Phalang I, Tamenglong district; 2 male, 04.x.2019, Tharon cave, Tamenglong district

Locality records: Phalang I (1012 m), Tamenglong district; Tharon cave (1190 m), Tamenglong district (Saikia et al. 2019; present study)

Remarks: A lactating female was collected by a villager from a small cave in Phalang I village in early June while two male individuals were collected from Tharon cave in October. This species was recently reported from the state (Saikia et al. 2019).

14. *Rhinolophus yunanensis* Dobson, 1827
(Dobson's Horseshoe Bat)

Material examined: 1 female, 07.vi.2017, 1 female, 05.x.2019, Lamtuai Kai, Dailong, Tamenglong district

Locality records: Lamtuai Kai, Dialong (1350 m), Tamenglong district (Saikia, et al. 2019; present study)

Remarks: Two female individuals were collected from two cave sites at Dailong during June and October respectively. In one cave site, it was sharing roosting space with a few *R. affinis* while in another cave, a single individual was roosting alone. These small caves were located on the hillside surrounded by semi evergreen forest. Because of its rich biodiversity and long tradition of conservation of forests, Dialong has been declared as Biodiversity Heritage Site in Manipur by the state government. This species was recently reported from the state (Saikia et al. 2019).

Family: Megadermatidae

15. *Lyroderma lyra* E. Geoffroy, 1810
(Greater False Vampire Bat**)**

Material examined: 1 female, 1 male, 02.x.2019, Buangmun, Pherzawl district;

Locality records: Buangmun (33 m), Pherzawl district and Jiribam (30 m), Jiribam district; Ningthoukong (800 m), Bishnupur district (present study).

Remarks: Apparently a common species especially in the valley area, no specimen or roosting colony could be located in the hilly region of the state. This species was invariably observed to roost in abandoned human dwellings and call signatures were obtained around human periphery as well. Our present report constitutes the first record of this species from Manipur.

Family: Vespertilionidae

16. *Myotis annectans* (Dobson, 1871)
(Hairy-Faced Bat)

Material examined: 1 female, 1 male, 02.x.2019, Buangmun, Pherzawl district;

Locality records: 1 female, 1 male, 15.x.2019, and 1 male, 23.x.2021 Lamdan (1272 m) Churchandpur district (present study).

Remarks: This species is little known bat from India and individuals were harp trapped on two occasions in mixed Oak-conifer forest at Lamdan. It is apparently a highland species since previous Indian records are around 1000 m or above. This is the first record of this species from Manipur.

Image 4. A—*Rhinolophus perniger* | B—*Rhinolophus lepidus* | C—*Rhinolophus sinicus* | D—*Lyroderma lyra* | E—*Pipistrellus tenuis* | F—*Pipistrellus javanicus* | G—*Pipistrellus coromandra* | H—*Mirostrellus joffrei.* © Uttam Saikia.

17. *Myotis formosus* (Hodgson,1835)
(Hodgson's bat)

Material examined: 1 female, 10.v.2018, Toubal, Bishnupur district

Locality records: Only single record from Toubul (760 m), Bishnupur district (present study)

Remarks: Based on a photograph, Saikia et al. 2019 erroneously reported this specimen as *Kerivoula picta*, however, re-examination of the specimen confirmed it to be *M. formosus* which is significantly larger than the former . The specimen was collected from a cow shed on the bank of Loktak lake and surrounded by farmlands on three sides. This record constitutes first mention of this species from Manipur.

18. *Myotis muricola* (Gray, 1846)
(Nepalese whiskered bat)

Material examined: 1 female, 12.vi.2017, Phalang III, Tamenglong district; 2 female, 16.x.2019, MMTA campsite, Lamdan, Churchandpur district;

Locality records: Phalang III (728 m), Tamenglong district; Lamdan (1272 m), Churchandpuir district (Saikia et al. 2019; present study).

Remarks: In Phalang III, one individual was taken down by villagers during early evening flight by beating with a flexible bamboo stick which is a common practice in the area. In Lamdan, two individuals were captured in harp trap amidst pine forest.

19. *Pipistrellus coromandra* (Gray, 1838)
(Coromandal Pipistrelle)

Material examined: 1 male, 3 female, 04.x.2018, Ningthoukhong, Bishnupur district

Locality records: Imphal district; Ningthoukhong (770 m), Bishnupur district (Mandal et al., 2005; Present study).

Remarks: The specimens were primarily identified based on bacular morphology of the male individual. The bacula is about 4 mm long which is significantly longer than that of *P. tenuis* specimen examined (3.4 mm), has a slightly cylindrical shaft with a bifid tip and the basal portion has two deflected lobes. A primarily commensal species roosting in human periphery and also found in tree holes, under bark etc. The present specimens were collected from the attic of a house which according to the owners have been roosting for several years. Likely to be widely distributed in the state especially the valley area.

20. *Pipistrellus javanicus* (Gray, 1838)
(Javan Pipistrelle)

Material examined: 1 male, 1 female, 16.x.2019, 2 male, 23.x.2021, Lamdan, Churchandpur distirct

Locality records: "Manipur" no exact locality; Lamdan (1270 m), Churchandpur district (Bates and Harrison, 1997; Present study).

Remarks: The bacula of the male specimen is about 5.2 mm in length, has a bilobate base, the shaft is thin and the tip is sharply bifid. This matches the description of Myanmar's specimens in Bates et al (2005). The present specimens were harp trapped inside a mixed coniferous forest on two occasions and apparently common in the area. On one occasion, call signatures resembling this species were also recorded near Leimatak village (600 m) in Churchandpur district.

21. *Pipistrellus tenuis* (Temminck, 1840)
(Indian Pygmy Pipistrelle)

Material examined: 2 male, 23.x.2021, Lamdan, Churchandpur distirct; 1 male, 20.x.2021, Paralon, Chandel District; 2 male, 6 female, 01.x.2019, Buangmun, Pherzawl district and 1 female, Tamenglong town, Tamenglong district.

Locality records: Uchathal (175 m), Jiribam District; Imphal city (790 m), Imphal district; Buangmun (33 m), Pherzawl district; Lamdan (1270 m), Churchandpur District; Tamenglong town (1580 m), Tamenglong district and Paralon (920 m), Chandel district (Mandal et al., 2005 as *P. mimus*; present study)

Remarks: The specimens were identified by a combination of skull and bacular morphology. Widely distributed in the state both in the hills and valleys. Specimens were caught in human periphery and also in relatively undisturbed forested areas.

22. *Murina huttonii* (Peters, 1872)
(Huton's Tube-nosed Bat)

Material examined: 1 female, 23.x.2021, Lamdan, Churchandpur distirct

Locality records: Lamdan (1270 m), Churchandpur District

Remarks: A specimen was collected in harp trap in mixed Pine forest at the same spot where *M. muricola* and *M. annectans* were also trapped. This is first record of this bat from the state.

23. *Murina cyclotis* Dobson, 1872
(Round-eared Tube-nosed Bat)

Material examined: 1 female, 1 male 20.x.2021, Forest at Paralon, Chandel distirct

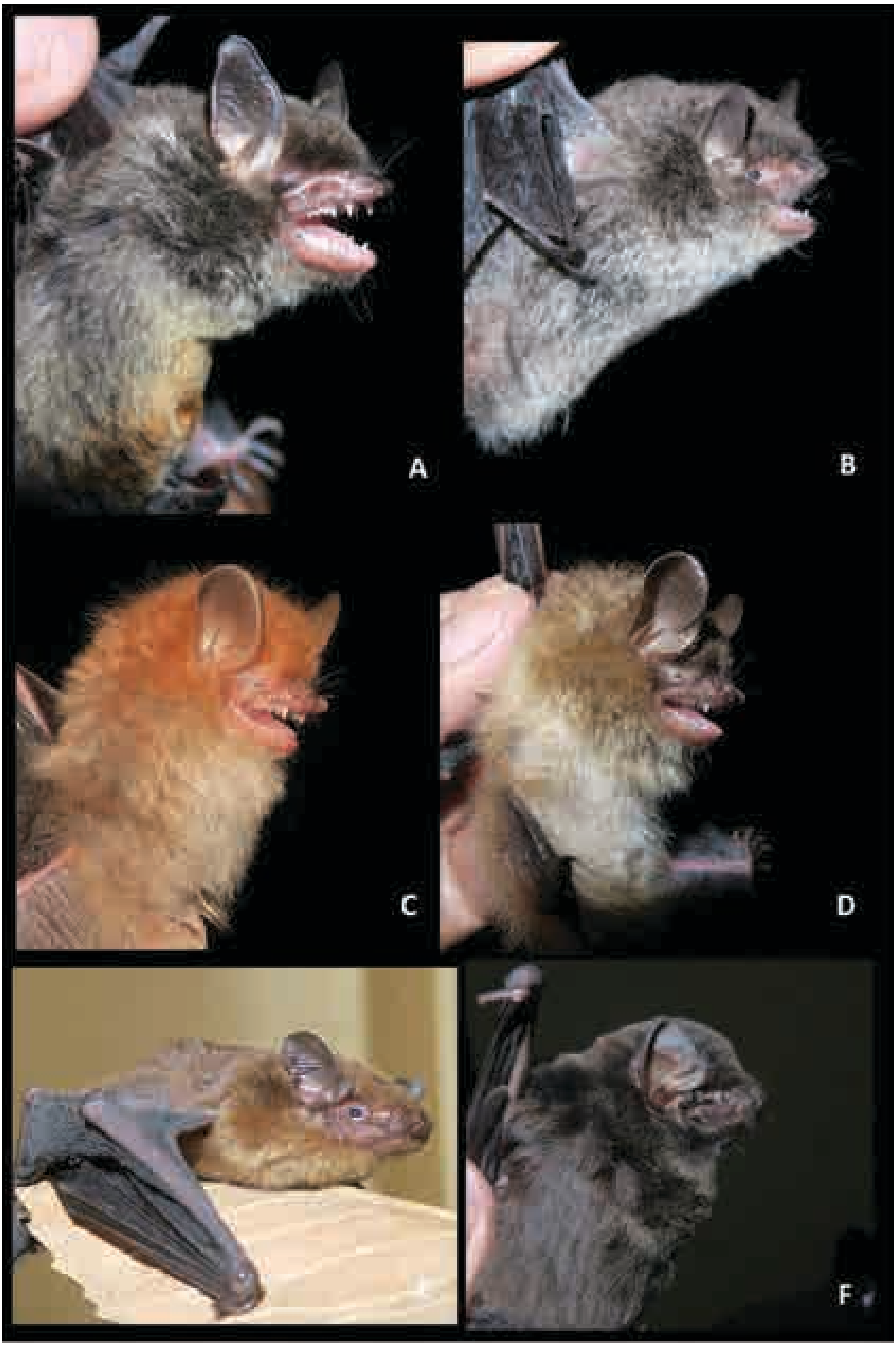

Image 5. A—*Myotis annectans* | B—*Myotis muricola* | C—*Murina cyclotis* | D—*Murina huttonii* | E—*Tylonycteris fulvida* | F—*Miniopterus magnater.* © Uttam Saikia

Locality records: Paralon (920 m), Chandel District

Remarks: Two specimens were mist netted across a newly constructed forest path in pine forest along with *P. tenuis.* The female was significantly bigger (FA=33.2 mm) than the male (FA=30.7 mm) (Appendix 1). First report of this species from the state.

24. *Mirostrellus joffrei* (Thomas, 1915)
(Joffrei's Pipistrelle)

Material examined: 1 male, 16.x.2021, Lamdan, Churchandpur distirct

Locality records: Lamdan (1260 m), Churchandpur District

Remarks: The specimen was caught in a mist net set across a forest path inside a semi-evergreen forest patch. An uncommon bat, this species was recently reported from Shillong in India (Saikia et al. 2017), but was also subsequently reported from Uttarakhand (Chakravarty et al. 2020). The external and craniodental character of this Manipur specimen conform well to the descriptions in Saikia et al. (2017). Like the specimen from Meghalaya, it was very docile and did not try to escape. The male individual caught in October did not show any sign of reproductive activity. This is an addition to the bat fauna of Manipur state.

25. *Scotophilus heathii* (Horsfield, 1831)
(Greater Yellow House Bat)

Material examined: 1 female, 10.x.2019, DC Office compound, Senapati, Senapati District; 2 male, 11.x.2019, Haipi village, Kongpokpi District.

Locality records: Jiribam (30m), Jiribam District; Senapati town (1100 m), Senapati district District; Haipi village (1150 m), Kongpokpi District (Mandal et al. 2005; present study).

Remarks: A huge colony of several hundred individuals was located on the ceiling of a school building at haipi Village, Kongpokpi district. According to the school authorities, this large bat colony was roosting there for many years and has become a nuisance but several efforts to chase them away proved futile. Such huge congregation of this species is of uncommon occurrence as according to Sinha (1986), colony size in India varies from one to about fifty individuals.

26. *Tylonycteris fulvida* (Blyth, 1859)
(Lesser Bamboo Bat)

Material examined: 1 female, 05.x.2019, 1 female, 12.vi.2017, Phalang III, Tamenglong District

Locality records: Phalang III (730 m), Tamenglong district (Blanford 1891; Saikia et al. 2019; present study).

Remarks: Specimens were caught by villagers from inside bamboo internodes. Bamboo bats are apparently very common in bamboo dominated areas in Tamenglong as several people reported finding them while cutting bamboos although species identity was not ascertained.

27. *Miniopterus magnater* Sanborn, 1931
(Western Bent-winged Bat)

Material examined: 1 female, 12.x.2017, Phalang III, Tamenglong District; 2 male, 1 female, 14.x.2019, Mova cave, Ukhrul district

Locality records: Phalang III (730 m), Tamenglong district and Mova cave (1280 m), Ukhrul District (Saikia et al. 2019; present study).

Remarks: After Ruedi et al. (2012) reported this species from Meghalaya, it was also reported from Manipur state (Saikia et al. 2019) and several other locations in Meghalaya by Saikia et al. (2020). A widespread species in the northeastern India and all earlier records of *M. fuliginosus* from this region are most likely referable to this species.

Order: Rodentia
Family: Sciuridae
28. *Callosciurus erythraeus* (Pallas, 1778)
(Pallas's Squirrel)

Material examined: Nil, Photograph of dead specimen and field sightings

Locality records: Luanglong Khullen (990 m), Phalang III (730 m), Tamenglong district Kanglatongbi (c. 1068 m), Imphal district; Buangmun (33 m), Pherzawl District; no exact locality, Senapati and Chandel Districts (Mandal et al. 2005; present study)

Remarks: Although we could record this species only on two occasions, from the previous records, it is apparently widely distributed both in the valleys and hilly region of the state

29. *Tamiops macclellandi* (Horsfield, 1840)
(Himalayan Striped Squirrel)

Material examined: Nil, field observations in Jiribam and Chandel districts.

Locality records: Uchathal (175 m), Jiribam Distrcit; Luanglong Khullen (990 m), Tamenglong district; Chandel town, Chandel District; no exact locality, Ukhrul District (Mandal et al. 2005; present study)

Remarks: A widely distributed and common species throughout the state.

30. *Ratufa bicolor* (Sparrman, 1778)
(Malayan Giant Squirrel)

Material examined: Nil, field sighting at Buangmun.

Locality records: Nanglea Atrow (990 m) Tamenglong districts and Buangmun (33 m), Pherzawl District (Mandal et al. 2005; present study).

Remarks: This species was briefly sighted once at Buangmun. According to locals, it is also distributed in forested areas of Chandel and Ukhrul districts but signings are infrequent now days presumably because of hunting pressure.

Family: Muridae

31. *Berylmys mackenziei* (Thomas, 1916)
(Kenneth's White-toothed Rat)

Material examined: 1 male, .vii.2017, Phalong, Tamenglong district.

Locality records: No exact locality, Bishnupur District; Luanglong Khullen (990 m) and Phalong (1090 m), Tamenglong districts; Kharam Waiphei (Senapati District) (Agrawal, 2000; Mandal et al. 2005; Chingangbam et al., 2014; present study).

Remarks: According to locals, this species is common in Tamenglong area especially in the crop fields. A few farmers at Mata Lambulan village in Churchandpur district also indicated the common presence of this large rat in their crop fields especially nearer to forests. People in the region hunt them for bush meat.

32. *Rattus nitidus* (Hodgson, 1845)
(Himalayan Field Rat)

Material examined: 1 male, viii.2017, Phalong, Tamenglong district.

Locality records: No exact locality, Imphal, Tamenglong and Senapati districts; Mao (1750 m), Senapati District; Phalong (1090 m), Tamenglong district (Agrawal, 2000; Chingangbam et al. 2014; present study).

Remarks: A male individual caught from Phalong during August was examined. It had a dark brown dorsum and greyish venter with a unicoloured tail which was subequal to head and body length. The hind feet were whitish. It was in reproductive stage with enlarged testes.

33. *Rattus rattus tistae* Hinton, 1918
(House Rat)

Material examined: 1 male, 23.x.2021, Lamdan, Churchandpur district.

Locality records: Practically distributed throughout the state. The recorded localities include Chandel (900 m), Chandel district; Lamdan (1200 m), Churchandpur (915 m), Churchandpur district; Turibari (c. 1250 m), Kongpokpi district; Ukhrul (1800 m), Ukhrul district; Tamenglong (1280 m), Tamenglong district (Mandal et al. 2005; present study).

34. *Niviventer fulvescens* (Gray, 1847)
(Indomalayan Niviventer)

Material examined: Nil, Filed sightings

Locality records: Nungba-Bishnupur Road (740 m), Noney district; Nungba-Tamenglong Road (1180 m), Tamenglong district.

Remarks: Several crushed carcasses were seen along the Nungba-Bishnupur Road and also along Nungba-Tamenglong stretch during October, 2021 presumably killed by farmers in the crop field. They all had characteristic rufous brown fur along the midback and grey brown along the flanks. The venter was pure white and the tail was bicoloured (Fig 5C). Villagers in Churchandpur district informed that white bellied rats with rufous back are also common in the area and presumably belong to this species.

35. *Cannomys badius* (Hodgson, 1841)
(Lesser Bamboo Rat)

Material examined: Nil, photograph of dead specimen (Image 5, A).

Locality records: Luanglong Khullen (990 m) and Phalong (1090 m), Tamenglong district; Bishnupur (Mandal et al. 2005; present study).

Family: Hystricidae

36. *Hystrix brachyura* Linnaeus, 1758
(Malayan Porcupine)

Material examined: Nil, photograph of dead specimen (Image 5B).

Locality records: Phalong (1090 m), Tamenglong district; no exact locality, Senapati district and Imphal, Imphal district (Roonwal 1950; Agrawal 2000; present study)

Remarks: A photograph of a killed animal from Phalong village in Tamenglong district was examined. Present status in the state is unclear as most of the earlier records are old.

37. *Atherurus macrourus* (Linnaeus, 1758)
(Asiatic Bush-tailed Porcupine)

Material examined: Nil, photograph of dead specimen (Image 5D).

Locality records: Phalong (1090 m), Tamenglong district (Mandal et al. 2005; present study).

Remarks: Along with *H. brachyura*, vigorously hunted by the locals as it is considered a delicacy. According to villagers in Phalong, it is much more uncommon than *H. brachyura* and one villager in Chandel reported it to be rare in the region.

Order: Eulipotyphla
Family: Soricidae
38. *Anourosorex squamipes* Milne Edwards, 1872
(Assam Mole Shrew)

Material examined: 1 male, 28.v.2015, Bhalok, Tamenglong distirct.

Locality records: Bhalok (580 m), Tamenglong district.

Remarks: One specimen was examined from Tamenglong area and according to the collector; it is not uncommon in the region especially in the Jhum fields and adjoining hilly tracts.

CONSERVATION ISSUES

Like elsewhere, most species of small mammals in Manipur are threatened primarily by human activity. This is more pronounced for bats and the larger rodents (murids and larger arboreal species). Globally, bats are under threat from severe human pressure like habitat destruction & degradation, overexploitation, persecution etc. and the situation is no different in India (Mistry 2003). Khangkhui cave in Ukhrul district is a well–known tourist destination in the state. We were told by the local guides that until 2016-17, the cave used to hold large roosting populations of Rhinolophid and Hipposiderid bats. But they were all killed and evicted out of the cave in recent times purportedly to make the cave "more tourist friendly". In some places, bats are also eaten for its supposed medicinal properties or as supplementary source of protein. In Wailou village in Chandel district, we were informed that people do occasionally hunt bats in a nearby cave although this practice is not widespread throughout the state. Another serious threat we noticed is death of bats as unintended victims of illegal bird trappings. This particular phenomenon was observed in Henglep and surrounding areas of Churchandpur district. Villagers set long nylon nets across flyways in hillside to catch birds. However, these nets also catch bats especially the larger ones which get entangled and die and people hardly bothers to remove them from the nets. We could observe large numbers of bat carcass especially *Cynopterus* and *Rousettus* at several locations along S. Sejol-Henglep Road which without doubt poses a serious threat to the fruit bat populations in the area. Hunting of rodents especially squirrels, porcupines and larger rats is a fairly common practice in the hilly region of the state. In fact, we could obtain photographic evidence of several species of rodents including highly protected Asiatic Bush-tailed Porcupine and Himalayan Crestless Porcupine that were killed for consumption. Many communities in the rural areas consider hunting wild animals as a traditional way of life that has been continuing for generations and are not aware of the importance of protecting wildlife. Fortunately, certain level of awareness about wildlife conservation has been growing in some areas in recent times. Special mention worthy is Dailong village in Tamenglong district which has been at the forefront of community led conservation efforts. The forests in and around Dailong village has rich biodiversity and for generations, people have been protecting these forests as their heritage. It has been declared as a Biodiversity Heritage Site by the Manipur government. It is desirable that the same level of awareness and wisdom spread to fur flung areas where enforcement of wildlife laws is inherently difficult. This is indeed a huge challenge, but the onus primarily lies with the government who can rope in community leaders, youth organizations, and non-governmental organizations. This should be one of the priorities of the State Government and should take steps before it is too late to act.

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Image 6. Photographs of dead rodents obtained during the present surveys (not to scale). All animals were killed by villagers and could not be retrieved: A—*Cannomys badius* | B—*Hystrix brachyura* | C—*Niviventer fulvescens* | D—*Atherurus macrourus* | E—*Callosciurus erythraeus* | F—*Tamiops macclellandi*. © Gaikhuanlung Ngaomei and Uttam Saikia.

Apendix 1. Biometrics of some of the bat species from Manipur examined during the present study.

Species	HF	TB	FA	ER	TR	GTLi	CCL	ZW	BW	POC	CM^3	M^3-M^3	MLi	CM_3	COH	No. of exs.
Eonycteris spelaea	19.5	30.4	68.9	15.8	-	-	-	-	-	-	-	-	-	-	-	1
Cynopterus sphinx	13.5, 15.6	25.4, 25.6	68.1, 68.9	16.9, 18.1	-	-	-	-	-	-	-	-	-	-	-	1
Lyroderma lyra	18.2, 19.7	35.6	68.1, 68.7	31.7, 34.8	11.9, 13.7	-	-	-	-	-	-	-	-	-	-	2
Hipposideros armiger	15.2–16.9 (16.1)	39.4–41.4 (40.5)	87.9–90.2 (89.3)	27.0–29.3 (28.3)	-	-	-	-	-	-	-	-	-	-	-	4
H. lankadiva	16.7	37.5	89.2	27.4	-	31.13	27.4	16.91	11.21	4.60	12.21	12.20	-	13.58	-	1
H. gentilis	7.3	17.4	38.9	20.5	-	-	-	-	-	-	-	-	-	-	-	1
Rhinolophus affinis	12.3		51.50	20.8	-	-	-	-	-	-	-	-	-	-	-	1
R. lepidus	6.2	15.9	37.5	13.8	-	-	-	-	-	-	-	-	-	-	-	1
R. macrotis	7.83	18.5	41	19.9	-	-	-	-	-	-	-	-	-	-	-	1
R. perniger																1
Rhinolophus sinicus	9.6, 11.5	20.5	49.0, 53.2	15.2, 16.9	-	22.67	19.22	10.88	8.90, 9.09	2.65	7.65, 8.78	8.06, 8.21	14.28, 15.18	8.22, 9.09	2.97, 3.08	2
R. yunanensis	14.4	25.5	54	22.0	-	26.60	22.83	12.86	10.14	3.20	10.38	9.37	18.20	11.32	-	1
Mirostrellus joffrei	9.0	15.65	38.5	10.3	4.3	14.90	14.12	10.82	7.73	4.58	5.08	7.43	10.77	5.68	4.00	1
Myotis annectans	11.4, 11.9	19.3, 19.9	43.0, 46.7	14.9, 16.5	6.3, 7.1	16.85	14.97	11.00	7.84	4.30	6.65	7.34	13.15	6.80	4.18	2
M. formosus	11.1	24	48.7	14	7.6	-	-	-	-	-	-	-	-	-	-	1
M. muricola	6.4– 8.6 (7.4)	16.3– 17.7 (17.0)	36.8– 37.8 (37.4)	13.8, 12 (12.6)	4.3–6.4 (5.3)	14.07– 14.30 (14.20)	12.25– 12.73 (12.43)	8.75–9.10 (8.93)	6.37– 6.51 (6.44)	3.29–3.53 (3.41)	4.92– 5.27 (5.14)	5.72– 5.82 (5.76)	10.32– 10.90 (10.66)	5.65– 5.57 (5.6)	2.70–3.18 (2.99)	3
Murina cyclotis	6.9–7.0	17.3–17.7	30.7–33.2	11.9–12.1	5.4–6.4	17.17	14.75	9.87	7.48	4.36	5.58	5.68	11.50	5.76	4.90	2
M. huttonii	9.4	15.8	34.7	15.0	7.2	18.07	15.83	10.38	8.00	4.72	6.00	6.12	12.91	6.66	4.77	1
Pipistrellus coromandra	4.4–6 (5.0)	11–12.2 (11.6)	27.5– 29.6 (28.4)	6.0–9.1 (7.6)	3.3–3.7 (3.5)	-	-	-	-	-	-	-	-	-	-	4
P. javanicus	6.7, 7.5	14, 14.3	32.4, 32.1	9.4, 10.1	4.4, 4.7	12.69, 12.90	11.28, 11.59	7.92, 8.02	6.50, 6.52	3.30, 3.61	4.37, 4.40	5.35, 5.58	8.72, 9.13	4.73, 4.80	2.54	2
P. tenuis	5.0, 6.4	12.5, 12.8	28.0, 30.7	8.5, 8.9	3.4, 4	11.10	9.87	7.18	5.76	3.37	3.35	5.33	7.83	4.24	2.44	2
Scotophilus heathii	12.9, 13.7	25.0, 25.4	58.5, 59.1	15.3, 16.2	7.0, 7.6	-	-	-	-	-	-	-	-	-	-	2
Tylonycteris fulvida	5.0	9.7	24.3	8.5	3.5	11.7	10.32	8.43	6.57	2.78	3.75	5.34	8.14	4.20	2.26	1
Miniopterus magnater	10.5–11.2 (10.9)	20.2– 21.9 (21.32)	50.1–51.3 (50.6)	9.0–11.0 (10.3)	3.9–4.3 (4.4)	17.02	16.05	9.85	8.58	4.28	6.87	7.50	13.14	7.23	-	4

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REVIEW

Conservation of Tiger *Panthera tigris* in Nepal: a review of current efforts and challenges

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Abstract: The Tiger *Panthera tigris* is one of the most charismatic and well known Asian big cats. In the lowlands of Nepal, Tigers along with the Greater One-Horned Rhinoceros *Rhinoceros unicornis* and the Asiatic Elephant *Elephas maximus* serve as flagship species gathering global conservation attention. Current surveys estimate a population of 235 tigers in Nepal. Tigers in Nepal are strictly protected in five protected areas located in the lowlands and their adjoining forest areas which cover 7,668.20 km^2. However, over the last century, tiger population and their distribution range drastically declined with the species heading towards extinction. The long-term survival of this charismatic species is challenging largely due to the loss and fragmentation of habitat, climate change, increasing human-wildlife interface and poaching for illegal trade of body parts. In response to this, the Government of Nepal along with conservation agencies and local communities have proceeded to execute various conservation initiatives both at national and international level. This paper tries to scrutinize the current status of tiger population, conservation efforts, and existing challenges to conserve tiger species in Nepal.

Keywords: Asian big cat, charismatic species, climate change, conservation efforts, flagship species, fragmentation of habitat, illegal trade, poaching, population.

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INTRODUCTION

The Tiger *Panthera tigris* is a keystone species, crucial in maintaining the integrity of the ecosystems in which it thrives. It is one of the biggest and most fearsome predators in the world (Dhakal et al. 2014; DNPWC 2018). Historically, Tigers existed as nine subspecies, three of which, i.e., the Javan Tiger *Panthera tigris sondaica*, the Caspian Tiger *P. t. virgat)*, and the Bali Tiger *P. t. balica,* are now considered extinct and a fourth, the South-China Tiger *P. t. amoyensis* is most likely extinct in the wild. Today the existing subspecies include the Bengal Tiger *P. t. tigris*, Indochinese Tiger *P. t. corbetti*, Sumatran Tiger *P. t. sumatrae*, Siberian Tiger *P. t. altaica*, and the Malayan Tiger *P. t. jacksoni* (Goodrich et al. 2015). However, a recent taxonomic revision by the IUCN Cat Specialist Group grouped the extant tigers into two sub species; *Panthera tigris tigris* distributed in mainland Asia, including India, Nepal, Bhutan, China, Russia, Indochina, and the Malay Peninsula and *Panthera tigris sondaica* found in Sumatra and formerly Java and Bali (Kitchener et al. 2017).

Tigers occupy a variety of different habitats which include the tropical rainforests of Sumatra, mangrove swamps of the Sunderbans of Bangladesh and western India, tropical forests and grasslands of Nepal and India, forests of Bhutan and the temperate regions of eastern Russia (GTIS 2010; DNPWC 2016, 2018) thus displaying ubiquity and adaptability across a wide range of habitats. That being said, tropical forests are considered to be the main habitat for tigers across their entire range. Just over a century ago, there were as many as 100,000 tigers living in the wild. At present, however, there are less than 5,000 wild tigers that remain (Table 1) and their range has reduced by 93% from 1990s to 2000s (Dinerstein et al. 2007; GTF 2016). Currently, suitable habitat for wild tigers covers about 1.2 million km^2 which has been categorized to include 76 tiger conservation landscapes (TCLs) across 13 tiger range countries (TRCs): Nepal, Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Russia, Thailand, and Vietnam (GTIS 2010).

The Bengal Tiger is the most abundant sub-species native to the Indian subcontinent including India, Nepal Bangladesh, Bhutan, and western Myanmar. The population estimate of this sub-species currently holds at approximately 3,389 individuals (Table 1). In Nepal, tigers are distributed among five protected areas across the Terai and Churia habitats within the Terai Arc Landscape (Dhakal et al. 2014; DNPWC 2018). The tiger census conducted in 2018 estimates a population of 235 adult tigers in Nepal (DNPWC 2018). Wild Tiger populations continue to decline due to habitat loss and degradation, prey depletion, retaliatory killing of tigers and poaching for illegal trade (Ripple et al. 2014). Therefore, to conserve this species, in 2010, at the Tiger Summit in St. Petersburg, Russia, Nepal and 12 other countries with wild tiger populations committed to double their wild tiger numbers (TX2 goal) by 2022 (GTF 2016). Owing to this, various conservation initiatives were undertaken both at national and international level which resulted in an increase in tiger population especially in Indian subcontinent. Yet, the long-term survival of this endangered wildlife species remains a challenging task. It is crucial now more than ever, for Nepal to execute pertinent actions and strategies for the long-term conservation of this species. In this context, the current paper intends to present the current status and distribution of tiger population in Nepal. Moreover, this paper also strives to illustrate the conservation efforts and its related challenges to conserve this iconic species in a national context.

Tiger population status and tiger habitats in Nepal

Tigers in Nepal are distributed across the lowlands of Terai and Churia habitats within the Terai Arc Landscape (TAL). At present, the tiger distribution in Nepal is more or less restricted to five protected areas of the TAL and their adjoining forest areas (Figure 1) in three isolated sub-populations, viz.: i) Parsa-Chitwan Complex (Barandabhar corridor and protected forest; Parsa National Park (PNP) and Chitwan National Park (CNP)); ii) Banke-Bardia Complex (Kamdi corridor, Karnali corridor, Khata corridor and protected forest; Banke National Park (BaNP) and Bardia National Park (BNP)); and iii) Kailali-Kanchanpur Complex (Basanta corridor and Protected forest, Laljhadi-Mohana corridor and Protected forest, Brahmadev corridor and Shuklaphanta National Park (ShNP) (DNPWC 2018).

The tiger census of 1995/1996 estimated a total of 93 to 97 breeding adult tigers in Nepal (DNPWC 2008). In the 1999/2000 census the population was estimated around 98 to 123 breeding adults showing some growth from the previous count (DNPWC 2008). But in 2007, the population was estimated at around 105 to 123 individuals showing no signs of growth, and the cause was attributed to increased poaching (DNPWC 2008; NTRP 2010). It should be, however, noted that early tiger estimates were based largely on pugmark projection methods, which have been proven to be unreliable surveys (Karanth et al. 2003). But from 2009, tiger censuses have been based on standardized,

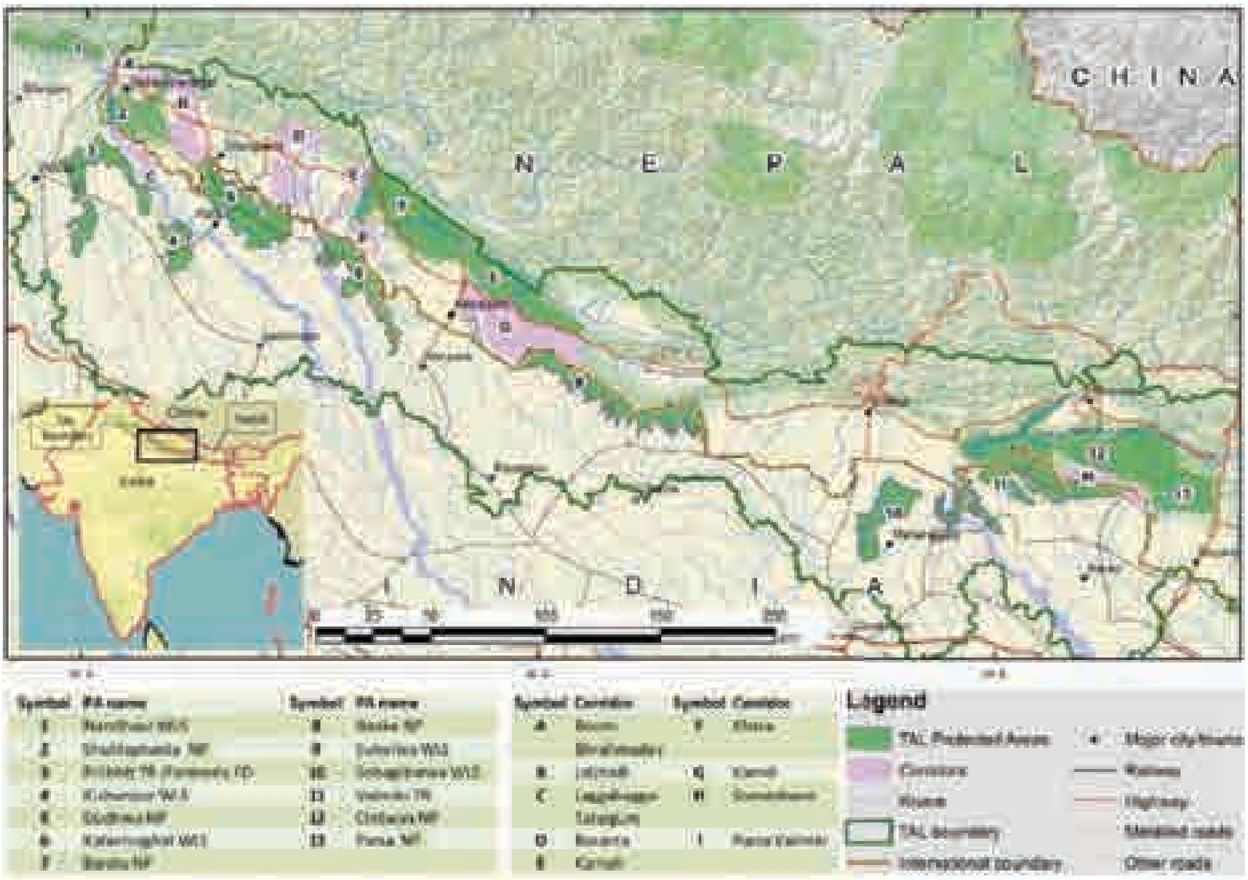

Figure 1. Map depicting tiger bearing protected areas and forest corridors in Nepal (adapted from DNPWC 2016).

science-based methods that use systematic camera trapping and transect surveys (DNPWC 2016). Thus the surveys conducted from 2009 onwards show an increase in tiger numbers in all protected areas, i.e., the population increased from 121 individuals in 2009 to 198 individuals in 2013 (Dhakal et al. 2014). The census of 2018 estimated that of the 235 individual tigers, 18 (16–24) tigers distributed in PNP and adjoining forests, 93 (89–102) tigers in CNP and adjoining forests, 21 (18–30) tigers in BaNP and adjoining forests, 87 (82–97) tigers in BNP and adjoining forests, and 16 (15–21) tigers in ShNP and adjoining forests (DNPWC 2018). The protected areas hosting tigers is presented in Table 2 along with their status. A national comparison indicates an approximate increase in the national tiger population by 19%, within the four-year period and a 94% increase within a period of nine years.

The largest population lives in Parsa-Chitwan Complex encompassing an area of 2,595 km^2 of prime lowland forest. Out of total habitat area, Parsa-Chitwan Complex encompasses 36.60% and Banke-Bardia complex and Suklaphanta Complex covers 41.60 % and 21.80 %, respectively (Table 2). Earlier information on tiger distribution in Nepal has not been reported at elevations higher than the Siwalik Hills (about 1,500 m). But recently, on 13 April 2020, a tiger was spotted at an elevation of 2,500 m in the Mahabharat range of Dadeldhura (DFO 2020). This is the first ever recorded sighting of a tiger at such altitudes. It was sighted by a camera trap which was set up by the Division Forest Office to track the presence of wildlife movement in the area. Reports such as this opens up new avenues for research in Nepal. Furthermore, a tiger was recently captured at an elevation of 3,165 m by a camera trap in the mountain forests of Ilam district in eastern Nepal, the highest proven sighting of a big cat ever in Nepal (DNPWC 2020). This finding provides the encouragement for conservation officials to continue their determined efforts to save the iconic animal which is endangered globally.

Conservation efforts

Nepal's effort to strengthen tiger conservation efforts dates back to 1970s when a tiger ecology project was launched in Chitwan in 1972 (McDougal 1977; Smith 1993). Following the endorsement of National Park and

Table 1. Current status of Tiger in tiger range countries.

	Country	Year 2010	Year 2015	Year 2018
1	Nepal	155	198	235
2	India	1411	2246	2967
3	Bangladesh	440	106	121
4	Bhutan	75	103	103
5	Myanmar	85	85	NA
6	China	45	45	34
7	Lao PDR	17	17	2
8	Thailand	200	200	189
9	Vietnam	10	10	<5
10	Cambodia	20	20	0
11	Indonesia	325	325	371
12	Malaysia	500	500	250
13	Russia	360	360	433
	Total Population	**3643**	**4215**	**4710**

NA—Not available. Source: GTF 2016; Wang et al. 2016; Aziz at al. 2017; DNPWC 2018; Jhala et al. 2019.

Wildlife Conservation Act (NPWCA) and establishment of Chitwan National Park in 1973 as the first national park of Nepal was a milestone in the history of wildlife conservation in Nepal which was well backed up by establishing Department of National Parks and Wildlife Conservation in 1980 (DNPWC 2018). After that, four more national parks, i.e. BNP, ShNP, PNP, and BaNP were set up to protect tigers and their habitats (DNPWC 2016, 2018). Since then, placing strong anti-poaching measures in the protected areas, managing habitats and providing compensation for human loss has led to the recovery of wild tiger populations.

To address the growing issue of conflict between national parks and people, the Government of Nepal in 1996 introduced a conciliatory approach called as the Buffer Zone Management System (MoFSC 1996; Ghimire 2019). They aimed to establish buffer zones around the country's national parks and wildlife reserves with the objective of making local communities self-reliant on forest products through community forestry, while also creating other livelihood opportunities for them (MoFSC 1996; Dhakal et al. 2014; Bhattarai et al. 2019). In addition, a legal provision was made to plow back a major slice of the revenue earned as a consequence of buffer zone development activities (MoFSC 1996). Over the time, the approach employed for wildlife conservation changed from protective to participatory and from species to landscape conservation (Ghimire 2019). In response to this, the Terai Arc Landscape (TAL) programme was initiated in 2001 specially to protect megafauna like tigers, rhinos and elephants. This programme is recognized by the Governments of both Nepal and India. The TAL covers an area of 51,002 km^2 which extends from Nepal's Bagmati River in the east to India's Yamuna River in the west. This landscape is identified as prime habitat of tiger population in Nepal (MoFSC 2015).

Nepal also set up strong legal provisions to control wildlife crimes particularly for protected mammals like tigers, rhinos, elephants, and snow leopards. In Nepal, tigers are strictly protected under the National Parks and Wildlife Conservation Act. For offenders and accomplices convicted of poaching and illegal trade of tiger and its body parts the Wildlife Conservation Act provisions a fine ranging from NPR 500,000 to NPR 1,500,000, or 5 to 15 years of imprisonment, or both (GoN 1973). Nepal, is one of the 13 countries, that committed to the St. Petersburg Declaration of 2010 to double the tiger population by 2022 (GTIS 2010). To support this commitment the Government of Nepal also implemented a National Tiger Recovery Program 2010 under the framework of the Global Tiger Recovery Program (2010–2022) (Dhakal et al. 2014; DNPWC 2018). In addition, frameworks such as Nepal Biodiversity Strategy and Action Plan (2014–2020), Terai Arc Landscape (TAL) Strategy and Action Plan (2015–2025), Tiger Conservation Action Plan for Nepal (2016–2020), Forest Policy 2019 and Forest Act 2019 were developed and implemented to serve as a benchmark for tackling the priority threats to the nation's mega fauna like the tiger (DNPWC 2016; MoFE 2019). Furthermore, seven additional forest habitat corridors (Table 3) covering area 2,157 km^2 were declared between the years 2010 and 2020 to facilitate movement and dispersal of wildlife, especially tigers, rhinoceros, and elephants (MoFSC 2015; Wegge et al. 2018). The Government of Nepal has also been taking proactive actions in and around protected areas including buffer zones to engage with communities and organize community based initiatives. Altogether 331 community-based anti-poaching units (CBAPUs) have been established since 2015 in different parts of the country (DNPWC 2018). With all these efforts, Nepal is set to become the first country to double its tiger population by 2022 with an impressive population of 235 individuals. The Government of Nepal is at the forefront in improving habitats, managing critical transboundary linkages, adopting latest science and technology in research, combating wildlife crime and supporting the local communities to cope with tiger conflict.

Table 2. The tiger bearing protected areas and tiger population.

Protected areas	Core area (Km²)	Buffer zone area (Km²)	Tiger population status		
			2009	2013	2018
PNP	627.39	285.30	4	7	18
CNP	952.63	729.37	91	120	93
BaNP	550	343	-	4	21
BNP	968	507	18	50	87
ShNP	305	243.5	8	17	16
Total			**121**	**198**	**235**

Table 3. Forest habitat corridors in Nepal.

	Name of Forest Corridors	Area covered		
		Forest corridor (Km²)	Impact zone (Km²)	Total (Km²)
1.	Barandabhar Corridor and Protected Forest	148	113	261
2.	Kamdi Corridor	291	159	450
3.	Karnali Corridor	149	78	227
4.	Khata Corridor and Protected Forest	74	128	202
5.	Basanta Corridor and Protected Forest	181	471	652
6.	Laljhadi-Mohana Corridor and Protected Forest	202	153	355
7.	Brahmadev Corridor	138	10	148
	Total	**1045**	**1112**	**2157**

Source: MoFSC 2015.

Conservation challenges and threats

Despite conservation measures, tigers are highly threatened and still face the threat of extinction. Of the two sub-species only *Panthera tigris tigris* is reported to exist today and is 'Endangered' while *Panthera tigris sondaica* is considered extinct (Dhakal at al. 2014; Goodrich et al. 2015; Kitchener et al. 2017). Global tiger populations are under threat from habitat degradation, prey depletion, and poaching. Some of the major impediments to effectively conserve tigers in Nepal can be summarize as below:

- Habitat degradation and fragmentation
- Depletion of prey species
- Poaching and illegal trade of tiger body parts
- Human-tiger conflict
- Spread of invasive/alien species like *Mikania micrantha*, *Lantana camara*, *Chromolaena odorata* in tiger prey habitat particularly in PNP, CNP, and BNP.
- Climate change impacts

Rapidly growing human population coupled with unsustainable agricultural practices not only degrade prime tiger habitat but also relegated the alarmingly dwindled tiger population to the confines of the wildlife habitats and adjoining forests. Settlements and linear infrastructure projects such as roads, railroads, transmission lines, irrigation canals, etc. are roughly planned inside protected areas or corridors which are responsible for fragmentation and degradation of tiger habitat in the country. The East-West highway passes through all five tiger bearing PAs of Nepal, which has resulted in the road kill of wildlife including tigers (DNPWC 2018; Bhattarai & Kindlmann 2018; Bhandari et al. 2019). Consequently, degradation and loss of tiger habitat resulted in low prey availability in both inside and outside PAs due to increased competition for food. On the other hand, continued illegal hunting outside PAs also contributes towards the depletion of natural prey-base. Moreover, collection of fodder, firewood, grasses from the forests, grazing, forest fire, and alien invasive species are major driving factors that lead to the degradation of tiger habitat. Similarly, floods, river cutting and pollution are other factors (Bhattarai & Kindlmann, 2018). Moreover, with the increase in number the problem of carrying capacity assessment is another growing issue for tiger conservation in Nepal (Bhandari et al. 2019).

Poaching and illegal trade of tigers and their body parts are a major threat to tiger populations globally. As Nepal is one of the countries that hosts a large wild tiger populations, it considered both a source and a transit point for illegal trade (Acharya 2003; DNPWC 2018). Despite the country's commitment to curb wildlife crime together with the success it achieved over the years in minimizing poaching and illegal trade, it still faces the problem of opportunistic poaching. In the past decade, skin from 49 tigers and 204 kg of tiger bones was seized, while 2,258 people were arrested in connection with their involvement in wildlife-related crime in the country (DNPWC 2018). Therefore, poaching and trade continues to be recognized as a major threat, and combatting wildlife crime remains a priority. Furthermore, human-wildlife interface (like livestock depredation and human attack) has become one of the major threats to wildlife conservation. Conserving mega fauna like tigers in a human dominated landscape has become a challenging job. Today, *human-tiger incidents* have played a significant role in declining tiger populations globally (Gurung et al. 2008; Bhattarai et al. 2019). The trend of human casualties has increased from an average of 1 to 7 persons per year from 1998 to 2006 (Gurung et al. 2008). Despite legal provision of a hefty fine or a sentence of up to 15 years in jail, or both, for killing a tiger and a compensation scheme for crop or livestock depredation, affected locals are sometimes known to resort to retaliatory killings. Habitat shrinkage, increasing human interface along the park boundaries, and increasing dependence on park/ reserves for forest resources are some of the major underlying causes of human-tiger interface.

Likewise, invasive-alien plant species such as *Mikania micrantha, Chromolaena odorata*, and *Lantana camera* in Parsa and Chitwan and *Lantana camara* in Bardia have heavily encroached most of potential tiger habitats and community forests in the buffer zones (DNPWC 2008; 2016). Water hyacinth *(Eichornia crassipes)* is prevalent in all lowland lakes, consequently this encourages siltation and dries up wetlands. Climate change is emerging as one of the prominent threats to biodiversity globally. Although information regarding the direct impact of climate change on wildlife species in the country is limited. However, climate change induced hazards including torrential precipitation, flash floods, prolonged droughts and frequent forest fires are observed to be major issues for tigers and their prey species (Thapa & Killy 2016; DNPWC 2018).

In spite of Nepal's favourable position on the road to achieving the TX2 goal and even with the upward growth rate of the global tiger population (after decades of constant decline), policy makers and experts at the third stock-talking conference held in Delhi in January 2019 (MoEFCC 2019) have pointed out that the goal of doubling the global tiger population by 2022 may be unrealistic. In 2010, global tiger population was pegged at 3,220 and at the halfway point in the timeline, i.e., 2016, it only reached 3890, below than the expected rate of increase (MoEFCC 2019). Therefore, the need for a differential approach to reach the TX2 goal was emphasized. Tiger and prey recovery is considered to be the main issue (globally) whereas in southern Asia, managing habitats outside the critical core tiger habitat through landscape approach, i.e., safeguarding tiger corridors and community engagement to enhance livelihood opportunities for people is emerging as an area of focus. On that account, an essential challenge now lies in setting appropriate priorities to respond to the issue at hand.

CONCLUSION

Nepal has been a leader in efforts to conserve tigers within its own territory and has won widespread praise from the international arena as well. The result shows the country is close to doubling its tiger population and achieving the global commitment made in the 2010 St. Petersburg Summit in Russia. The success in tiger conservation is the result of the concerted efforts of government agencies, conservation organisations, donors and community-based organisations. The conservation policies and strategies area well implemented. This is evident when we work together, we can save the planet's wildlife, even species facing extinction. Yet, conservation in an ever changing world that demands long term persistent efforts. Despite successes, threats to tigers from poaching, human-tiger interface, climate change, habitat degradation and depletion of prey base due to unplanned developmental activities persist even today. Thus, learning from past failures, and reflecting on current success actions and strategies need to be adapted for the long-term survival of this valuable species. More than that, there is a need for massive public awareness about wildlife protection and involvement of local community in conservation strategies.

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COMMUNICATION

Effects of visitor disturbance on tetrapod vertebrates in the Horton Plains National Park, Sri Lanka

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Abstract: Effect of visitor disturbances on tetrapod vertebrates was studied from December 2017 to October 2018 in the Horton Plains National Park (HPNP), which is one of the world's best nature reserves and a popular tourist destination of Sri Lanka. Roads and nature trails with cloud forest, aquatic and grasslands habitats inside the HPNP were selected to compare the effect of visitor disturbances. Three 100 meter fixed length line transects were marked along the roads and the nature trails in each habitat. Vehicle noise was measured using sound meter software. Visitor activities that cause disturbance included road kills, photography, trampling and animal feeding. Amphibian and reptile road kills were higher compared to other tetrapod road kills during vacation periods. Behavioral response of species to visitor disturbances included avoidance, habituation and attraction. When the vehicle noise range was from 63±2.11 dB to 69±2.11 dB, habituation behavior was displayed. When the vehicle noise range increased to the range of 70±4.71 dB to 88±4.71 dB, avoidance behavior was displayed. Animals display a propensity to habituation behavior compared to avoidance behavior when vehicle speed was less than 30 kmh/hr. The results of this study can be used to integrate with the future visitor, park and wildlife management practices of the park.

Keywords: Behavioral response, disturbance, habitat, HPNP, nature reserves, road kills, tourist destination.

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Author contributions: DMTD—main researcher on this research findings, field sampling, data collection, data analysis and preparation of the paper were the main contribution. WADM—main supervisor of this research and who gave me the guidance, support and encouragement throughout my research with sharing her valuable experience and knowledge.

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INTRODUCTION

Sri Lanka is an island nation in the Indian ocean, and is considered a global hotspot for biological diversity along with the Western Ghats of India (Myer et al. 2000). Protected areas of the island spread over 1,710,000 ha. There are 22 national parks (NPs) in Sri Lanka governed by the Department of Wildlife Conservation (Newsome 2013). NPs are one of the protected areas to allow in park recreational activities with limited opportunities that are provided for the public to observe and study wildlife within these areas (Senevirathna et al. 2013). Despite the economic gains obtained, a number of negative impacts may arise due to heavy visitor arrivals to NPs which keeps increasing day by day.

According to Knight & Cole (1995) human disturbance is an anthropogenic activity that causes a change in metabolism and/or behavior of an animal. It can produce short-term or long-term effects on individuals, populations, and communities. Many studies have been conducted worldwide related to impact of human disturbance on animal populations (Bélanger & Bédard 1989; Stockwell et al. 1991; Poster et al. 1992; Reijnen et al. 1995; Andersen et al. 1996; Gill et al. 1996).

Behavioral response

Most reported disturbances occur related to viewing of wildlife which results in behavioral change as a response by the animal. Behavioral changes may arise when animals are approached for viewing, touching, feeding, and photographing (Valentine & Birtles 2004; Lemelin & Wiersma 2007). Nineteen out of 27 studies have proven that birds are negatively affected by wildlife observation and photography (Boyle & Samson 1985). However, it is not only birds, other wildlife also gets affected by such activities in varying degrees. Disturbance occurred by photography is greater than that of nature observations (Klein 1993; Tershy 1997).

Road-kills

The greatest non-natural source of vertebrate death is road mortality which is increasing even within protected areas (reserves and parks) (Bernardino & Dalrymple 1992; Kline & Swann 1998). The continuation and prevalence of natural habitats can be disrupted by the presence of trails and roads. There is evidence that recreational trails can change breeding bird communities in both grassland and forest ecosystems (Miller et al. 1998). Width of the road, vehicular traffic and speed level can affect the road kill rates. Mortality of wildlife due to vehicular traffic is among the direct impacts when natural habitats are replaced with roads (Laurance et al. 2009). Despite a number of studies that have been conducted regarding the impact of roads on animals, only two studies have been reported (Maduwage et al. 2003; Amarakoon et al. 2010) from Sri Lanka. Horton Plains National Park (HPNP) was included in the study conducted by Karunarathna et al. (2013) on the impact of road traffic mortality of reptiles.

Noise

Noise is one of the most negatively affecting road disturbance types (Forman & Alexander 1998; Forman et al. 2003; Coffin 2007). Many animals use acoustic communication to communicate with each other via acoustic signals (e.g., amphibians, birds, and mammals). Those acoustic signals get interfered in areas affected by traffic noise (Collins 2004; Marler 2004). The disturbance of anthropogenic noise on wildlife can be quantified (Brumm & Slabbekoorn 2005; Morley et al. 2014). A number of studies highlight the negative and adverse impacts of anthropogenic noise on wildlife (Stone 2000; Barber et al. 2010; Verzijden et al. 2010; Hanna et al. 2011).

At present, Sri Lanka's NPs are becoming prime tourist destinations for both international and domestic tourists. Hence, HPNP was selected to conduct this research which demonstrated the second highest visitor rate within the period concerned. Total number of visitors at HPNP in 2019 was 329,792 (STDA 2019). A total of 109 species of indigenous plants species can be observed in the park. The vertebrate fauna of the park includes five out of 19 mammal species that are endemic, nine mammal species are nationally threatened and five among them are globally threatened, thirteen out of 64 bird species are endemic and three globally threatened species, five out of six species of reptiles are endemic, 13 out of 14 species of amphibians are endemic species; the point endemism within the park is highly remarkable for both fauna and flora (De Alwis et al. 2007). The vegetation consists of cloud forest and wet patana grasslands, with a narrow ecotone belt of shrubs and herbs between them (Gunatilleke & Gunatillke 1990). In HPNP, visitors are allowed to walk along the nature trails in the unique scenic landscape. Road access of 5 km through the park area is also available where visitor vehicles are allowed. Baker's fall, Small World's End, and Greater World's End are popular attractions of the park (Rathnayake 2015). Therefore, over a long period of time, anthropogenic activities have been concentrated within HPNP through the process of ecotourism activities. This research was focused on identifying and quantifying the impact of roads and nature trails from visitors in HPNP. It will also highlight the management and conservation steps that need to be taken in order to conserve the country's remaining wildlife within protected areas.

Study sites

Present study was conducted from December 2017 to October 2018 covering three main habitats types in HPNP (6.78–6.83 N & 80.76°–80.83 E) including cloud forest, grasslands, and aquatic habitat. The selected three habitat types were identified, based on the base line survey in HPNP (DWC 2007) (Image 1).

METHOD AND MATERIALS

Disturbances were surveyed using line transects in the three selected habitats along the roads and nature trails. For each month, a total of 18 transects were monitored (Appendix 1) with triplicates of survey attempt in the time periods: morning (0800–1100 h), mid-day (1130–1430 h) and evening (1500–1800 h) in an expansion four consecutive days. Each transect was 100 m in length and width of transect line was 20 m, and three such transects were laid in each habitat on the road as well as the nature trail.

Road-kills

On each sampling day, road-kills were recorded while walking in transects. Throughout the survey, in both vehicle road and nature trail, surface and verges (50 cm on either side of the road and nature trails) were scanned. The specimens were identified using field guides (Wijeratne 2008; De silva 2009; Somaweera & Somaweera 2009; Harrison 2011). All specimens were photographed and identifications were verified (Karunarathna et al. 2013). These monthly data were converted for vacation (December, April, and August) and non-vacation periods (February to November).

Visitor activities

Visitor activities were recorded under photography, trampling and animal feeding in the roads and nature trails ((Valentine & Birtles 2004; Lemelin & Wiersma 2007).

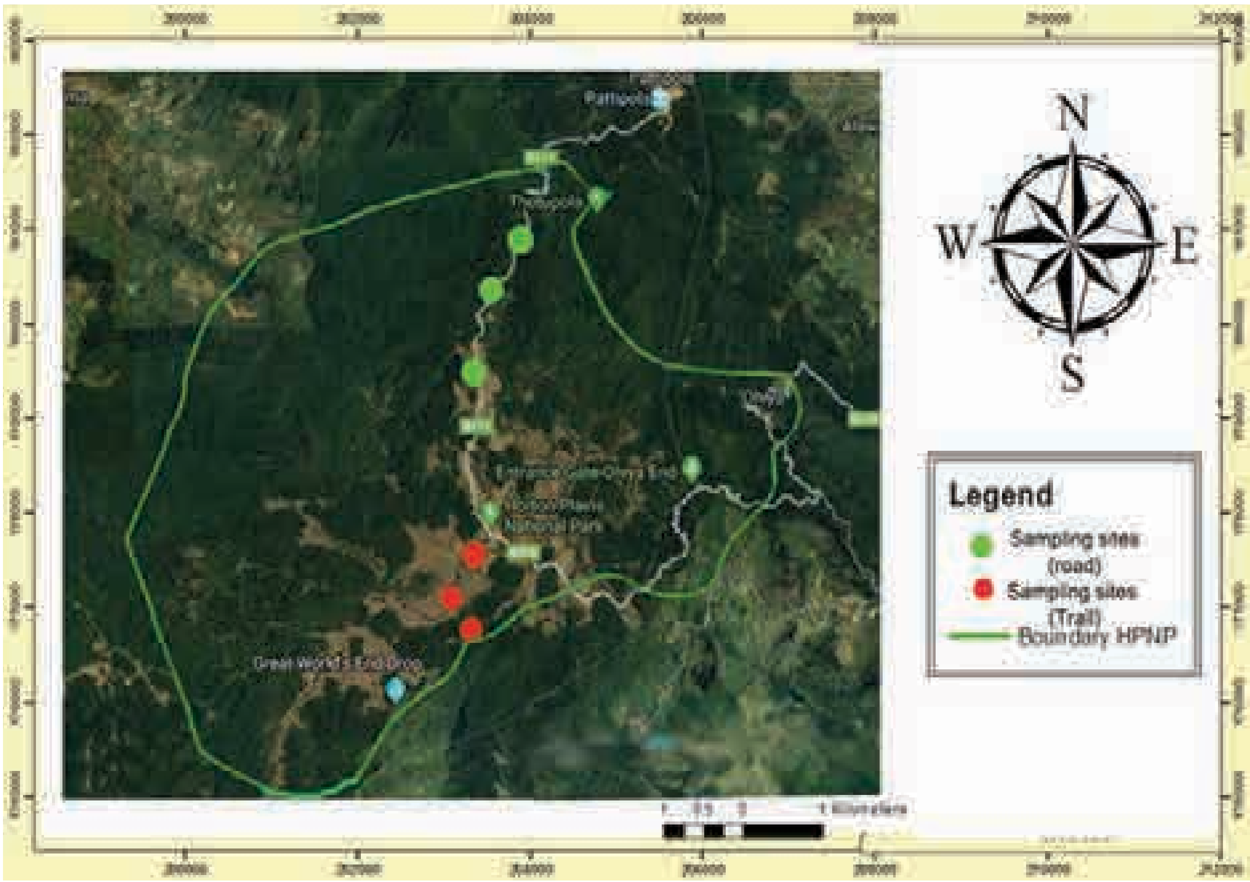

Image 1. Locations of sampling sites within the Horton Plains National Park, Sri Lanka.

Behavioral changes

Animal behavioral changes were monitored under habituation, attraction, and avoidance (Knight & Cole 1995). These behavioral responses were recorded at stopping the vehicles within the sight of animal, then not get out and stopping the vehicle within sight of animal, and then getting out. Habituation is defined as a declining of a response to a repeated stimulus. It does not display either a positive or a negative reward. Attraction is defined as the strengthening of an animal's behavior. It displays positive rewards. Avoidance is defined as moving away from humans. It displays negative reward (Knight & Cole 1995).

Noise

Vehicle noise was measured using sound level meter (UNI-T UT353) along transect lines in all habitat of vehicle road sites (Murphy & King 2016). While measuring noise, animal behavioral response was observed whether it was avoidance or habituation. The noise level was recorded in decibels (dB).

Vehicle speed

Vehicle speed was recorded, using radar gun (Montella et al. 2013) to observe avoidance and habituation behavioral responses of species. Speed level was recorded in km/h.

RESULTS

Amount of tetrapod vertebrate road kills during vacation and non-vacation period in the nature trails

Highest average number of road-kills was recorded in vacation months than non-vacation months. Highest average number (2.67±0.46) of road-kills belonged to reptiles. During the vacation time period, and amphibian road-kills (1.00±0.40) were recorded. No road-kills were recorded for mammals and birds within the trail site habitats (Figure 1A).

Amount of tetrapod vertebrate road kills during vacation and non-vacation period in the roads

Highest average number of road kills was recorded in vacation months compared to non-vacation months for all tetrapods. Birds (0.33±0.12) were the lowest road kills during vacation periods. Highest road kills was recorded for retiles (4.33±0.88) during vacation periods. A value of 2.00±0.14 was recorded of mammals and 2.67± 0.33 was recorded for amphibians during vacation period. No road kills were recorded in non-vacation months for birds (Figure 1B).

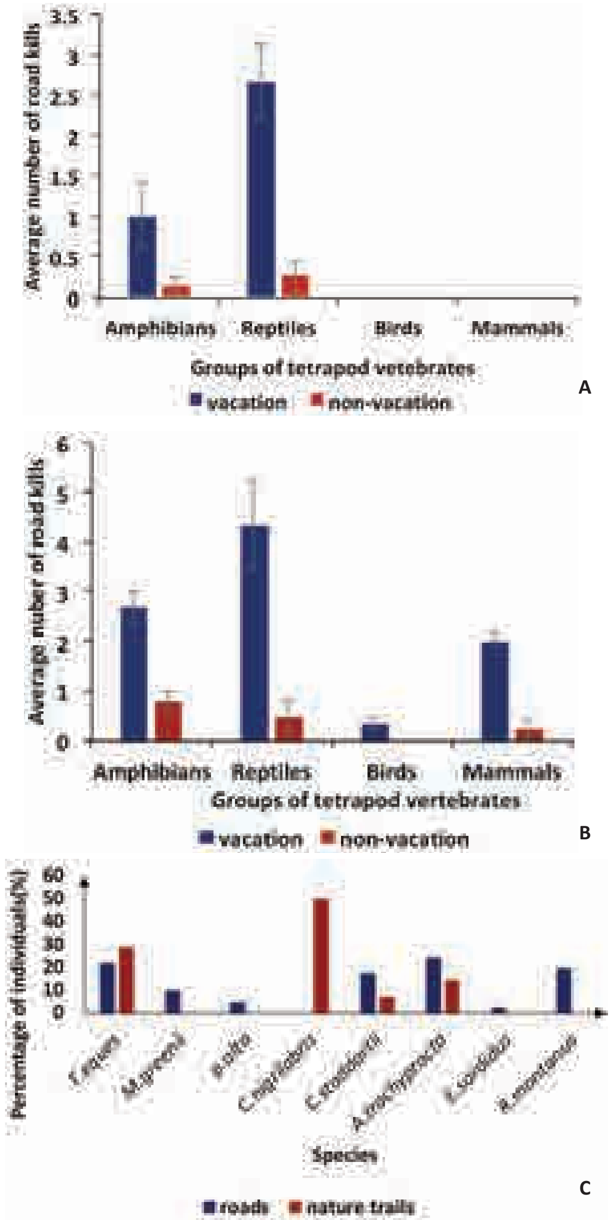

Figure 1. A—Amount of tetrapod vertebrate road kills during vacation and non-vacation period in the nature trails | B—roads | C—recorded road kills species in the nature trails and roads.

Road-kill specimens recorded in the nature trails and roads

Amphibians and reptiles road-kills were generally higher on roads. Taruga eques road-kills were higher in trail site than road site. *Minervarya greenii* road-kills were only recorded in road site. Highest percentage of road-kills recorded were *Calotes nigrilabris*, *Ceratophora stoddartii*, and *Aspidura trachyprocta* road-kills were also recorded. *Eumyias sordidus* and *Rattus montanus*

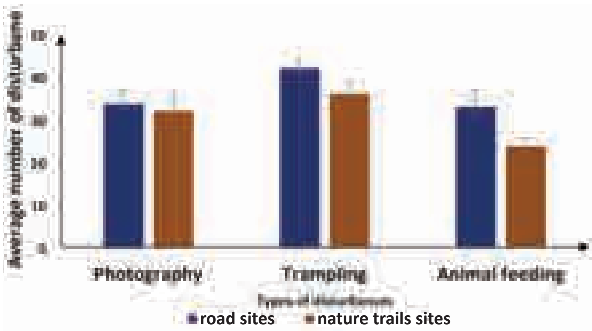

Figure 2. Categories of disturbances in the nature trails and roads.

were two bird and mammal species that were road-killed (Figure 1C).

Categories of disturbance in the nature trails and roads

Photography (33.5±10.72%) followed by animal feeding (32.78±13.25%) were the most prominent disturbance types recorded in roads, whereas, trampling was more common in roads rather than in trails (Image 3). Average percentage of disturbances were significantly higher in roads than in nature trails (Mann-Whitney U test, P >0.05) (Figure 2).

Variation of behavioral responses in the presence of visitors

Behavioral responses of amphibians

All species recorded displayed only avoidance and habituation behavioral responses. Attraction behavioral response was absent in amphibians. *M. greeni* (73%), *T. eques* (82%), and *P. schmarda* (88%) displayed habituation behavioral response as the more prominent response. Avoidance behavioral response was shown in lower percentages despite being shown by all three species (Figure 3A).

Reptiles behavioral response

Only habituation behavioral response (100%) was recorded from *Cophotics ceylanica*. Both avoidance and habituation behavioral responses were observed from *C. nigrilabris* (85–15 %), *C. stoddartii* (88–12 %), and *A. trachyprocta*, avoidance being more prominent (Figure 3B).

Behavioral responses of birds

Only avoidance behavioral response (100%) was observed from *E. sordidus*, *Pericrocotus flammeus, Dicaeum erythrorhynchos, Rhopocichla atriceps, Turdoides rufescens, Pomatorhinus melanurus, Zosterops ceylonensis, Mortacilla flava, Hirundo domicola*, and *Lonchura malacca*. Only habituation behavioral response (100%) was observed from *Gallus lafayetii* (Figure 3C).

Behavioral responses of mammals

A mixture of behavioral responses was observed in most of the animals. *Rusa unicolor* and *Funambulus obscurus* were recorded as the species that showed all three behavioral responses. Attraction behavioral response was observed from *R. unicolor* (78%) and *F. obscurus* (75%) rather than other behavioral responses. Lowest percentage of individuals was recorded showing avoidance behavioral response in both these species (Figure 3D).

Behavioral responses under vehicle noise

Average values of vehicle noise were 66.5 dB and 79.0 dB for habituation and avoidance respectively. The vehicle noise recorded was in the range of 63±2.11 dB to 69±2.11 dB under habituation behavior. It ranged from 70±4.71 dB to 88±4.71 dB where avoidance behavior was observed (Figure 4).

Behavioral response of tetrapod vertebrates under vehicle speed

When tetrapod vertebrates show behavioral responses to vehicle speed, the average values of vehicle speed for habituation and avoidance behaviors were 18.73 km/h1 and 38.45 km/h, respectively. Vehicle speed range was from 11±6.07 km/h to 29±6.07 km/h under habituation behavior. Vehicle speed range was from 30±5.01 km/h to 45±5.01 km/h under avoidance behavior (Figure 5).

DISCUSSION

Most studies of the effects of roads on wildlife emphasize upon traffic mortality which has revealed that roads act as complete or partial barriers to movement for some species (Rondinini & Doncaster 2002; Shine et al. 2004; Whittington et al. 2004). Average number of road-kills recorded was higher during vacation period in nature trails as well as roads than in non-vacation period. However, road-kills were greater on roads than nature trails. The reason for this is obviously the speed of the vehicles which have a higher probability of colliding with animals when compared to the slow-moving human visitors. However, the occasional road-kills were observed even on the nature trails due to the faults of unaware visitors.

Amphibian road-kills were higher on the roads as well

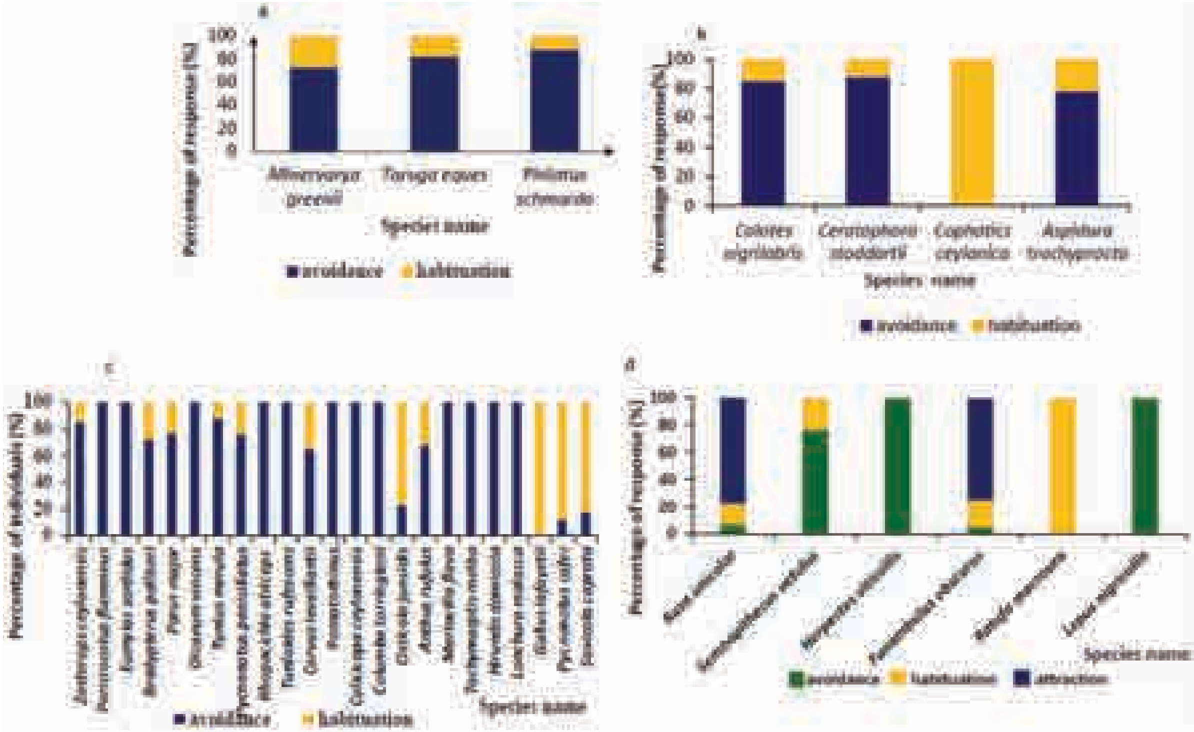

Figure 3. A—behavioral response of amphibians | B—behavioral response of reptiles | C—behavioral response of birds | D—behavioral response of mammals.

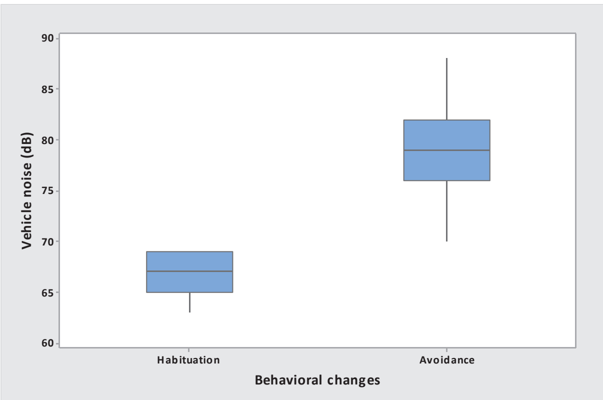

Figure 4. Behavioral responses against vehicle noise.

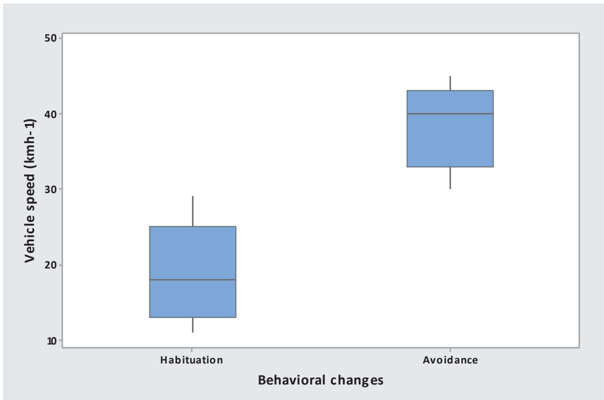

Figure 5. Behavioral responses against vehicle speed.

as nature trails adjacent to aquatic habitats than in other areas. Immobilization behavior of amphibians (Mazerolle et al. 2005) on road and nature trails leads to increased mortality rate. Pond-breeding amphibians (*Rana arvalis*) that migrate in large numbers to and from breeding sites, are particularly vulnerable to ''collisions'' with vehicles (Fahrig et al. 1995).

Reptile road-kills were also recorded in nature trails and roads. The possible reason could be snakes and lizards getting attracted to open patches created by roads to use as basking sites (Bambaradeniya et al. 2001; Karunarathna & Karunarathna 2005) which consequently improves foraging efficiency. Road-kills of birds were only recorded nearby the cloud forest of road site. Throughout the survey, the only recorded road-kill was of a Dull Blue Fly Catcher during its breeding months. Their nest sites being located in road banks and tree holes (Dharmarathne 2018) become a possible threat to this species, particularly by the visitor vehicles. Present study indicates that all road killed specimens of mammals were of small mammals.

Most amphibian and reptile road-kills were not identified to the species level due to rapid deterioration of carcasses by travelling vehicle and weather conditions. Present study indicated that *C. nigrilabris* has the highest average percentage of nature trail mortality compared to other lizards species in HPNP. The results highlight that road-kills occurred on road and nature trails are a threat to endemic species vertebrate fauna of HPNP, especially the amphibians and reptiles.

Highest photography disturbance was recorded on the nature trails. A lot of visitors preferred to take photographs in aquatic habitat and cloud forest of nature trails. Visitors were interested in taking photographs of chimney pool associated habitats and tetrapod vertebrates that lived in there. Visitors often involve in close approaches to wildlife for purposes of identification or photography (Green & Giese 2004), hence there is potential negative impact on animals, especially if flashes are used. Klein (1993) identifies photographers as the most disruptive disturbance. Display of attraction behavior of sambar was noticed due to animal feeding. Animal feeding was more prominent disturbance on roads than in nature trails.

All amphibians were displaying high amount of avoidance behavior indicating their high sensitiveness for the human presence. Black-lipped lizards, Rhino horn lizards and Common rough sided snake showed both avoidance behavior and habituation behavior. Habituation behavioral response was mostly recorded from Pygmy lizard which is a cryptic species that depends highly on its camouflage (Keerthiratne 2019). However, except for the Red Vented Bulbul, Pied Bush Chat, and Sri Lanka Jungle Fowl, most other species more frequently avoid the approaching visitors. Therefore, in general birds were one group that were highly disturbed by the human presence in these habitats. Dusky striped squirrel and Sambar displayed habituation, avoidance as well as attraction behavioral responses. These two species were frequently fed by visitors in the nature trail and could be identified as two species that prefers human feeding over their natural foraging. Certain individuals of these species could be observed habituated to sites where more visitors gather.

Avoidance behavior was recorded at high traffic noise level. High traffic noise poses a large impact on birds, making it difficult for them to establish and maintain their territory and attract mates. Moreover, Parris & Schneider (2009) suggest that it reduces their reproductive success. Due to the inability of detecting low frequency songs under traffic noise interference, they tend to sing at high frequencies (Slabbekoorn & Peet 2003).

Trampling disturbance was posing more danger to

Image 2. Road-kills in the study areas in HPNP: a—Endangered *Ceratophora stoddartii* | b—*Rattus montanus* | c—Endangered *Taruga eques* | d—Endangered *Calotes nigrilabris* | e—Near Threatened *Eumyias sordidus* © Tharanga Dasanayaka, Dulan Jayasekara, Chathuranga Dharmarathne.

Image 3. Photos of disturbances in the study areas in Park: a—Photography of cloud forest | b—Trampling of grassland | c—Animal feeding. © Tharanga Dasanayaka, Dulan Jayasekara, Chathuranga Dharmarathne.

C. nigrilabris which more often have their nest sites in the grassland habitat. Natural grazing ecosystem of *R. unicolor* was also damaged by trampling of grassland habitat. Egg masses of amphibians and some amphibians may be destroyed while trampling in aquatic habitat and cloud forest.

Management implications

Since HPNP is a national park, visitor disturbance and vehicle disturbance are always present in different levels in cloud forest, aquatic habitat and grassland of nature trail and road within HPNP. Effective visitor education is crucial in this regard whereby they understand how to protect wildlife while enjoying wildlife. Previous posters had displayed only sentences. If pictures are used to convince the humans regarding their restrictions within HPNP it will be more effective since people can quickly understand the pictures than sentences (without any language barrier). According to present data, a maximum vehicle speed limit of 30 km/h is recommended within HPNP. Road signs can be used to indicate that amphibians are crossing a road and indicate the vehicle drivers to drive carefully and slowly around aquatic habitats. If these measures do not reduce road mortality effectively, a shuttle service should be established especially during vacation periods. It can reduce the number of vehicles that enter HPNP. If medium sized buses are used as shuttles, a group of visitors could be served at one round. Moreover, some implementation should be applied in the vacation period to reduce vehicular disturbances such as parking reservations for private vehicles outside of the park. Animal feeding and trampling should be strictly prohibited within the park and if people contravene this rule that could be fined by department of wildlife conservation.

Appendix 1. Lat.-long. of starting to ending point within each transect of habitats.

Study sites		Cloud forest			Grasslands			Aquatic habitat		
	Transect	A	B	C	D	E	F	G	H	I
Nature trails	Start points	6.793160° 80.805249°	6.792020° 80.805369°	6.790795° 80.805298°	6.796226° 80.805046°	6.795560° 80.805128°	6.794735° 80.804905°	6.793655° 80.802986°	6.793006° 80.802009°	6.792414° 80.801383°
	End points	6.792394° 80.805579°	6.791502° 80.805230°	6.789718° 80.805417°	6.795560° 80.805128°	6.794735° 80.804905°	6.793867° 80.804257°	6.793086° 80.802415°	6.792409° 80.801318°	6.791904° 80.800601°
Roads	Start points	6.826310° 80.805438	6.826915° 80.806135°	6.829553° 80.806104°	6.806246° 80.805426°	6.808065° 80.804211°	6.810245° 80.802119°	6.830929° 80.806961°	6.832925° 80.807812°	6.838810° 80.811630°
	Ends points	6.826915° 80.806135°	6.827565° 80.806488°	6.830460° 80.806806°	6.807325° 80.805243°	6.808932° 80.803578°	6.811071° 80.801873°	6.831927° 80.807382°	6.833247° 80.808554°	6.839460° 80.812393°

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COMMUNICATION

Population density and nesting behaviour of Indian Giant Squirrel *Ratufa indica* (Erxlebeln, 1777) in Bhimashankar Wildlife Sanctuary, Western Ghats of Maharashtra, India

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Abstract: The Indian Giant Squirrel *Ratufa indica* (Erxlebeln, 1777) has been officially designated as Maharashtra's state animal. It is restricted to the eco-sensitive Western Ghats region and is currently classified as Least Concern species on the IUCN Red List. However, the species is dependent on intact habitat and is negatively impacted by habitat fragmentation. Population density and nesting behavior were studied in a major habitat in the tropical semi-evergreen and evergreen forest of India's Bhimashankar Wildlife Sanctuary. Two-hundred-and-twenty-three direct sighting along 60 km line transects were used to estimate squirrel density. It averaged 13.9±0.18 squirrels/km^2. Nesting characteristics were evaluated using 4,224 nests. The squirrel uses 52 different tree species for nesting, with *Mangifera indica* (15.57%), *Olea dioica* (14.65%), and *Mallotus phillippensis* (9.78%) being the most popular. The drays were found on trees that are taller than average, have a massive girth at the breast height, and have continuous closed canopies. To avoid predators, Indian Giant Squirrels usually flee to the nearest adjacent tree.

Keywords: Cryptic behaviour, drey, population density, rodent, Rodentia, sacred grove, Sciuridae.

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Author contributions: GR—Identification of Indian giant squirrels nesting sites, designing and finalizing of the techniques (methodology), field surveys and data collection, data analysis, data interpretation, and revision of the paper. EB—Conceptualization of study, guiding at every step and discussions periodically regarding the data collection. Writing the manuscript and correcting at every stage till it is finalised. KY—Finalization of topic, providing all necessary help for permissions, time to time discussion and submission of work.

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INTRODUCTION

The Indian Giant Squirrel *Ratufa indica* is the world's largest tree squirrel and can be found in a variety of forest habitats (Borges et al. 2008). It is most common in continuous forest canopies. Its large body size and intense vocalisations limit it to arboreal niches. It does, however, require continuous canopies to move through its territories. It is frugivorous and granivorous, making it an excellent natural pollinator. It constructs a globular nest out of leaves and twigs (Borges et al. 1989; Ramachandran et al. 1992). It's a good indicator of forest disturbance. Because of its widespread distribution across almost the entire subcontinent, it is currently classified as 'Least Concern' on the IUCN Red List. However, due to anthropogenic activities such as deforestation and habitat fragmentation, this species is declining (Rajamani & Marsh 2010).

The density of squirrel in Bhimashankar Rai (Riparian area within Bhimashankar) was reported to be 100 individual/km^2 (Borges et al. 1989). From 1992 to 1993, Mali et al. (1998) and Somnathan et al. (2007) conducted a status survey of *Ratufa indica* in protected areas and intervening reserved forests in the Western Ghats and central India. The survey confirmed the extinction of *Ratufa indica dealbata* in Gujarat and the vulnerable status of *Ratufa indica* in the Western Ghats of Maharashtra. The researcher also compared the Indian Giant Squirrel's home range and distribution in Bhimashankar Wildlife Sanctuary (Borges et al. 2007; Somnathan et al. 2007; Mehta et al. 2012). According to data from the intensive study area, the population's home range had decreased by 20% after a seven-year gap. The main reason for this decline was habitat degradation in the Bhimashankar Wildlife Sanctuary (Borges et al. 2007; Somnathan et al. 2007; Mehta et al. 2012).

MATERIALS AND METHODS

Study area

In 2019, this research was conducted throughout the Bhimshankar Wildlife Sanctuary (BWS). The sanctuary is located between the coordinates 19.132 ^{0}N and 73.554 ^{0}E. It has a total area of 131 km^2 (51 sq.mi.) and is located in the northern part of Maharashtra, in the Western Ghats. The sanctuary contains a variety of habitats, including steep slopes, plateaus, uplands, gorges, valleys, and cliffs. In the sanctuary's heart is an ancient Shiva temple. It is close to the source of the Bhima River. Bhimashankar has two ranges: Bhima 1 (Bhimashankar, Ahupe, Bhorgiri, Kondwal, Nigdale, Sakeri, Bhatti, Pathan, Yelavli, and Ghatghar beat.) and Bhima 2 (Slope and Plains on the konkan side of Bhimashankar, Razpa, Khopivali, Narivali, Zamburde, Dongarnave, Khandas, and Nandgaon beat).

The rainy season (June–October) brings an average of 3,000 mm of rain to BWS. Seasonal montane cloud forests can be found here. These forests have high conservation value because they serve as water catchment areas. Furthermore, the protected areas are rich in endemics such as epiphytes and bryophytes. The sanctuary is said to be home to over 529 faunal species, including the Giant Squirrel, Leopard, Golden Jackal, and Mouse Deer. Furthermore, approximately 20% of the mammals reported by BWS are listed in Schedule I of the Wildlife Protection Act (Borges et al. 1992; Somanathan et al. 2007).

The tropical ecosystem relies heavily on vegetation. The sanctuary's vegetation consists of evergreen, semi-evergreen, and moist-deciduous forests, with the latter two being the most prevalent. *Mangifera indica, Olea dioica, Macaranga peltate, Memecylon umbellatum, Atlantia racemose*, and *Xantolis tomentosa* are the main plant species in this sanctuary. *Carvia callosa* is widely distributed throughout the sanctuary (Ghate et al. 1994).

Population density

To estimate the population density of giant squirrels in the study area, the line transect method (Jathanna et al. 2008; Thomas et al. 2010) and distance sampling method were used. Field sampling was conducted from 20 May to 30 June 2019. During the study, we sampled the abundance of the squirrel using 43 randomly selected line transects. Each transect was surveyed between 0600 & 1000 h and 1600 & 1830 h. Each transect was different in length, ranging from 1–3 km. The squirrel was observed directly using a portable Garmin GPS etrex 10 receiver. A Bunshell pro Yardage sport 450 rangefinder was used to measure the direct distance of the observation, the height of the sighting, and the tree height. The population density of the Indian Giant Squirrel was estimated using distance-sampling techniques and a modelled detection function using the software Distance; version 6.0 (Thomas et al. 2010). The model with the Akaike information criteria (AIC) was chosen (Jathanna et al. 2008; Thomas et al. 2010). Squirrel cluster density (C) and standard errors were estimated by grouping the data into 10 m perpendicular intervals. To select the best model for estimating density, we used the minimum AIC as the standard model

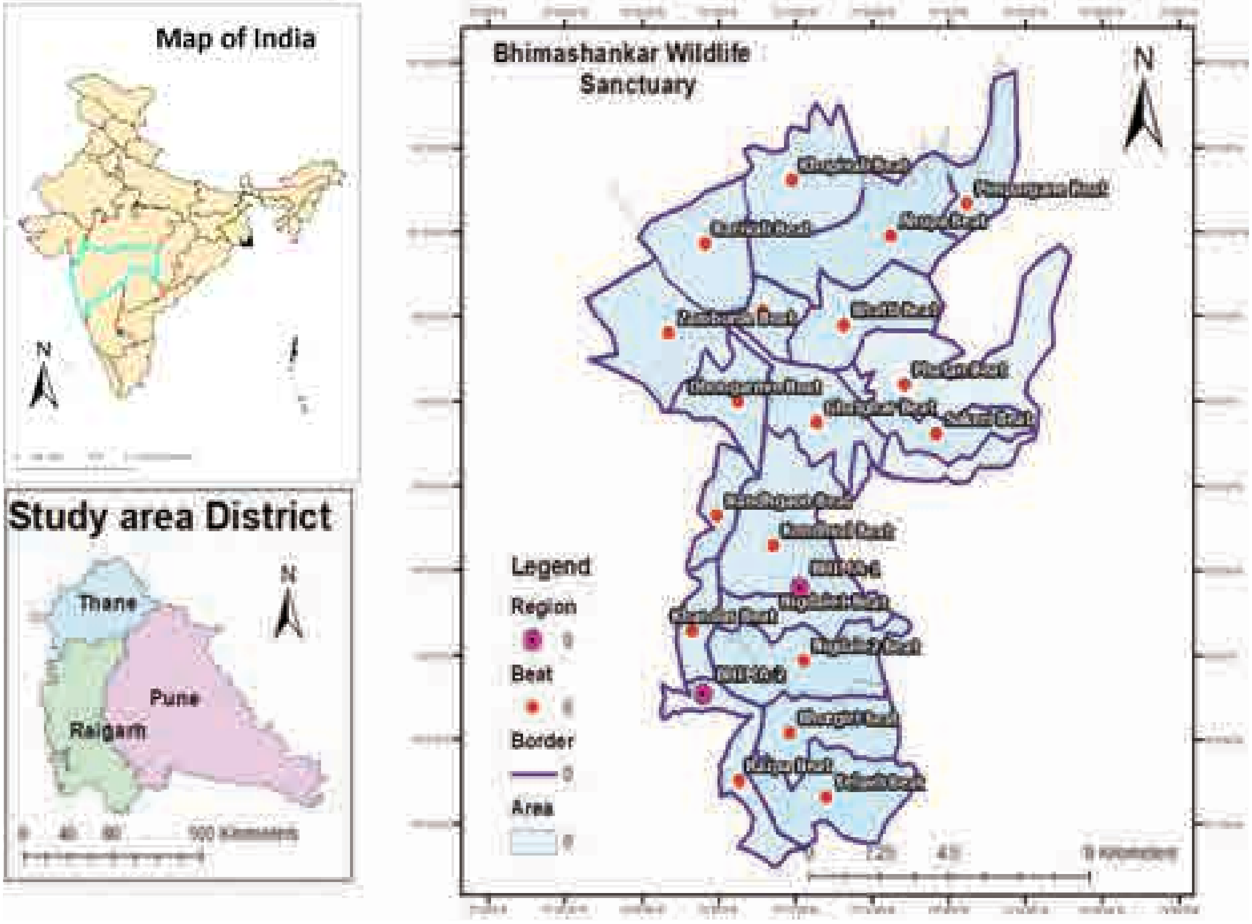

Figure 1. Map of the study area.

selection procedure.

Nesting characteristics

Data were collected when the squirrels were most active and visible in the morning between 0600 h & 1000 h and in the evening between 1600 h & 1830 h. To sample the squirrel nests, line transects were randomly placed. Nest quality (old/new), size, shape, thickness, and leaf compositions of the nest, host tree, tree height, girth at breast height (GBH), canopy height and continuity, and height of the nest from the ground were all measured. The nest's locations were recorded using a portable GPS receiver, the etrex 10. Trees were defined as plants with girths greater than 10 cm at breast height. DSLR camera (NIKON D3400) were used to photograph the nests and squirrels. Wherever possible, a standard Olympus binocular was used for observations as well as the identification of leaves used to build the nests.

RESULTS AND DISCUSSION

Population density

There were 223 sightings of Indian Giant Squirrels within the sanctuary's 43 line transect totalling 60 km. Half-normal with cosine proved to be the best fit for giant squirrel data based on the lowest AIC value (311.5) the encounter rate was 61.2 km per hour walked. The squirrel is known to be a solitary animal, as evidence by this study, which recorded no more than two individuals in a group. The mean group size was 0.929, and the group density per square km was 13.929 ± 0.18, in BWS (Table 1).

In comparison to reports from southern and central India (Jathanna et al. 2008; Baskaran et al. 2011), it is clear that the Indian Giant Squirrel population at BWS is relatively dense (Table 2). The variation in different estimates used and the differences between habitat types in the different studies could be the cause. Seasonal variation and observer differences, on the other hand, limit the comparison. Climate, environment,

Table 1. Population density and average group size of Indian Giant Squirrel (density/km2) estimated in Bhimashankar Wildlife Sanctuary.

Parameters	Value
No. of transects	43
Effort (km)	60
Number of group detection (n)	223
Key function model	Half-normal key
Key adjustment	Cosine
Detection probability	37.6
Effective strip width (m)	1.0
Encounter rate of group/km (n/l)	3.7
Encounter rate % CV	61.2
Mean group size	0.929
Group density/km^2	13.929 ± 0.18
Group density % CV	1.35
Group density 95% CI	13.56
AIC	311.5

Table 2. Density estimates of the Indian Giant Squirrel by earlier studies in India.

Study area	Density/km^2 of Indian giant squirrel	Authors
Bhimasankar Wildlife Sanctuary	13.92	Present study
Similipal Tiger Reserve	25.6	Palei et al. (2015)
Satpura National Park	5.59	Gurjar et al. (2013)
Madumalai Tiger Reserve	6.4	Ramesh et al. (2012)
Madumalai Wildlife Sanctuary	2.9	Baskaran et al. (2011)
Bandipur Tiger Reserve	2.36	Jathana et al. (2008)
Bhandra Tiger Reserve	12.25	Jathana et al. (2008)
Bhimasankar Wildlife Sanctuary	12.4	Borges et al. (1999)
Bhimasankar Wildlife Sanctuary	15.89	Mehta et al. (2011)

and topography all play a role in the distribution of this species. Several studies have suggested that tree cover and food plant diversity have a significant impact on the presence of the Indian Giant Squirrel in tropical areas (Jathanna et al. 2008; Baskaran et al. 2011; Mehta & Kulkarni 2011). The presence of a continuous canopy and the availability of more food plant species will allow for more favourable conditions in terms of their density. As a result of our research, BWS has the second largest population of Indian Giant Squirrels in India (Borges et al. 1999; Jathanna et al. 2008; Baskaran et al. 2011; Mehta & Kulkarni. 2011; Gurjar et al. 2013; Palei et al. 2015).

Habitat use and status

Forests are currently found in small fragments or riverine strips. They are thus frequently seen in Maharashtra's sacred groves and hill stations like Mahabaleshwer and Matheran, where the forest has been left relatively intact. As a result, the population's local status ranges from near threatened to endangered, and even locally extinct. This the determined by the size and integrity of the forest, the availability and abundance of food (floral diversity), and the appearance of the forest in areas where poaching is prohibited. Furthermore, connectivity between forest fragments may be linked to hunting pressure in forest corridors outside of protected areas. However, residents of Bhimashankar claim that this is no longer a serious concern (Image 1).

Food sources in most tropical forests are distributed at random in space and time (Fleming et al. 1987; Schaik et al. 1993). The giant squirrel, like other species, requires a diverse landscape with the preferred resources. Only 9% to 11% of tree species were not utilised by the giant squirrel (Borges et al. 2007) (Image 4 & 5).

Giant squirrels adapted to their arboreal habitat through a variety of morphological and behavioural adaptations. It is mostly graceful and can perform breathtaking leaps between trees. It feeds while suspended by its hind limbs only. Its long tails serve as a balancing mechanism. They used their teeth to break tree twigs and use those twigs to build their nests. Surprisingly, when food is scarce, these squirrels feed on the nesting materials (Borges et al. 1993a; Datta et al. 1998). The availability of resources and the costs of defence response are usually linked to aggressive and territorial behaviour (Datta & Goyal 1996; Baskaran et al. 2011) (Image 6).

Nesting

Nest characteristics: The Indian Giant Squirrel uses leaves and twigs to build large multi-layered globular shaped single chambered nests or dreys. These dreys are used for resting and sleeping, as well as nurseries. The size of the nest varies, but the largest one seen was about 75 cm x 60 cm.

The nests were typically built away from the main tree trunks, but approximately 10% of the dreys were found adjacent to the tree trunks or on thick branches. Because of the falling leaves, the nest was most easily found in march and April. During the monsoon season, nests remained mostly hidden in the canopy and were difficult to find due to the dense canopy (Image 2).

The globular dreys are usually built at the intersection of crowns of neighbouring trees. This allowed the squirrels to easily move from the drey to other trees for foraging and other daily activities. This observation is similar to Ramachandran (1998) and Rout & Swain (1996). A few nests were also constructed on trees that had no continuity with neighbouring trees.

Dreys were constructed by gathering soft leaves from nesting trees as well as other plant species such as *Butea monosperma*, *Mangifera indica*, *Syzygium cumini*, and *Mallotus phillippensis.* These squirrels do not always use the leaves of the host plants where their dreys are located. As a result, more research is needed to understand why some trees are used for nesting but their leaves cannot be used for the nest building. The nest's consistency and rigidity were achieved through the interweaving of leaves. According to a study of old and newly constructed fallen nests, the leaves were deposited in 4 to 5 layers, with the inner layer becoming soft and mat-like (Image 3).

Within its home range, the Indian Giant Squirrel builds multiple nests (6–8), 3–4 of which are used concurrently (Borges et al. 2007). During the survey, 4,224 dreys and 223 squirrels were spotted, with 27 directly using the nests. While 196 could be seen feeding or resting on the thick branches of the trees. Some squirrels may be resting in the dreys. As a result, the number of dreys was far greater than the total number of squirrel sightings.

Nesting Trees: During this survey, 4,224 dreys were supported by a total of 4,253 nesting trees from 52 tree species (Table 3). 51.51% were new and 47.80% were old. *Mangifera indica* (Amba) and *Olea dioica* (Karap) were the most preferred nesting trees, supporting 15.57% and 14.65% dreys, respectively (Figure 2). As a result, approximately one-third of the dreys are built solely on two tree species that were not the most abundant trees on the site. It suggests that squirrels prefer specific trees to build their dreys. The reason could be the feeding habitat and the quality of the leaves used as nest construction material.

Nesting (Dreys): Indian Giant Squirrel builds new globular nests out of green leaves, twigs, and branches. The dry and moist leaves, twigs, and branches are old, and some have fallen to the ground or nest materials have become unsettled. This observation is sufficient to identify the old nest.

Number of dreys vs Number of trees

Mangifera indica, *Olea dioica*, *Mallotus phillippensis*, *Syzygium cumini*, *Terminalia chebula*, *Ficus racemosa*, and *Amerphophallus commutatus* are the most common tree species in the forest. As a result, the squirrels do not choose the tree at random for nesting. However, leaves such as *Olea dioica* and *Mallotus phillippensis* are used selectively to construct the nests (Figure 4).

Tree height and nest height

The nest was observed in trees ranging in height from 3–45 m. Trees heights less than 9 m and greater than 36.5 m are only chosen on rare occasions (Figure 5). As a result, the number of dreys on these smaller trees was noticeably lower (Table 4).

According to the observation, the most preferred tree height classes for nesting of Indian Giant Squirrels were 12–24 m, which supported 60.16% of the total observed dreys. Tree heights less than 12 m supported only 11.40% dreys, while tree heights greater than 24 m supported only 28.42% dreys. The percentage of dreys on different tree height classes thus represents the Indian Giant Squirrels nesting preference at various heights. This highlights the importance of old-growth tall trees with large interconnected canopies that provide ideal habitat for giant squirrels. The dreys were built in the middle of small branches at a mean height of about 15 m above the ground, usually in the trees sub-canopy. The average tree height minus the average nesting heights was found to be 2.3 m. Based on the data, it can be concluded that the majority of the dreys were located very close to the top canopy, which protects the squirrels and their young from large predators such as Jungle cats, civets, Leopards, snakes, and raptors.

Each giant squirrel builds several nests within its territory. Nest building is an important activity and squirrels spent nearly 3% of total hours per day (Borges 1989a). Due to population density and the fact that some adults also use other nests, nest parasitism can be seen in Indian Giant Squirrels (Borges et al. 1999). Nests are large, dome-shaped structures with lateral opening, constructed using a framework of twigs and lined by leaf sprays usually built-in tall trees. Nursery nests are large and are built either in trees densely overgrown with lianas or in those with wide-spreading branches. The nests facilitate insulated resting places throughout the territory. This avoids extremes of temperature and rain at any time (Borges 1989b). In addition, rotation of nest may also help to reduce ectoparasite load on the squirrels.

Nest construction was mostly similar in pattern. It was constructed by depositing a large no of forked twigs with leaves. The leaves were arranged in three to four layers. The nest-building process Indian giant squirrel includes a gathering of materials (cutting twigs, peeling barks), carrying materials in the mouth to the nest site, and placing materials in the nest once completed. At

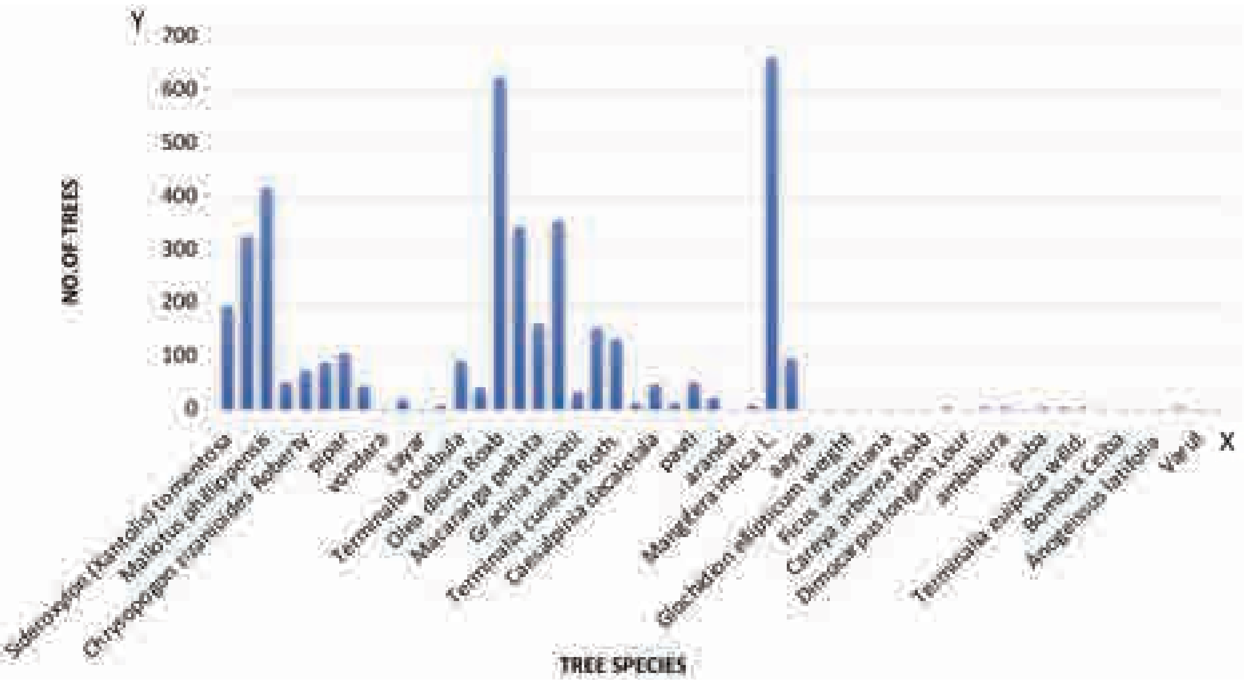

Figure 2. Nesting trees of Indian Giant Squirrel at Bhimashankar Wildlife Sanctuary.

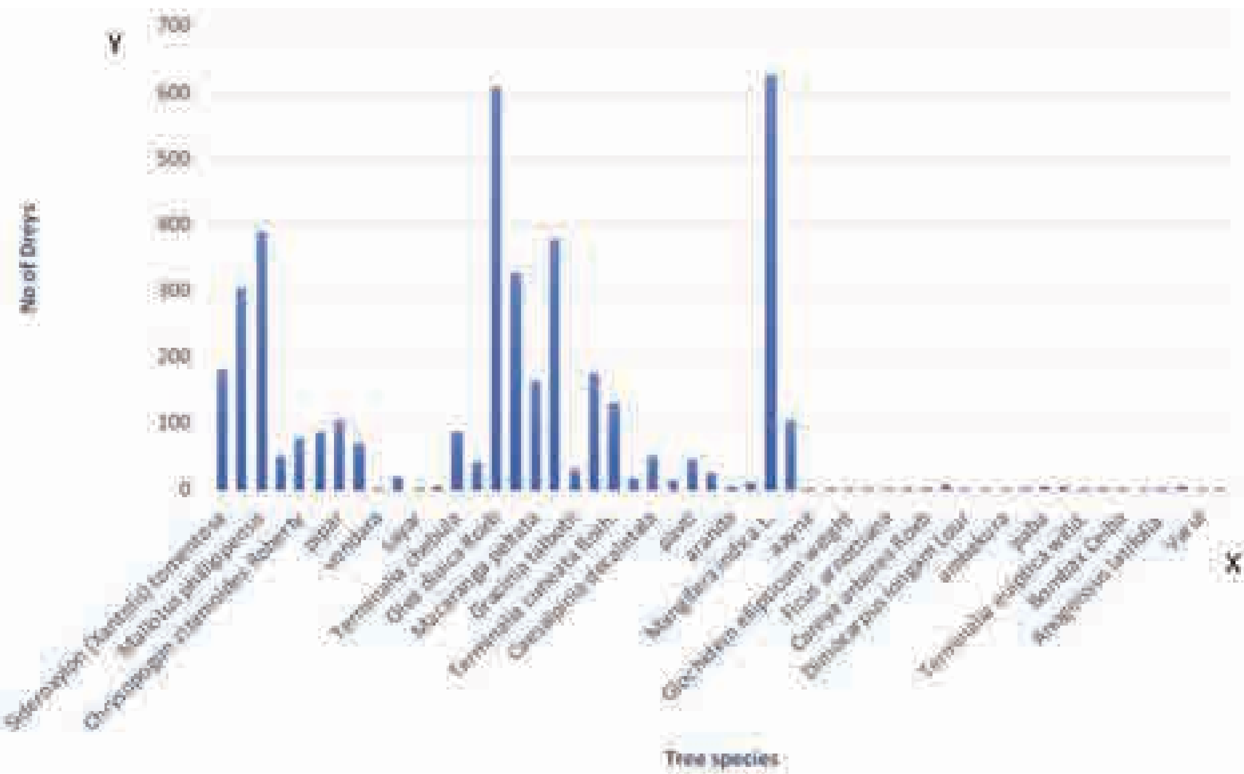

Figure 3. Dreys of Indian Giant Squirrel at Bhimashankar Wildlife Sanctuary.

Table 3. Nesting behavior and nesting characteristics of Indian Giant Squirrel at Bhimashankar Wildlife Sanctuary.

	Nesting tree species	Local name	No. of trees	Old nest	New nest	No. of dreys	% of trees	% of dreys
1	*Acalypha brachustachya*	Khokali	2	0	2	2	0.05%	0.05%
2	*Actinodaphne*	Malva	345	160	167	327	8.11%	7.74%
3	*Amerphophallus commutatus*	Loth	156	88	89	177	3.67%	4.19%
4	*Anogeissus latifolia*	Dhavda	2	0	1	1	0.05%	0.02%
5	*Atalantia*	Chingar	89	47	42	89	2.09%	2.11%
6	*Bombax Ceiba*	Savar	1	0	1	1	0.02%	0.02%
7	*Bridelia squamosa*	Ashind	8	3	8	11	0.19%	0.26%
8	*Bridellia retusa*	Asana	3	1	2	3	0.07%	0.07%
9	*Butea menosperma*	Palas	24	17	10	27	0.56%	0.64%
10	*Caesalpinia decaletala*	Chilahr	48	24	28	52	1.13%	1.23%
11	*Careya arberea*	Kumbh	1	0	1	1	0.02%	0.02%
12	*Catunaregam spinosatirumes*	Gel	11	9	5	14	0.26%	0.33%
13	*Chrysopogon zizanioides*	Yalaa	74	41	35	76	1.74%	1.80%
14	*Dimocarpus longam*	Umb	1	1	0	1	0.02%	0.02%
15	*Ficus arnottiana*	Payar	1	1	0	1	0.02%	0.02%
16	*Ficus racemosa L.*	Umber	45	36	35	71	1.06%	1.68%
17	*Glochidion ellipticum*	Bhoma	1	0	1	1	0.02%	0.02%
18	*Gracinia talbotii*	Fanasada	33	11	22	33	0.78%	0.78%
19	*Grewia serrulata*	Dhaman	20	10	10	20	0.47%	0.47%
20	*Heterophragma quadriloculare*	Varas	41	17	26	43	0.96%	1.02%
21	*Jatropa curcus*	Aranda	3	4	2	6	0.07%	0.14%
22	*Konkiri*	Konkiri	11	6	11	17	0.26%	0.40%
23	*Lepisanthes tetraphylla*	Lokhandi	7	3	4	7	0.16%	0.17%
24	*Macaranga peltata*	Chandada	163	87	79	166	3.83%	3.93%
25	*Mallotus phillippensis*	Shendri	416	179	212	391	9.78%	9.26%
26	*Mangifera indica*	Amba	662	285	343	628	15.57%	14.87%
27	*Mitragyna parvifolia*	Kalmba	4	0	2	2	0.09%	0.05%
28	*Olea dioica*	Karambu	354	187	191	378	8.32%	8.95%
29	*Olea dioica*	Karap	623	287	324	611	14.65%	14.46%
30	*Phyllanthus emblica*	Avla	1	1	0	1	0.02%	0.02%
31	*Pongamia pinnata*	Karanj	5	2	4	6	0.12%	0.14%
32	*Schleichera oleosa*	koshimba	6	5	4	9	0.14%	0.21%
33	*Sideroxylon* (*Xantolis*) *tomentosa*	Kombal	196	113	70	183	4.61%	4.33%
34	*Syzygium cumini*	Jambal	326	142	164	306	7.67%	7.24%
35	*Terminalia chebula*	Majkudhal	92	44	45	89	2.16%	2.11%
36	*Terminalia chebula*	Heerda	53	24	29	53	1.25%	1.25%
37	*Terminalia cuneata*	Sadhda	132	63	67	130	3.10%	3.08%
38	*Terminalia eliptica*	Ain	4	2	2	4	0.09%	0.09%
39	-	Pipar	106	53	53	106	2.49%	2.51%
40	-	Vondara	1	0	1	1	0.02%	0.02%
41	-	Sayar	1	0	1	1	0.02%	0.02%
42	-	Adhal	8	2	5	7	0.19%	0.17%
43	-	Pavti	53	20	26	46	1.25%	1.09%
44	-	Sandha	96	52	55	107	2.26%	2.53%

	Nesting tree species	Local name	No. of trees	Old nest	New nest	No. of dreys	% of trees	% of dreys
45	-	Aayna	3	0	1	1	0.07%	0.02%
46	-	Bhonda	1	0	1	1	0.02%	0.02%
47	-	Ambakura	7	1	2	3	0.16%	0.07%
48	-	Paba	7	3	4	7	0.16%	0.17%
49	-	Padal	1	1	0	1	0.02%	0.02%
50	-	Pareli	2	0	2	2	0.05%	0.05%
51	-	Varul	1	0	1	1	0.02%	0.02%
52	-	Sajeri	2	1	1	2	0.05%	0.05%
	Total		4253	2033	2191	4224	100.00%	100.00%

Table 4. The height class intervals with the numbers of dreys, number of trees, and number of new and old dreys.

Tree height (class interval)	Class AV. Tree height (m)	No. of trees	No. of dreys	Old nests	New nests	% Of dreys
10–19	4.5	120	118	43	75	2.793561
20–29	7.5	145	142	46	96	3.361742
30–39	10.6	220	218	95	123	5.160985
40–49	13.6	627	624	177	447	14.77273
50–59	16.6	755	753	270	483	17.8267
60–69	19.7	602	600	238	362	14.20455
70–79	22.7	575	571	282	289	13.51799
80–89	25.7	258	256	118	138	6.060606
90–99	28.8	150	149	65	84	3.527462
100–109	31.8	220	218	117	101	5.160985
110–119	34.8	170	168	72	96	3.977273
120–129	37.9	115	114	52	62	2.698864
130–139	41.0	170	169	87	82	4.000947
140–149	43.9	126	124	55	69	2.935606
Total		4253	4224	1717	2507	100%

the building site, the twigs were forced into place with a forwarding thrusting movement of the snout and alternate stamping motion of the forefeet (Kumbhar et al. 2012). The squirrel frequently builds dreys and uses more than one nest within his territory. Nonetheless, they came to the nest every morning and evening. The Indian giant squirrel did not use the nest on the first day of completion, but it was used by the individuals the following day. The total time spent on the nest building was approximately 2.5 hours. The occurrence of multiple nest might be either to escape from predators like langurs, Bonnet Monkeys, small cats or to provide protection from climatic factors like temperature, cold, and rain. Freshly constructed nests were observed from May to June. Yet the multiple nest phenomenon requires further investigation.

The nest of the Indian Giant Squirrel was distinct from a bird's nest in having leaves of nesting trees interwoven in the middle of the trees. The nest was either round or oval. The entry of the nest was placed horizontally to the ground. The entrance was around 10 cm in diameter. All nests sighted in the study area were observed to be east-facing, which might be related to morning sunlight. The depth of the nest was 48 cm and the inner diameter was 24 cm. Only a few hairs and food particles were found in the nest chamber but no faecal matter. One old nest of the Indian Giant Squirrel was located in *Ficus racemosa* where 113 twigs were used for constructing that nest. Nests were very often found at the highest point on the tree that offered maximum security and protection to the animal (Pradhan et al. 2012).

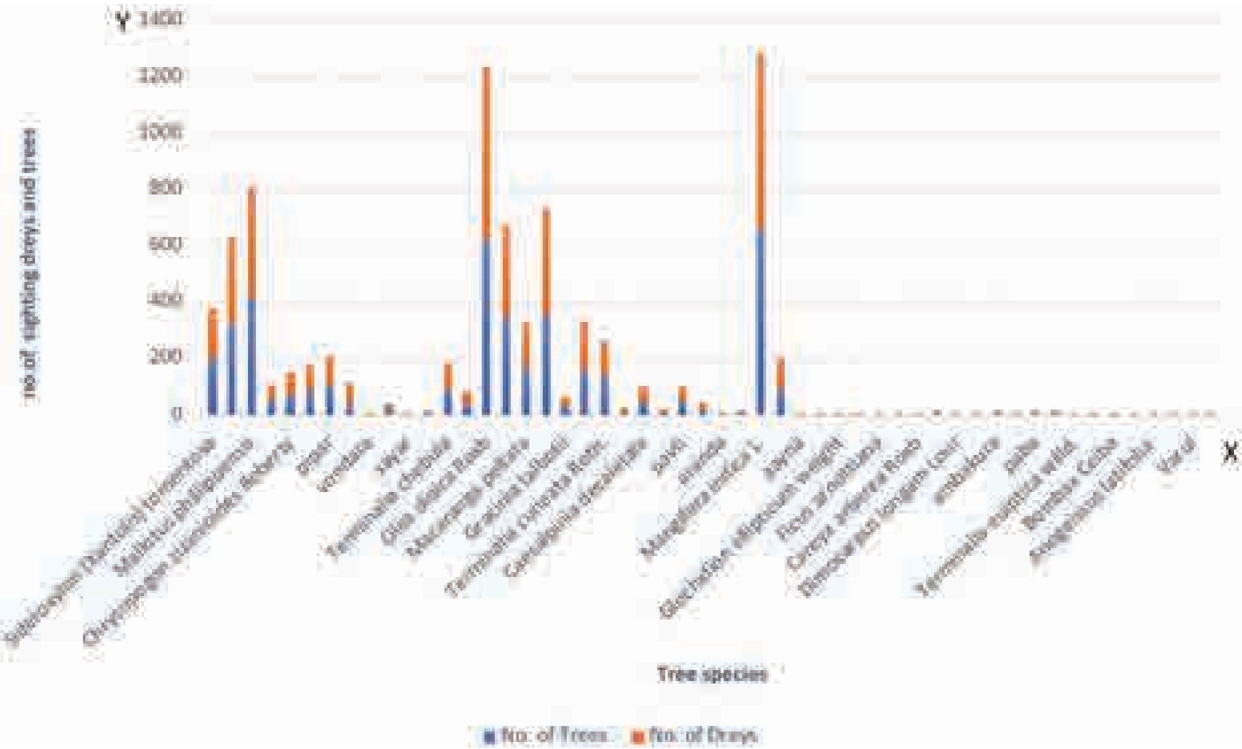

Figure 4. Nesting behaviours can show the number of trees vs number of dreys in Bhimashankar Wildlife Sanctuary.

Figure 5. Tree height preference for nesting by Indian Giant Squirrel in Bhimashankar Wildlife Sanctuary.

CONCLUSION

The finding of the present study suggests the significant importance of the conservation of the Indian Giant Squirrel and its habitat. It will facilitate further research on the density and nutrient composition of forage plants of the species. The tropical forests are in danger of losing their habitats due to anthropogenic activities such as grazing and firewood collection, which indicates a decline in the population of giant squirrels in these areas. More significant conservation implementation measures, such as nature trails and roads, can be well planned. Therefore, the provision of adequate forest officers to monitor the animal and systematic scientific research focusing on an inclusive conservation strategy are a matter of urgent need.

Image 1. Old dreys of Indian Giant Squirrel.

Image 2. New nest by the Indian Giant Squirrels.

Image 3. Fallen drey of Indian Giant Squirrel.

Image 4. Indian Giant Squirrel feeding on *Mangifera indica* fruits.

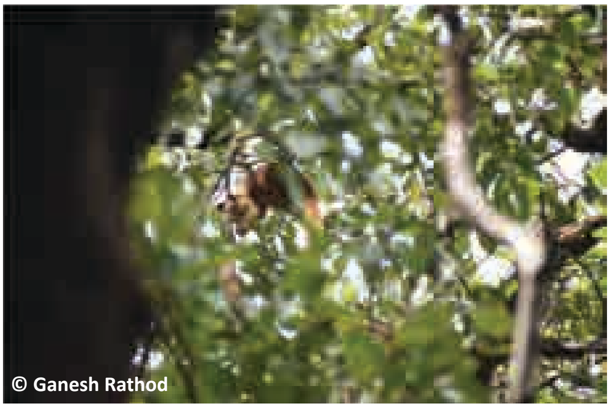

Image 5. Indian Giant Squirrel feeding on *Ficus racemosa*.

It is not only restoring the habitat and control the anthropogenic pressure but also helps the long-term conservation and management of the species.

Image 6. Indian Giant Squirrel holding the branch with the feet and balancing with tail.

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COMMUNICATION

First camera-trap confirmation of Tibetan Brown Bear *Ursus arctos pruinosus* Blyth, 1854 (Mammalia: Carnivora: Ursidae) with a review of its distribution and status in Nepal

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Abstract: The Tibetan Brown Bear *Ursus arctos pruinosus* is a large mammalian carnivore of high-altitude environments that is closely associated with the pastoral landscape. Limited information is available on this species, probably due to its rarity in the Himalaya. To date, scientific evidence of the presence of Tibetan Brown Bears has not been reported officially. The information presented here is based on data collected in the central Himalayan region of Nepal in 2003–2014 during biodiversity surveys and other research. Methods included random walks along livestock trails, transect surveys, opportunistic camera trapping, and herders' reports & interviews. This is the first camera-trap confirmation of the Tibetan Brown Bear in the central Himalaya. The distribution map was updated based on direct observation, signs and field reports gathered from reliable sources. The presence of signs (diggings, footprints, and feces) and direct observation in the Annapurna-Manaslu landscape reveal that bears are closely associated with Himalayan marmots and other small rodents. Local folklore, legends, and cultural beliefs have played important roles in Brown Bear conservation in the central Himalaya.

Keywords: Distribution, first record, central Himalaya, subspecies.

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INTRODUCTION

Bears are distributed in a wide variety of habitats. Of eight global species, three are found in Nepal: the Sloth Bear *Melursus ursinus*, the Asiatic Black Bear *Ursus tibetanus*, and the Brown Bear *Ursus arctos* (Chetri 2008). The habitats of these species in Nepal are separated by altitude; Sloth Bears are mainly distributed in the lowland protected areas and Terai plains (<1,000 m), the Asiatic Black Bear in the middle mountains up to the treeline (>1,000 m up to 4,000 m), and the Brown Bear above the treeline (4,000–6,000 m; Madhu Chetri pers. obs.). The Brown Bear is a protected species under the National Park and Wildlife Conservation Act of 1973 of the government of Nepal (GoN). The taxonomic classification of this species at the subspecies level is contradictory (https://dnpwc.gov.np/en/mammals/). In the protected list of GoN it is listed as Himalayan Brown Bear. Similarly, a recent taxonomic study revealed that the Asiatic Black Bear found in the Nepal Himalaya belongs to a subspecies Himalayan Black Bear *Ursus tibetanus laniger* (Kadariya et al. 2018).

In the Himalaya, information concerning Brown Bears is limited (Chetri 2008; Aryal et al. 2010). In nearby China, a population of about 5,000 bears has been reported (Wu 2014). Brown Bears often come into conflict with humans by killing livestock. In Qinghai-Tibetan Plateau they are considered dangerous as they damage houses and injure people (Worthy & Foggin 2008). The population of Brown Bear in Nepal is estimated to be as few as 20 individuals (Jnawali et al. 2011), based on anecdotal reports. Bear signs (diggings, pugmarks, and feces) are mostly seen during the summer in high-altitude pastures. Their fur color ranges from sandy to reddish-brown, and varies individually and seasonally from dark to light. White tips in their hair give the coat a silvery tinge, nose color variable, patches of variable size, and often show a shoulder hump distinctive from other bears. Usually, they have a highly variable white, cream, or buffy collar across the shoulder. They feed on grasses, forbs, berries, roots, insects, and other small mammals as well (Aryal et al. 2012; Nawaz et al. 2019).

To date, very little ecological research has been done on Brown Bears in the Himalaya. The species is listed on the IUCN Red List of Threatened Animals as 'Least Concern' (McLellan et al. 2017). In Nepal, the Brown Bear is listed as Critically Endangered in the National Red Data List (Jnawali et al. 2011) and protected under schedule 1 of the National Parks and Wildlife Conservation (NPWC) Act, 1973. Brown Bears are also listed under Appendix II of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES 2019).

The main objective of this study was to provide information with regards to the camera trap records of Tibetan Brown Bear in upper Mustang, and update distribution information for the Nepal Himalaya. The present manuscript resulted from the long-term systematic biodiversity surveys and monitoring (2003–2014) in the Annapurna-Manaslu landscape.

MATERIALS AND METHODS

Study area

The main study area is located (28–29 °N, 83–85 °E) in the northern part of Annapurna Conservation Area (ACA) and the Manaslu Conservation Area (MCA) in the central Himalaya of Nepal (Figure 1). These two conservation areas represent 27% of the protected areas (http://www.dnpwc.gov.np) and harbor a unique assemblage of trans- and semi-Himalayan flora and fauna diversity of global significance. The distribution of species is also governed by topography, microhabitats, and altitudinal gradients. Above the treeline, the areas represent a grassland typical of the Tibetan plateau and landscapes continue to the Tibetan Autonomous Region of the People's Republic of China. The Bharal *Pseudois nayaur*, Tibetan Argali *Ovis ammon hogdsoni*, Kiang *Equus kiang*, and Tibetan Gazelle *Procapra picticaudata* are the dominant ungulates found in Brown Bear habitats. The grassland habitats also support the Himalayan Marmot *Marmota himalayensis*, along with several species of pikas and voles. The high-altitude habitats are also home to several predator species such as Snow Leopard *Panthera uncia*, Himalayan Wolf *Canis lupus chanco*, Golden Jackal *Canis aureus*, Red Fox *Vulpes vulpes*, Tibetan Sand Fox *Vulpes ferrilata*, Eurasian Lynx *Lynx lynx*, weasels *Mustela* spp., and marten *Martes* spp.

The local economy is mainly based on animal husbandry. The main livestock consists of yaks, cattle-yak hybrids (dzo, jhopas), dwarf lulu cows, horses, goats, and sheep. Local people residing within the conservation area use all accessible areas for livestock grazing. In the study area, the density of livestock is five times higher than that of wild ungulates (Chetri et al. 2017).

Field surveys, data collection and compilation

Information about Brown Bears was compiled from various biodiversity and monitoring surveys, village reports, and interviews. In 2003–2006, four biodiversity monitoring efforts were conducted in the upper Mustang of ACA as part of the requirement of the

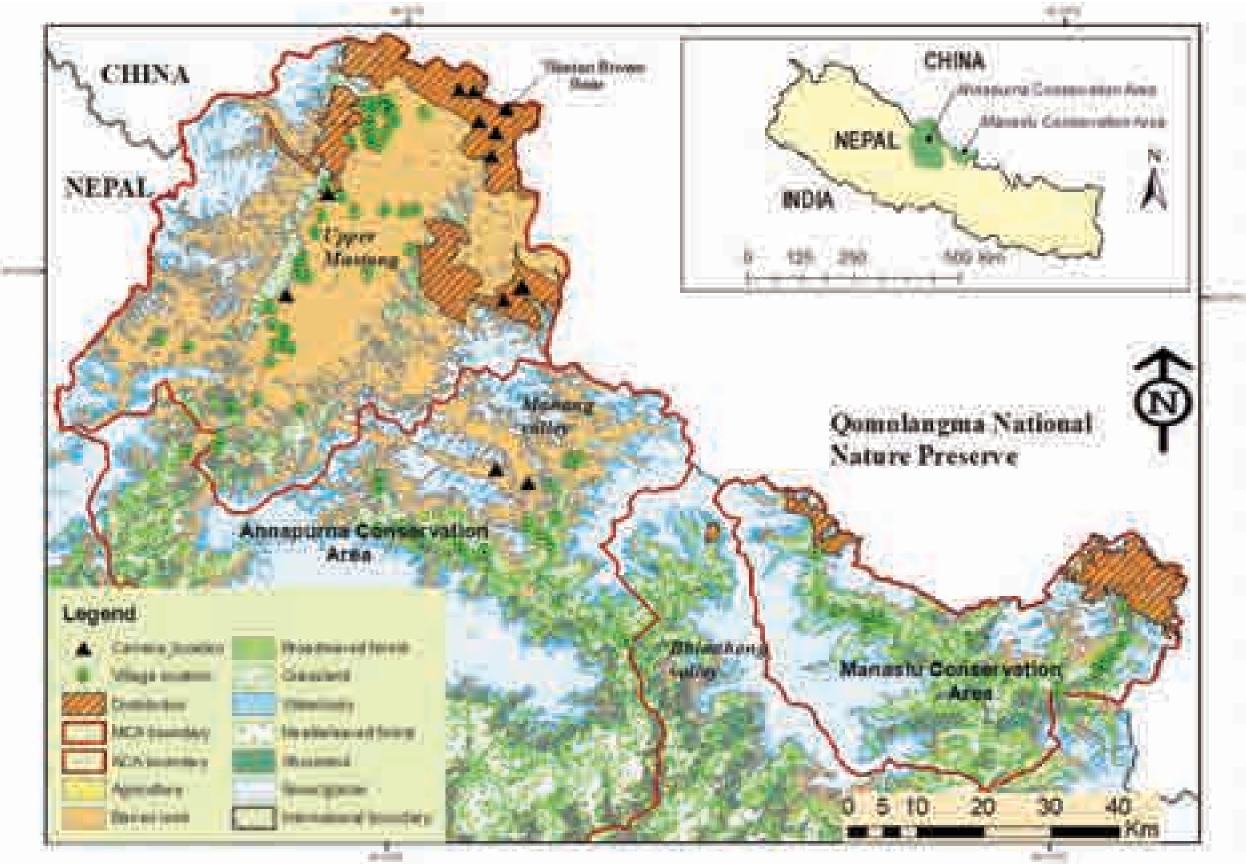

Figure 1. Map showing the location of Tibetan Brown Bear record sites and distribution of signs in Annapurna-Manaslu landscape, central Himalaya.

biodiversity conservation project funded by the UNDP-Global Environment Facility. The surveys in 2007–2008 and 2011–2012 in ACA and MCA were conducted as part of the biodiversity monitoring program of the National Trust for Nature Conservation through its Annapurna and Manaslu Conservation Area Project. The survey in 2013–2014 was a part of the author's Ph.D. fieldwork. Altogether, 10 years of survey data were compiled to show the distribution pattern of the Brown Bear in the Annapurna-Manaslu landscape. Data were collected from a random walk along the livestock trails (2003–2012), and well-defined transects (2013–2014). The occurrence of the Tibetan Brown Bear was confirmed through camera trap images. Observation of signs such as digging, feces, and footprints were also recorded from the same landscape. The Brown Bear digging signs are easy to identify as it excavates the pasture area in search of Himalayan Marmot, which is also an important prey (Chetri 2008; Aryal et al. 2010). Additionally, digging areas contain claw marks, pugmarks and sometimes hairs. Feces is easy to identify as it is usually deposited in the form of a dung pile (Image 1). Feces in the form of single scat are very large compared to Snow Leopards, Wolves, and Red Foxes, whose habitats are closely associated with Brown Bear in the study area. Only fresh signs were recorded as bear presence. In addition, during 2013–2014, six Reconyx HC550 HyperFire camera traps were used to obtain photographs of the species. The cameras were set in a strategic location where the probability of getting pictures was higher. Camera traps were deployed in 12 locations and the number of camera traps days varied (1–42 days) depending on survey time, availability of suitable habitats, human disturbances, and duration of field works (Figure 1). Besides, possible areas were scanned from the vantage point in the early morning and the afternoon using binoculars (10 x 50 and 12 x 50) and spotting scopes (Nikon ED III spotting scope). In addition, villagers and herders, whenever encountered in the pastures, were also asked about the bear sighting and fresh diggings signs.

RESULTS

Direct sightings of the Tibetan Brown Bear and local villager's reports

Direct sightings of the Tibetan Brown Bear, digging signs, and footprints recorded in various pastures of the Annapurna-Manaslu landscape are given in Table 1. The presence of the species was also confirmed from MCA. During May 2008, a yak herder reported sightings of four bears (two adults and two cubs) near the Tibet border at 5,100 m in Samdo pasture (Dorje Lama, pers. comm. November 2014). In September 2013, one yak herder spotted two bears digging a marmot den in Bhajo kharka (Sherap Lama pers. comm. October 2013).

Camera traps and signs

Of the 12 camera locations, Tibetan Brown Bear were only photographed in Kopchum Jhalam (29.24 °N, 84.15 °E, 5,000 m) in Dhalung-Chhujung rangeland of upper Mustang of ACA (Image 2A–C). The camera was deployed in a cliff area having single livestock trail leading to a narrow gorge and a small stream. Other interesting species photographed by the camera traps are: Himalayan Wolf, Snow Leopard, Red Fox, Steppe Polecat *Mustela eversmanii*, and Tibetan Dwarf Hamster *Cricetulus alticola*. Among all these species, the most frequently photographed species were the livestock and the Himalayan Wolf. The Tibetan Brown Bear signs - footprints, diggings, and feces were encountered in an area where Himalayan Marmots are present.

Distribution update of Brown Bear in Nepal

Various survey records show five important areas of Tibetan Brown Bear distribution in the Annapurna-Manaslu landscape. These include the upper Mustang region—the Damodar Kunda valley, Dhalung-Chhujung valley, Ghemi lekh in upper Mustang of ACA—and the upper reaches of Tsum and Nubri valley in MCA (Table 1, Figure 1). Recent information reveals that the Brown Bear is also present in Limi valley in Humla district (Naresh Kusi pers. comm. November 2021). Local villagers have also photographed this species from Yangma in Kanchenjunga Conservation Area (Hem Raj Acharya pers. comm. August 2021). In 2020, Brown Bears were

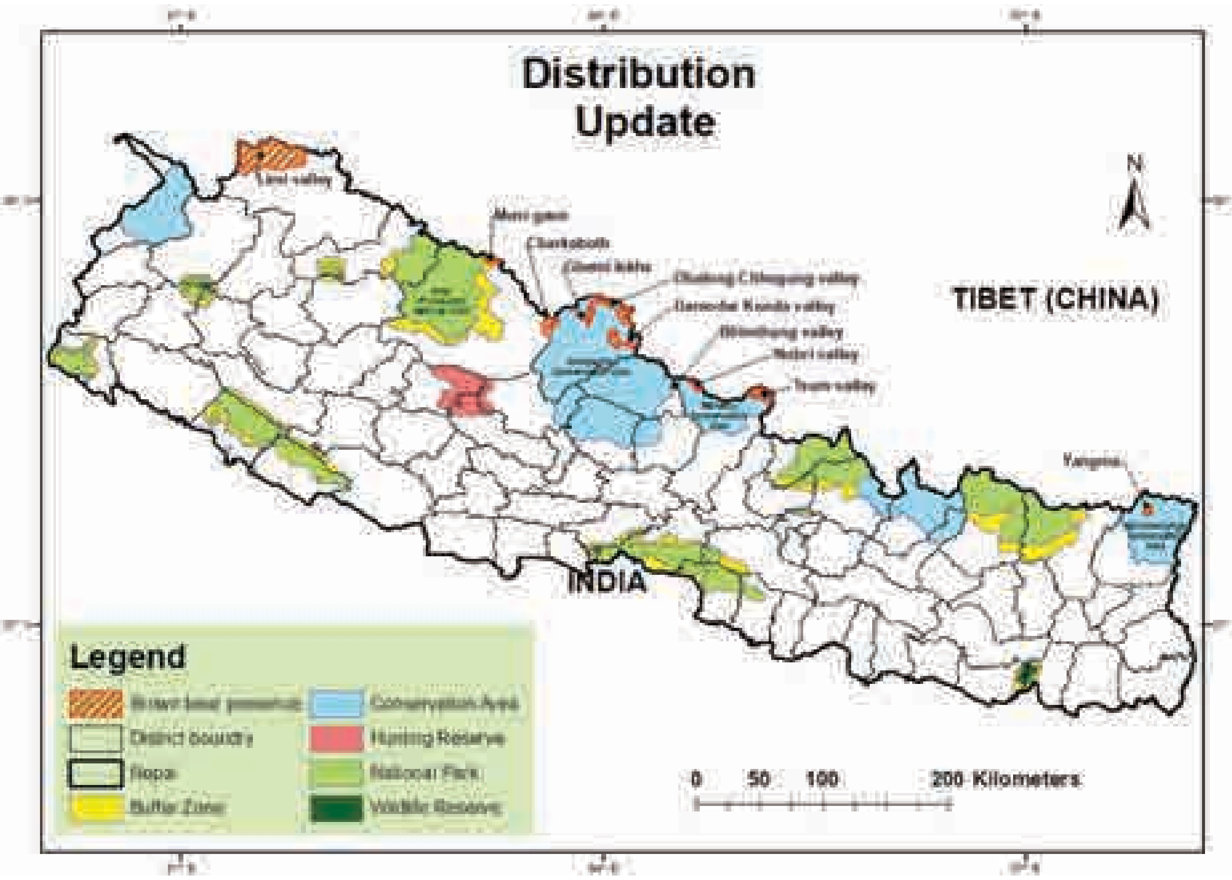

Figure 2. Distribution update of Brown Bear in Nepal Himalaya.

Table 1. Records of Tibetan Brown Bears in Annapurna-Manaslu landscape, central Himalaya – direct sightings, camera traps, and herder reports.

	Date (month.year)	Area	Record type	Altitude (m)	Remarks
1	07.2014	Kopchung Jhalam (Dhalung-Chhujung)	Camera trap	5000	Camera trap photo
2	05.2014	Dhalung-Chhujung	Direct sighting-1 adult	4800	Ridgeline
3	09.2013	Bhajo kharka	Direct sighting-2 adults, Yak herder report	4800	Digging marmot den
4	05.2008	Samdo pasture	Direct sighting-2 adults & 2 cubs, yak herder report	5100	Along Nepal-Tibet border
5	09.2007	Lower Damodar Kunda	Direct sighting-1 adult	5200	Digging marmot den
6	08.2005	Kekyap pasture (Ghemi lekh)	Direct sighting-2 adults, yak herder report	5300	Digging marmot den
7	07.2003	Shya Pasture	Direct sightings-villagers report	4800	Digging marmot den

captured in a camera trap from 'musi gaun' in Shey Phoksundo National Park (Gopal Khanal pers. comm. September 2021). All these areas abut with the Tibetan border in the north. Based on direct observation, signs, and field reports obtained from confirmed sources, a distribution map of Brown Bears was updated (Figure 2).

DISCUSSION

In the Himalaya, two subspecies of Brown Bear are recognized: *Ursus arctos isabellinus* and *Ursus arctos pruinosus*. The population in the central Himalaya of Nepal is thought to be connected to the large Tibetan Brown Bear population (McLellan et al. 2016). Nepal's location is such that there is possibility of *isabellinus* in the west and *pruinosus* in the east. The ssp. *isabellinus* occurs in Uttarakhand, and hence it is plausible both subspecies may occur in the Nepal Himalaya. According to Pocock (1941), these two subspecies have a distinct skull feature. Also, the Himalayan Brown Bear is characterized by its paler and reddish-brown fur, while the Tibetan Brown Bear has generally darker fur with a developed, white or light yellowish 'collar' around the neck. Image 2 shows a distinct collar around the neck and a darker grizzly fur, small ears with black fur on legs and feet and well distinct shoulder hump are a common physical characteristic of the Tibetan Brown Bear (Lydekker 1897; Sowerby 1920; Pocock 1941). In 2014, a nomadic herdsman (Sonam Norbu) collected a hair sample from Chunjung upper Mustang, Nepal which is close to camera trap location and genetic analysis revealed that the sample belonged to Tibetan Brown Bear (Lan et al. 2017).

The photographs obtained from a camera trap in upper Mustang were sent for confirmation to experts, and based on morphology and pelage pattern, sighting of Tibetan Brown Bear was confirmed (Dave Garshelis pers.comm. December 2020; Xue Yadong pers.comm. December 2020). A small and isolated population of Himalayan Brown Bear was found at higher elevations in the western Himalaya, ranging from mid-Uttarakhand to Jammu & Kashmir in India up to Pakistan. It is unknown whether this subpopulation is connected to Tibet or not (McLellan et al. 2016). Recent genetic study shows that *Ursus arctos isabellinus* is one of the first branching clades within the Brown Bear lineage, and *Ursus arctos pruinosus* diverged much later (Lan et al. 2017). It was also shown that extant bears in the region are likely descendants of populations that survived in local refugia during the Pleistocene glaciations (Lan et al. 2017). This is the first camera trap confirmation of the extant of Tibetan Brown Bear in the central Himalaya of Nepal. Earlier in September 2007, the author captured a video of a Brown Bear from the eastern part of upper Mustang-the Damodar Kunda Valley (Chetri 2008). However, the subspecies could not be confirmed as the picture was blurry and taken from a long distance using a camera mount on the spotting scope.

In the Annapurna-Manaslu landscape, signs of Brown Bears are found at an altitude ranging from 4,000–6,000 m. The distribution of Brown Bears correlates with the presence of Himalayan Marmot and other small rodents. Flat alpine grassland with <10° slope, and the valley floor is the most suitable habitat for diggings. Livestock trails are also used by Brown Bears. The present distribution ranges show that the habitat of Tibetan Brown Bears is contiguous with the Tibetan border. In the Manang and Naar-Phu valley of ACA, no signs of Brown Bears have been detected (Figure 2). Evidence of marmot presence in these two valleys is not known until date, which is one of the key prey species of Brown Bears (Aryal et al. 2012). Brown Bear signs were also recorded farther west of upper Mustang, i.e., the area between Shey Phoksundo

Image 1. Signs of Brown Bear in Annapurna-Manaslu landscape: A—Diggings for Himalayan Marmot | B—Feces (in the form of dung pile) | C—Single Feces | D—Resting site | E—Resting site. © Madhu Chetri.

National Park and ACA. Aryal et al. (2012) also reported the presence of bears in the area. Recent reports and evidence suggest that they are also distributed in the eastern and far-western regions of Nepal Himalaya (Figure 2). This suggests that research on Brown Bears has not been prioritized in Nepal, probably due to their rarity and logistical difficulties, as they inhabit harsh habitats. Long-term biodiversity monitoring surveys reveal that the Himalayan marmot population is highly fluctuating year-to-year, and in some areas they are locally extinct. Only traces of old dens can be seen in some pastures in upper Mustang. Monitoring of marmots and other small rodents is essential as they are also an important prey species of sympatric carnivores associated with the Brown Bear.

Several important areas and habitats are identified in the upper Mustang of ACA. These include the Damodar Kunda valley, Dhalung-Chhujung valley, and Ghemi lekh. In the MCA, several signs were recorded in the eastern part (Nubri valley) as well as the western part (Tsum valley) in the flat plains and the areas close to the Tibetan border. Signs of Brown Bears can be seen in

Image 2. Tibetan Brown Bear in the upper Mustang of ACA: A—Frontal view – large claws with distinct light yellowish collars around the neck | B—Lateral view with grizzly fur, black fur on the legs and feet (see also C) | C—Lateral view with a well distinct hump at shoulder producing a sloping backline. Note: Brownface, grizzled fur, long claws, black fur in legs, and whitish stripe around the back is a common characteristic of this subspecies (Dave Garshelis pers. comm. December 2020; Xue Yadong pers.comm. December 2020). © Madhu Chetri.

the flat alpine grassland in Bhajo kharka, Nula-dhojang, Yamdo kharka, Daldhang kharka, and Hinde kharka in the eastern part of MCA. Similarly, in the western part of MCA, Chettang kharka, Yajothang, and the Gala pass area are the important areas of bear distribution.

The Brown Bear is known as 'Mithe' by the local villagers. They are once said to be found even in the close vicinity of the villages in the upper Mustang of ACA. These days they are found only in a few high altitudes pastures that abut the Nepal-Tibet border and are occasionally observed by the herders while grazing their livestock in highland pastures during the summer season. The tale of legendary yeti still exists in the region and locals avoid the areas due to fear as Mithe are said to have no heels and extraordinary power.

CONCLUSION

This study provides the first photographic evidence of Tibetan Brown Bear in upper Mustang of Annapurna Conservation Area. Brown Bear sightings and signs (pugmark, hair, scat, and diggings) reveal a close association with Himalayan Marmot and pikas. Recently several sighting and camera-traps records reveals the presence of Brown Bear in eastern and western part of Nepal's Himalaya. Therefore, further research in Brown Bear ecology particularly focusing on taxonomy, population genetics, movement, habitat use, and human-bear interactions is warranted. Additionally, understanding rangeland ecology, human-induced land-use changes, and the impact of climate change in this important changing pastoral landscape will aid in conservation planning and biodiversity conservation in the region.

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COMMUNICATION

Age estimation of Tiger *Panthera tigris* (Linnaeus, 1758) and Lion *Panthera leo* (Linnaeus, 1758) (Mammalia: Carnivora: Felidae): applicability of cementum annuli analysis method

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Abstract: We describe the applicability of the cementum annuli analysis technique for estimating the age of Tiger *Panthera tigris* and Asiatic Lion *Panthera leo* using incisor teeth. We used I_2 and I_3 incisor teeth from the right mandible of Tiger and I^2 and I^3 from the left premaxilla of the Lion. The longitudinal sections of the teeth were prepared using an economical hand grinding technique with the help of sandpaper, followed by decalcification and staining with hematoxylin. Two cementum layers were observed under the microscope in each of the I_2 and I_3 incisor teeth of the Tiger and six cementum layers were observed in each of the I^2 and I^3 incisor teeth of the Lion. The permanent incisors in Tiger and Lion erupt between 12 and 14 months of age; hence, we added one year to the counted number of cementum layers to estimate the final age of Tiger and Lion incisors. The age of Tiger and Lion incisors were estimated to be of three years and seven years, respectively. This method may be suitable for estimating other carnivores' age and applicable in wildlife forensic studies.

Keywords: Big cats, carnivore, epoxy, grinding, incisor, premolar, teeth, wildlife forensics.

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Author contributions: V, CPS, SPG & SKG conceived the study. V, CPS & VS carried out the laboratory work. V & HS did the data analysis. V, VS & SKG wrote the article. CPS, SKG, SPG & HS reviewed the article.

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INTRODUCTION

The age of carnivores needs to be estimated in studies about the demography of species and for understanding population dynamics (Skalski et al. 2005; Foresman 2012), age class (Angerbjorn et al. 2004; Creel et al. 2004), population monitoring trends (Barthold et al. 2016), human-wildlife interactions (Conover 2002; Frank et al. 2005), and illegal wildlife trade (Williams et al. 2015). The widely used methods for age estimation of carnivores are assessments of tooth eruption (Slaughter et al. 1974), wearing of a tooth crown (Harris 1978; Stander 1997; Gipson et al. 2000), closure of pulp chamber (Marks & Erickson 1966; Zapata et al. 1997; Binder & Van Valkenburgh 2010), and cementum analysis (Klevezal & Kleinenberg 1967; Matson 1981; White & Belant 2016).

The method to estimate the age of the Tiger *Panthera tigris* has mostly been limited to assessing tooth eruption, wearing (Mazak 1979, 1981; Miles & Grigson 2003), and gum line recession (Fàbregas & Garcés-Narro 2014). The methods described to assess the age of the Lion *Panthera leo* refer to sizes of body and mane, pigmentation on the nose, tooth wear (Schaller 1972; Smuts et al. 1978; Whitman et al. 2004; Whitman & Packer 2007; Ferreira & Funston 2010), closure of the pulp chamber (White & Belant 2016), the ratio of tooth areas (White et al. 2016), tooth eruption (Schneider 1959) and cementum analysis (Spinage 1976; Smuts et al. 1978; White & Belant 2016).

Amongst the various age determination methods available, the cementum analysis method has been recommended for its accuracy (Mundy & Fuller 1964; Marks & Erickson 1966; Klevezal & Kleinenberg 1967; Craighead et al. 1970; Willey 1974, Grue & Jensen 1979; Johnston et al. 1987; Matson et al. 1993; Mbizah et al. 2016; Vipin et al. 2018). The described technique does not need a costly microtome for tooth sectioning, so most of the items required are generally available in a standard lab (Vipin et al. 2018).

To date, studies on age estimation of South Asian mammals through cementum layer analysis are limited to Chital *Axis axis* (Vipin et al. 2018). Here we present the applicability of this method for estimating the age of Tiger and Asiatic Lion.

MATERIAL AND METHODS

We used Tiger mandible and Lion skull from Wildlife Forensic and Conservation Genetics Cell's repository. We tested the applicability of the developed method to estimate the age of an incisor (I_3) from the mandible of a Tiger seized in the illegal wildlife trade, which was sent to Wildlife Institute of India, Dehradun, for species confirmation.

Sample collection and preparation of longitudinal section of teeth

Canines of Tigers and Lions are in high demand compared to other species' teeth in the illegal wildlife trade. Hence, in comparison to other types, the chances of their availability for determining age are limited. In both species, the permanent incisors number is six times more than premolar (PM^2), which is a plus point if some tooth gets damaged during processing for cementum analysis. Therefore, we selected incisors in the current study and based on the availability of their types, the incisors were extracted.

Two permanent incisor teeth (I_2, I_3) out of three were used from the right mandible of a Tiger (Image 1A, B, C) and two incisors (I^2, I^3) from the left premaxilla of a Lion. The teeth from the Tiger mandible were extracted by boiling it in water for ten minutes, after which they detached easily from the mandible. From the Lion premaxilla, the teeth were removed with the help of pliers with utmost care so that the periodontal membrane remained intact. We used the protocol described by Vipin et al. (2018) for preparing the longitudinal sections of the incisor teeth with a thickness of around 57 µm with steps, as shown in Image 2. We then used a Leica DMR microscope to examine the tooth sections.

Calculation of age from cementum annuli

In felids, all permanent incisors except I^3 erupt before other teeth (Miles & Grigson 2003). In Tiger, the permanent tooth eruption starts between 8.8–9.5 months and completes at the age of 12–14 months (Mazák 1979, 1981). In Lion, permanent I^1, I_1, I^2, I_2 fully erupts between 9–11 months and I^3 and I_3 start erupting by the end of this period (Smuts et al. 1978). I^3 and I_3 completely replace their deciduous counterparts at the age of 12 to 14 months, while P^2 starts erupting between this period in Lions (Smuts et al. 1978). Though no published data related to age estimation of Tiger using cementum analysis is available; many researchers have used permanent incisors, canine, and second premolar teeth to develop age estimation methods in Lions utilizing this technique (Smuts et al. 1978; Cheater 2006; White & Belant 2016). The time taken by different tooth types for their permanent eruption has been reported unequal in other species of carnivores and ungulates (Zapata et al. 1995; Azorit et al. 2004). In P^2 of African Lions, it is established that the first rest is formed in the second

Image 1. Tiger mandible: A—extracted incisors (I_1, I_2, I_3) | B—side view | C—lingual view

year of age, so we had to add one to the counted number of cementum lines to estimate the final age (White & Belant 2016). We counted the acellular cementum layer in the root portion of the teeth, which is formed annually and stains dark with hematoxylin (Matson et al. 1993). Therefore, we added a minimum of one year in both species' final age estimation. The presence of one cementum layer in a permanent incisor tooth of Tiger and Lion indicates that the animal has lived one year at least. The age of sectioned teeth in years was calculated according to the formula

Age in year = Number of cementum layers + 1 year

The cementum layers in the incisor teeth were photographed wherever these were seen distinctly and clearly.

RESULTS

The teeth sections of the Tiger showed two cementum layers for I_2 (Image 3 A, B, C) and I_3 (Image 4 A, B); thus, the Tiger's age was estimated to be three years. The Lion had six cementum layers in I^2 (Image 5A, B) and I^3 (Image 6); therefore, Lion's age was estimated to be seven years

We found two dark cementum layers on the Tiger's incisor seized in the illegal wildlife trade; hence its age was estimated as three years (Image 7). Therefore, the developed method may also be applied to estimate the age of tigers in the illegal wildlife trade.

DISCUSSION

White & Belant (2016) used paired PM^2 teeth for estimating the age of free-ranging African Lions of unknown age through cementum line count and showed that cementum layer count in PM^2 is unsuitable for ageing Lions. Their analysis revealed that in 19 out of 31 PM^2 pairs, the cementum line count differed by 1–2 lines and even increased to seven lines for other pairs. According to Smut et al. (1978), cementum lines in canine teeth of Lions complied significantly with their known ages. So to compare the results of White & Balent (2016) about Asiatic Lions, a large sample size of the PM^2 teeth is needed, or more incisors or a different tooth type needs to be analysed for cementum layer count. In ungulates, the accuracy of age estimation through cementum analysis decreases with the age of the specimens (Hamlin et al. 2000). More research is necessary to assess whether this is also true for carnivores.

We recommend validating the current procedure while estimating age based on cementum layer count. Matson et al. (1993) suggested two main tests for validating the cementum analysis for estimating age, namely the "blind" duplicate test when two or more teeth are available and using a tooth of known age but without having the prior knowledge of its age. Teeth of known age were not available for both species; however, all incisor teeth showed clear and distinct cementum layers. The periodontal membrane in all studied teeth

Image 2. Flow chart of the procedure followed for age determination through cementum layer count in incisor tooth.

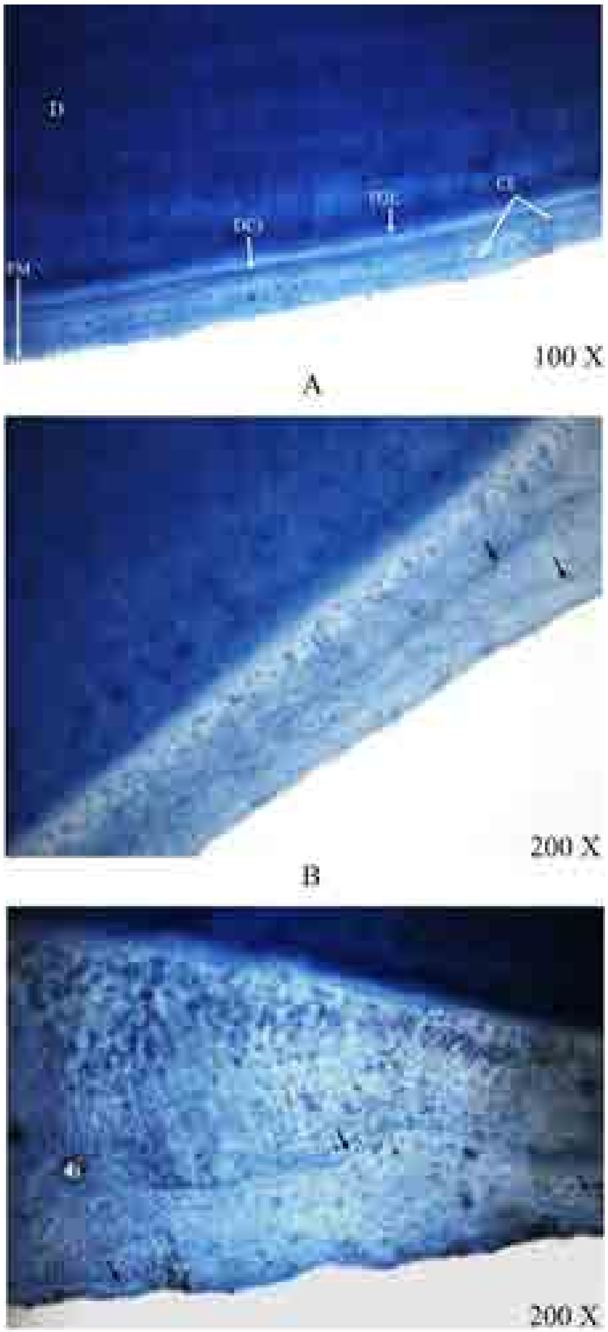

Image 3. The longitudinal section of I_2 tooth of Tiger showing two cementum layers in three different regions (A, B and C) under 100X and 200X magnifications. D—dentine | TGM—Tome's Granular Layer | CL—Cementum Layer | DCJ—Dentine Cementum Junction | PM—Periodontal Membrane.

confirms that all cementum layers were present in the longitudinal sections. Hence, the current method can show all cementum layers clearly and distinctly in incisor teeth.

The same protocol may be applied to develop age estimation protocols for other mammal species.

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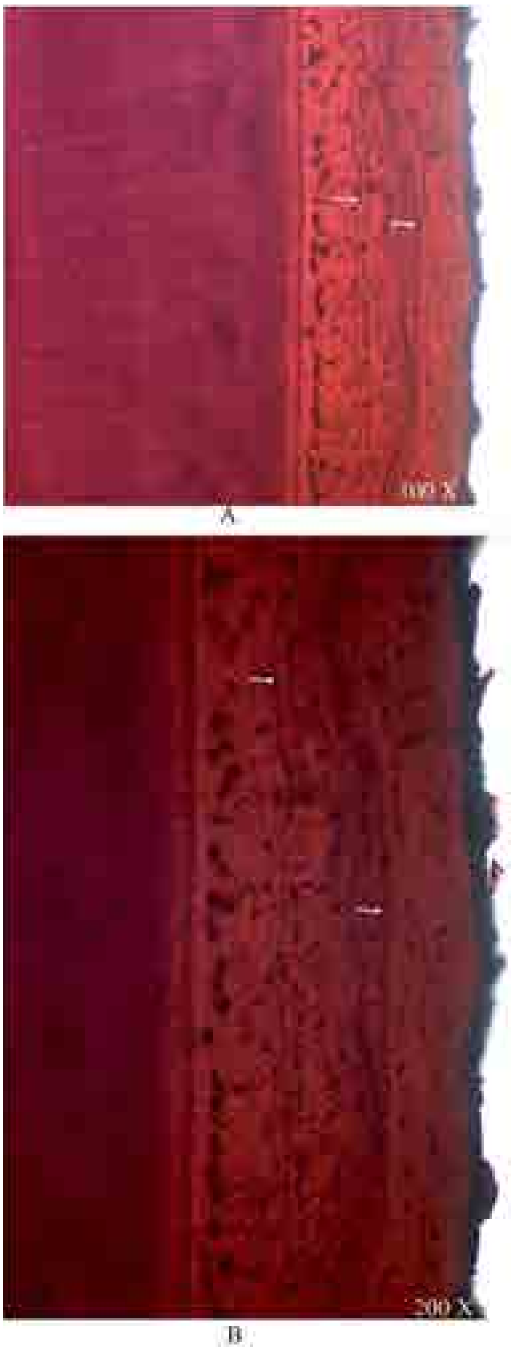

Image 4. The arrows in the longitudinal section of I_3 of the Tiger showing two cementum layers at 100X and 200X magnifications.

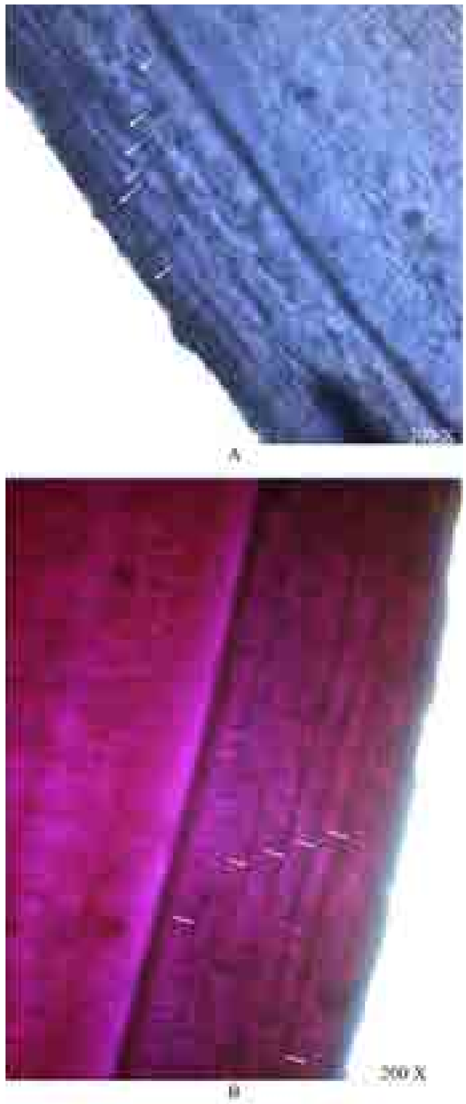

Image 5. The arrows in the longitudinal section of I^2 of the Lion showing six cementum layers in two different regions (A and B).

Image 6. The arrows in the longitudinal section of I^3 of the Lion showing six cementum layers.

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Image 7. The arrows in the longitudinal section of I_3 from seized Tiger skeleton showing two cementum layers.

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COMMUNICATION

Hematological value of captive Asian Elephants *Elephas maximus* around Chitwan National Park, Sauraha, Nepal

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Abstract: Veterinary hematology serves as an important screening procedure to assess general health conditions, diagnosis, and treatment of disease. This study aims to interpret and establish a set of hematology reference ranges for Asian Elephants managed by private and government facilities in Nepal. Blood samples from 50 elephants around Chitwan National Park, Sauraha were collected and hematological parameters such as total erythrocyte count and total leukocyte count were determined. The results show that the majority of hematological values were in line with the values previously published by different authors. The mean erythrocyte and leukocyte counts were reported as 3.32±0.93 × 10^6 cell/µL and 10448±335.49 cells/µL respectively. No sex-associated significant difference was observed in the case of total erythrocyte count, whereas total leukocyte counts varied significantly within sexes. Our findings revealed no significant difference in hematological parameters between government and privately owned elephants. The hematological values from our study can be used as reference values for assessing the health condition of elephants in Nepal. Further research work should be conducted to evaluate the factors affecting hematological parameters.

Keywords: Captive, erythrocyte count, free-ranging, hemocytometer, human-wildlife coexistence, Leukocyte count, mega-herbivore, Proboscidea, rouleaux.

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Competing interests: The authors declare no competing interests.

Ethical statement: All activities were performed under the ethical guidelines of NTNC, Sauraha, Nepal.

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Author contributions: Conceptualization: Roshan Ghimire, Sagar Regmi, Amir Sadaula. Methodology: Roshan Ghimire, Sagar Regmi, Rakshya Shrestha. Data analysis: Sagar Regmi, Roshan Ghimire. Writing-original draft: Sagar Regmi, Roshan Ghimire, Rakshya Shrestha. Reviewing and editing: Amir Sadaula, Sagar Regmi, Janardan Dev Joshi. All authors have agreed to the final version of the manuscript.

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INTRODUCTION

Asian Elephants *Elephas maximus* are the largest of all mammals in Nepal and are one of three species of elephants existing today under the order Proboscidea. Wild elephants in Nepal occur in four isolated populations — the eastern population in Koshi Tappu Wildlife Reserve and Jhapa district, the central population in Chitwan National Park and Parsa National Park, the western population in Bardia National Park and adjoining municipalities, and the far-western population in Suklaphanta National Park and adjoining municipalities (Pradhan et al 2008). Being a mega-herbivore and having long-range movements including dispersing behavior, there is frequent contact of wild elephants with human beings. So, there is a chance of human-wildlife interaction as wild elephants pose a problem to the local communities because of the destruction of private property, crop destruction, attack, and injury (Shrestha 2007). However, captive elephants in Nepal have restricted freedom and have no independent grazing time.

Captive (working) elephants are prone to various health problems including swelling of the eye by foreign body pricks, opacity of the cornea, lameness due to sole pricks, and contusion by hitting rocks and logs. Infection of the sole may occur due to injuries. Various equipment used while controlling the animals, and the pressure of Hauda, a seat to provide passengers a safe and comfortable ride on the back while carrying guests and other loads, and Gaddi, metallic objects with pointed ends to restrain elephants, can cause wounds. Ecto- and endo-parasitism are also a common problem seen in captive elephants. The major infectious diseases affecting the elephant are anthrax, hemorrhagic septicemia, foot and mouth disease, rabies, tuberculosis, tetanus, encephalo-myocarditis, pox, salmonellosis, and herpes virus infection. Other parasitic diseases affecting blood cells include babesiosis, anaplasmosis, trypanosomiasis, and ehrlichiosis (Miller et al. 2015). The majority of captive elephants in Nepal are found in and around Chitwan National Park and are used for patrolling and tourism purposes. As the majority of captive private elephants are used for tourism purposes, they are economically important, which increases the need for proper veterinary care to improve their health status. Hematology is defined as the study of components of blood (red blood cells (RBC), white blood cells (WBC), Platelets) for diagnosis and monitoring disease (Wolfrum 2010). There is a broad variation in how animals respond to captivity when managed under different conditions of management practices. In general, captive elephants are raised under good management conditions like proper health care, good dietary plans, so they are often healthier than free-ranging wild elephants.

Knowing the normal hematological values plays a major role in the proper diagnosis, treatment, and interpretation of diseases. Precise hematological reference intervals and normal blood values are useful for evaluating the health status of animals, monitoring the course of the disease, proper diagnosis, and to know the treatment efficacy (Silva & Kuruwita 1993; Janyamethakul et al. 2017). Although normal hematological values exist for Asiatic Elephants (Nirmalan et al. 1967; Janyamethakul et al. 2017), they may not be relevant because these values are affected by different genetic and non-genetic factors. So, elephants under different geography or different conditions of feeding, and housing practices may differ in hematologic values. Stress due to daily duty and activity, clinical condition (diseased state), temperature, and sex can make significant differences in hematological values (Swenson 1984; Addass et al. 2012; Yaqub et al. 2013). As no major work has been done in Nepal till now to establish the hematological parameters for captive elephants, the study aimed to evaluate and devise a set of hematology reference ranges for Asian Elephants in Nepal used in the private sector as well as in the government sector.

MATERIALS AND METHODS

Study area

The study was conducted within Chitwan National Park (CNP) which was established in 1973 as the first national park in Nepal and listed as a World Heritage Site in 1984. It is situated in the sub-tropical lowlands of the Inner Terai at an elevation of about 150 m in south-central region of Nepal. Sal *Shorea robusta* trees cover about 70% of the national park, area and the buffer zone mostly consists of agricultural fields along with community forests.

Feeding, housing, and working routine

Captive elephants in Nepal have restricted freedom. Mahouts take the elephants to cut and collect grasses for fodder in the morning (0500–0700 h) and bring them back to the hattisar (place where elephants are kept). The elephants are then taken back to the jungle for grazing from 1000 h to 1600 h. Besides grazing and fodder, they are fed daily with 15 kg of unhusked rice, 1.5 kg molasses, 25 g of table salt, and 25 g of gram packed in a bundle of succulent grass collectively called Kuchi. The elephants who have no specific allocated work are freed from chains to collect fodder in the morning and graze during the afternoon.

Blood sample collection

Elephants between 4 to 70 years of age were included in the study. The age of most elephants were known and the age of a few elephants was estimated by the mahouts. Blood samples from 50 elephants from around Chitwan National Park, Sauraha were collected from the auricular vein between 0700–0900 h. All elephants were kept under similar conditions (i.e., housing, feeding, exercise). None of the sampled elephants suffered from visible or known clinical health issues or had been diagnosed and treated for any health issues in the months prior to this study which would alter the blood parameters. Blood samples were divided into two separate tubes:

1) EDTA tube and

2) Serum tube in which the serum was separated by centrifugation at 1,500 rpm for 5 min.

The samples were submitted to NTNC-BCC molecular lab, Sauraha, Chitwan, and hematology was performed within two hours of blood collection. Total RBC count and WBC count were determined using hemocytometer (Neubaur Counting Chamber).

We performed RBC and WBC counts manually using a hemocytometer because blood cells in elephants are larger and rouleaux formation occurs in elephants' RBC which differ from human blood cells due to which an automated human hematology analyzer can lead to unreliable results (Dutton 2008).

Data analysis

Statistical analysis was done using SPSS Version 20. The reference interval with 95% confidence intervals for each parameter was calculated. P values from the student T-test were used to determine significant differences of blood parameters between males and females and comparison with feeding habit and exercise of animals. The level of statistical significance was set at α <0.05.

RESULTS AND DISCUSSIONS

From our study, the number of captive female elephants was found to be significantly greater (n = 42) than captive male elephants (n = 8) in Sauraha. The aggressive behavior of males makes them more difficult to control under captive conditions, and aggressiveness further increases during the musth period. In the private sector where elephants are primarily used for tourism purposes, only female elephants are kept because they are more docile. But in the government sector, a few male elephants are kept for patrolling purposes. Our study showed that reference hematological values fall within the range published by other authors for Asian Elephants (Janyamethakul et al. 2017).

From our study the average erythrocyte count in male elephant was found to be (3.21±0.15) × 10^6 cells/µL ranging from 2.40 × 106 cells/µL–3.16 × 106 cells/µL. In the case of female elephants, the erythrocyte count ranges from 2.04 × 106 cells/µL–4.95 × 106 cells/µL with an average of (3.34±0.11) × 106 cells/µL. No sex-associated significant difference was observed in elephants from our study. Our study also revealed that the privately owned elephants showed fairly low RBC close to, or at a level which can be judged to be slightly anemic, whilst none of the government owned elephants showed such low RBC levels. The range of the erythrocyte count in both male and female elephants during our study was in line with the values reported by Janyamethakul et al. (2017) and slightly lower than values reported by Debbie & Clausen (1975) in African Elephants. The mean value of erythrocyte was found in line with the values reported by Brown & White, (1980) but greater than the value reported by earlier researchers during their study (Lewis 1974; Woodford 1979; Gromadzka-Ostrowska 1988). Comparably the overall mean value of total erythrocyte count was found to be lower than the mean value reported by Young & Lombard (1967) in African Elephants. The red blood cells in African and Indian elephants are biconcave discs and are large, possibly larger than in any other mammal, and have a mean diameter (MD) slightly greater than 9 pm (1pm = 1 × $10^{\wedge -12}$m) (Brown & White 1980). The larger

Table 1. Reference range of hematology (total erythrocyte count and total leucocytes count values for sampled captive elephants in Sauraha for both sexes).

Parameters	Unit	Range (Male, n = 8)	Range (Female, n = 42)	All elephants (n = 50)
RBC count	×10^6 cells/µL	2.40–3.16	2.04–4.95	2.04–4.95
WBC count	cells/µL	8500–15500	7100–16750	7100–16750

Table 2. Total erythrocyte count and leukocyte count of all sampled captive elephants in Sauraha irrespective of sex (Mean±S.E.).

Parameters	Unit	All elephants (n = 50)
RBC count	×10^6 cells/µL	3.32±0.93
WBC count	cells/µL	10448±335.49
S.E.—Standard error		

Table 3. Effect of sex on hematology of sampled captive elephants in Sauraha (Mean±S.E.).

Parameters		Total RBC count (×10^6 cells/µL)	Total WBC count (cells/µL)
Sex	Male	3.21±0.15	12312.5±729.16
	Female	3.34±0.11	10092.86±351.60
P-value		0.607[NS]	0.014*

*—showed significant difference of blood parameters between sexes (P <0.05) | NS—Not significant.

Table 4. Effect of age on hematology of sampled captive elephants in Sauraha (Mean±S.E.).

Parameters			Total RBC count (×10^6 cells/µL)	Total WBC count (cells/µL)
Age	Calf (0–4 years)	N = 2	3.20±0.03	10975.5±2475
	Juvenile (5–12 years)	N = 5	3.39±0.13	10790±712.99
	Sub-adult (13–20 years)	N = 12	3.72±0.19	9941.67±2398.75
	Adult (above 21 years)	N = 31	3.16±0.68	10554.84±248.44
P-value			0.013*	0.165 [NS]

*—showed significant difference of blood parameters between sexes (P <0.05) | NS—Not significant | N—No of elephants.

Table 5. Hematological parameters of sampled captive elephants in private and government facilities in Sauraha (Mean±S.E.).

Parameters			Total RBC count (×10^6 cells/µL)	Total WBC count (cells/µL)
Owner	Private	N = 27	3.14±0.12	9983.33±484.05
	Government	N = 23	3.54±0.14	10993.48±425.79
P-value			0.256[NS]	0.023*

*—showed significant difference of blood parameters between sexes (P <0.05) | NS—Not significant | N—No. of elephants.

size of elephant red blood cells was further reported by Jarernsak Salakij et al. (2005) and Gromadzka-Ostrowska et al. (1988). Despite the large size, the total RBC count in elephants is lower than other mammals. Low erythrocyte count seen in elephants suggests that the erythrocytes are still in the primitive state compared with other mammals and have not attained the efficiency in the transportation of blood gases that results from a reduction in size to facilitate numerical increase (Nirmalan et al. 1967). The lower erythrocyte count in elephants than in other species was supported by values reported by Benjamin (1978) and Egbe-Nwiyi et al. (2000) in species like sheep, goats, cattle, dogs, cats as well as finding of Windberger (2003) in different mammalian species including horses and rabbits. Lewis (1974) also reported that the total erythrocyte value of elephants is lower than in humans. A significant effect of sex was observed in hematological values in numerous species (Etim et al. 2013). But our study showed no sex-associated significant difference in the erythrocyte count. Janyamethakul et al. (2017) also found no sex-associated significant difference in total RBC count in Asian elephants. This finding was further supported by the findings of earlier researchers (Silva & Kuruwita 1993; Salakij et al. 2005).

Our study revealed the average leucocyte count in male elephants to be 12,312.5±729.16 cells/µL ranging from 8,500 cells/µL–15,500 cells/µL. In the case of female elephants, the total leukocyte count ranges from 7,100 cells/µL–16,750 cells/µL with an average of 10,092.86±351.60 cells/µL. Sex-associated significant difference was observed in elephants. The result of our study was in line with the findings of Janyamethakul et al. (2017) and Young & Lombard (1967). However, our mean value was lower than the value reported by Lewis (1974) and Brown & White (1980) in Indian elephants and by Debbie & Clausen (1975) in African elephants. Comparably, the mean value reported during our study was found to be greater than the value reported in African elephants (Woodford 1979). Our finding

Table 6. Age, sex, RBC count, and WBC count of sampled elephants during the study.

	Elephant's name	Owner	Sex	Age (in years)	RBC Count (× 10^6 cell/µL)	WBC count (cells/µL)
1	Sudarkali	Private	F	55	2.64	8750
2	Champakali (Ramu)	Private	F	45	2.62	16750
3	Punamkali	Private	F	48	2.93	9200
4	Sherkali	Private	F	60	3.5	7350
5	Ekatakali	Private	F	35	3.1	9900
6	Sambridikali	Private	F	15	3.86	9000
7	Sonakali	Private	F	50	2.6	8400
8	Gulabkali	Private	F	20	3.67	9750
9	Selfiekali	Private	F	13	4.67	8900
10	Basantikali	Private	F	48	3.14	11050
11	Laxmikali	Private	F	20	3.51	7950
12	Champakali (Balram)	Private	F	52	3.7	11200
13	Marutikali	Private	F	50	2.6	13650
14	Champakali (Wildlife camp)	Private	F	52	2.6	12550
15	Bijulikali (Wildlife camp)	Private	F	18	3.17	11650
16	Bobkin (Rain forest)	Private	F	50	3.21	10900
17	Champakali (Jungle wildlife camp)	Private	F	45	2.04	9450
18	Ranikali (Forest Resort)	Private	F	45	2.72	8550
19	Rupakali	Private	F	50	2.74	7550
20	Shantikali	Private	F	65	2.77	7550
21	Suvakali	Private	F	15	4.52	7500
22	Champakali (Om Rijal)	Private	F	55	3.7	8100
23	Laxmikali (Bikash Mishra)	Private	F	50	3.05	7650
24	Tulsikali	Private	F	6	3.3	8400
25	Rajkali	Private	F	50	3.07	16050
26	Gulabkali (Bikash Mishra)	Private	F	20	2.82	8550
27	Dipendragaj	Private	M	52	2.4	13250
28	Sherprasad	CNP	M	15	3.14	15500
29	Sundarmala	CNP	F	70	3.16	13550
30	Sanochanchankali	CNP	F	59	2.96	10500
31	Sano Ramgaj	CNP	M	11	3.76	10950
32	Binayak Prasad	CNP	M	27	3.68	12650
33	Madigaj	CNP	M	8	3.2	11450
34	Prakritikali	CNP	F	15	3.82	9900
35	Maankali	NTNC	F	55	4.24	11000
36	Malekali	NTNC	F	70	4.5	11100
37	Rajagaj	NTNC	M	4	3.23	13450
38	Junkali	NTNC	F	50	3.01	11850
39	Luckygaj	NTNC	M	4	3.17	8500
40	Rampyari	CNP	F	60	2.95	9500
41	Ganeshkali	CNP	F	31	2.92	12100
42	Koshikali	CNP	F	31	2.83	11100
43	Krishnachandragaj	CNP	M	5	3.09	12750
44	Himanikali	CNP	F	18	3.5	8750
45	Simsimkali	CNP	F	5	3.6	10400
46	Devikali	CNP	F	50	4.7	7100
47	Karnalikali	CNP	F	21	3.06	10750
48	Loktantrakali	CNP	F	13	3.1	8450
49	Chintamankali	CNP	F	30	4.95	8150
50	Tamarkali	CNP	F	16	4.8	13400

CNP—Chitwan National Park (Government) | NTNC—National Trust For Nature Conservation (Government).

revealed a sex-associated significant difference ($p < 0.05$) in elephant WBC count which was in agreement with the reports given by Young & Lombard (1967) and Salakij et al. (2005).

A significant difference ($p < 0.05$) was reported in RBC counts among different age groups (i.e., calf, juvenile, sub-adult, and adult, respectively) of elephants during our study. The total leukocyte count of the elephants in the calf age group (age up to 5 years) was found greater than other age groups which is in agreement with findings reported by Nirmalan et al. (1967). However, total leukocyte count in other age groups was found to be similar. This finding was further supported by Niemuller et al. (1990) where he found that the total leukocyte count in Asian elephants was a constant overtime and was similar in the different age groups of elephants (Niemuller et al. 1990). The variation of parameters might be due to different lab errors like sample preparation and transportation, storage, and blood collection method. During our study, a non-significant increase in total leukocyte count was found in a pregnant elephant as opposed to a non-pregnant, non-lactating female elephant. However the high leukocyte count in the pregnant elephant was also reported by Ajitkumar et al. (2009).

The elephants sampled in our study kept under private facilities showed lower average and wider range on RBC and WBC counts compared to elephants within government facilities. The wider range determines higher variation on blood parameters among elephants managed under private facilities. Management practices like deworming, vaccination, and foot dipping are performed on regular intervals within government facilities under the supervision of licensed veterinarians. But the elephants under private facilities were treated and dewormed only at health camps organized by the government at irregular intervals. No specific study has been done to date comparing the blood parameters of elephants kept under private and government facilities in Nepal. Our study involved samples collected within the same season. So the effect of season on hematological value was not possible to determine. However Gromadzka-Ostrowska et al. (1988) reported a slight increase in white blood cell counts and lowered red blood cell counts during the winter season. The lower RBC counts in the winter season may be due to the non-availability of green fodder and a poor diet.

CONCLUSION AND RECOMMENDATIONS

No visible or known clinical health issues had been diagnosed in the sampled elephants; none of the study elephants had been treated for any health issues in the months before this study. Knowing normal hematological values is paramount for proper diagnosis of disease. Further standardization of these values is needed for an accurate diagnosis. Since elephant blood parameters are affected by different factors, further research should be conducted to evaluate the effects.

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COMMUNICATION

Foraging strata and dietary preferences of fifteen species of babblers in Sarawak, Malaysia

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Abstract: Babblers are the primary insectivorous birds of the tropical forests in southeastern Asia which have shown to be affected by forest disturbance. Their high diversity, microhabitat specificity and specialised feeding guilds provide a good opportunity for ecological research pertaining to niche segregation. We examined the diet and foraging strata of 15 sympatric babbler species mist-netted in nine forests in Sarawak, eastern Malaysia. Based on 222 birds captured from December 2014 to March 2016, a segregation in foraging strata was found, with half of the species captured frequenting low strata, while only three were found at mid strata and four at high strata. Both species richness and abundance were found to decrease when the foraging height increased. From a total of 136 prey items retrieved from regurgitated and faecal samples of 13 babbler species, we found that Coleoptera (41.5%), Hymenoptera (36.2%), and Araneae (12.3%) formed the major diet of the birds. Diet overlaps among the babblers were relatively low. Our study demonstrated the possible presence of spatial and trophic niche segregation among babblers, and justified their ecological role as indicators of tropical forest ecosystem health, especially in the case of specialists, that deserve further conservation attention.

Keywords: Forest fragmentation, forest health indicator, forest specialist, insectivorous birds, niche differentiation.

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Author contributions: AAT initiated the project and AFS carried out the fieldwork which was co-supervised by JMA. AFS analysed the data and wrote the masnucript with input from JMA, AAT and CLP.

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INTRODUCTION

Bird communities in the tropics can be good systems to investigate complex interactions among sympatric species (Mansor & Mohd Sah 2012; Styring et al. 2016; Mansor & Ramli 2017; Sherry et al. 2020). How communities are structured are dependent on how they partition their resources and differentiate niches. Understanding how sympatric species utilise their resources can provide evidence about the coexistence of potential competitors (Morin 1999). Coexisting species in a community separate their ecological needs by resource partitioning along temporal, spatial, and behavioural niches (Mohd-Azlan et al. 2014). In general, when resources are a limiting factor, competitive interactions between species can result in non-random pattern of resource use (Morin 1999). Some studies on closely related species have shown that birds partition food resources by utilising different vertical strata, or by differential use of microhabitats (Styring & Hussin 2004; Mohd-Azlan et al. 2014).

Insectivorous birds consume a substantial amount of arthropods, hence their ecological importance in many ecosystems is significant (Nyffeler et al. 2018). Many studies have demonstrated the effects of forest disturbance on insectivorous birds, which may be linked to the decline of insect communities particularly certain insect groups (Didham et al. 1996; Didham 1997; Şekercioğlu et al. 2002; Stratford & Stouffer 2015; Bowler et al. 2019). In the tropics, understory insectivores are characterized by high habitat specificity and lower mobility relative to other passerines (Şekercioğlu et al. 2002; Yong 2009). Thus birds of the understory strata are sensitive to forest disturbance (Thiollay 1992; Kattan et al. 1994; Stouffer & Bierregaard 1995; Canaday 1996; Stratford & Stouffer 1999) and they have adapted to occupy specialized niches when foraging for their insect prey (Sekercloğlu et al. 2002). For instance, small forest fragments have been shown to experience a decline in the number of invertebrates dwelling among the leaf litter and soil while increasing the generalist numbers at the forest edge (Didham et al. 1996; Didham et al. 1997). These changes can affect understorey insectivores that avoid relatively open or edge habitats and specialise on arthropod prey that hide within leaf litter and soil (Canaday 1996).

With the increasing reports on the effects of forest disturbance on arthropods in the tropics (Hamer et al. 1997; Chey et al. 1998; Holloway 1998; Lawton et al. 1998; Schowalter & Ganio 1999; Floren & Linsenmair 2001, 2003; Hartshorn et al. 2021), concerns over the associated effects on insectivorous birds are also raised. Equally, there is a need for more in-depth study on the foraging ecology of the tropical insectivorous birds in the tropics so as to determine which species are particularly affected by or resilient to forest disturbance.

In southeastern Asia, babblers primarily refer to two insectivorous families, namely Timaliidae (54 extant species) and Pellornidae (64 species), the majority of which rely on forest or wooded habitats. As many babbler species are sedentary, with poor ability to disperse across non-forest habitat (Yong 2009), and are associated especially to lower forest strata of forest interior, they serve as suitable indicators of the level of forest disturbance (Lambert & Collar 2002; Hamer et al. 2015). Past studies based on relative abundance have shown that certain babbler species (Hussin & Francis 2001; Lambert & Collar 2002; Moradi & Mohamed 2010) and even specific feeding guilds (Johns 1986; Yong et al. 2011) are sensitive to forest fragmentation.

In the tropical forests of Malaysia, babblers form a major portion of the diverse middle and understorey avian insectivores (38 species; Puan et al. 2020), with high numbers of congeneric and sympatric species (Lambert & Collar 2002). This makes them suitable candidates for the research on avian community ecology including trophic diversification, resource partitioning and functional morphology, all of which are essential in driving the associated biotic community assembly in the tropical forests. Such research is feasible by examining their diets, which comprises of indigestible exoskeletons of arthropods, as demonstrated in studies elsewhere on food partitioning (Kent & Sherry 2020; Sherry et al. 2020), seasonal dietary patterns in relation to changes in the environment (Poulin et al. 1992) or abundance of resources (Yard et al. 2004). In central Peninsular Malaysia, Mansor et al. (2018) found little dietary overlaps among 12 babbler species. Despite most being morphologically similar (Styring et al. 2016; Mansor & Ramli 2017; Puan et al. 2018), niche differentiation with respect to foraging tactics have been demonstrated based on opportunistic visual observations on the Malaysian babbler species (Mansor & Mohd Sah 2012; Mansor et al. 2015; Styring et al. 2016; Mansor & Ramli 2017). Owing to their diversity and specialised feeding guilds of being terrestrial, foliage and/or bark gleaning insectivores (Johns 1986; Mitra & Sheldon 1993; Yong et al. 2011), this study examined niche segregation, i.e., diet and foraging strata, of 15 sympatric babbler species found in Sarawak, Borneo.

MATERIALS AND METHODS

Study sites

A total of nine sampling sites were chosen in Sarawak, eastern Malaysia, which can be grouped according to Pelagus (three sites), Ulu Baleh (three sites), and Baram (three sites) (Figure 1). Pelagus is located about 33 km from the Kapit town and the three sampling sites were Nanga Benin (2.165°N, 113.074°E), Nanga Pelagus (2.171°N, 113.055°E) and Nanga Peraran (2.193°N, 113.118°E) located along Batang Rajang River. Ulu Baleh is located along the Baleh River which is about 176 km from Kapit town. The three sampling sites were Nanga Gaat (1.645°N, 113.133°E), Putai (1.595°N, 113.791°E) and Long Singut (1.560°N, 114.202°E). Baram is located about 120 km from the Miri city. The three sampling sites were Long San (3.293°N, 114.779°E), Selunggo (3.208°N, 115.185°E) and Lio Mato (3.174°N, 3.174°E). Except the Pelagus National Park, all sampling sites comprised logged over secondary forests located close to human settlements and some agriculture lands.

Bird sampling

From December 2014 to March 2016, three double-stacked mist-nets (measuring 9 × 4 m each) were deployed from 0600–1830 h for four consecutive days at each of the two sampling stations at each site. The distance of the two stations was 100–1000 m away from human settlement areas, so as to assess the effects of anthropogenic disturbance on birds in another study (Mohd-Azlan et al. unpubl. data). The double-stacked nets were set vertically to create six shelves representing foraging strata based on the distance from the forest floor, i.e. Shelves 1 and 2 were categorized as low strata (0–1.2 m from the forest floor), Shelves 3 and 4 as mid strata (1.3–2.4 m) and Shelves 5 and 6 as high strata (2.5–3.6 m). All birds caught were weighed, measured and had the capture shelve numbers recorded.

Diet analysis

All babbler species, except juveniles and birds caught during the first hour of the sampling (Lopes et al. 2005), were administered with tartar emetic (Poulin & Lefebvre 1995; Zduniak 2005) before being released immediately. Depending on body weight and species, careful administration of acceptable concentration of tartar emetic solution (Sing-Tyan et al. 2017) will extract stomach contents via regurgitation. For every 100 g of the body mass, a dosage of 0.8 ml of 1.2% potassium antimony tartrate was used (Durães & Marini 2003). The regurgitated items and faeces were preserved using 70% alcohol in the field before being examined under a compound microscope in the laboratory. All prey items were identified up to taxonomic order and each order

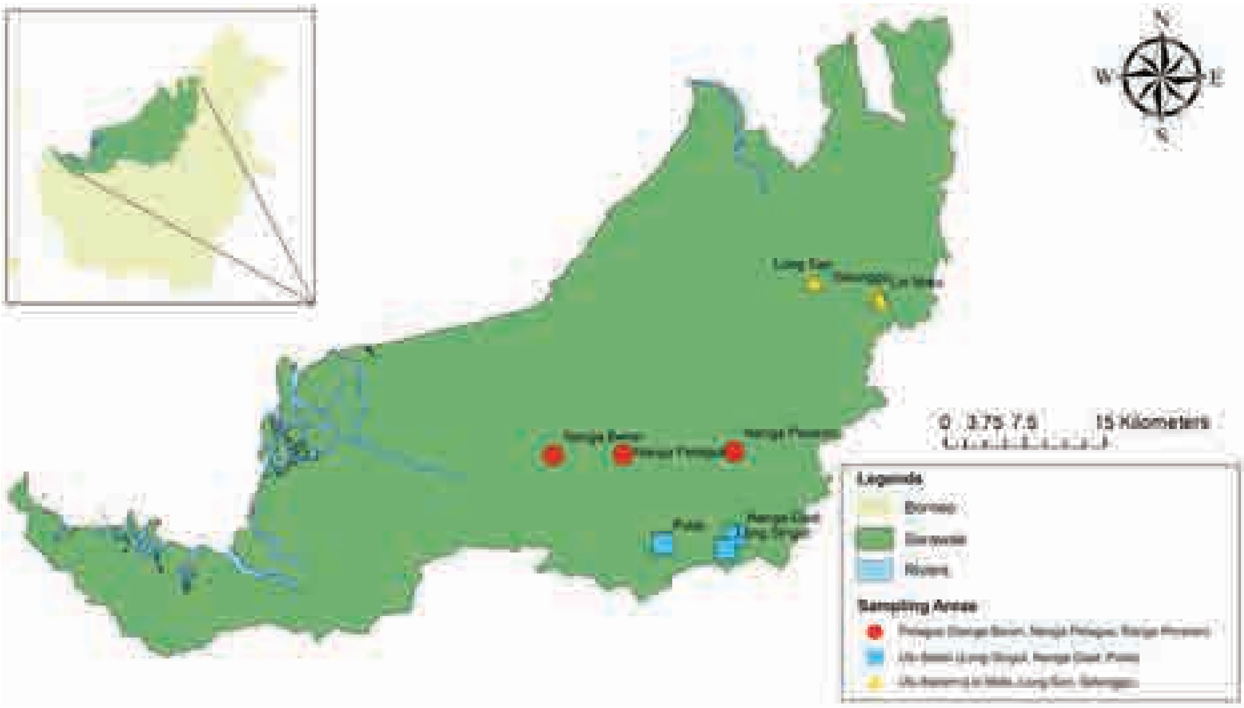

Figure 1. Mist netted areas located in the interior parts of Sarawak within the Heart of Borneo Forest Complex: A—Long San | B—Selunggo | C—Lio Mato | D—Nanga Benin | E—Nanga Pelagus | F—Nanga Peraran | G—Putai | H—Long Singut | I—Nanga Gaat.

found in an individual sample was counted as one prey item.

Data analysis

Analysis of bipartite ecological webs (Dormann et al. 2017) was performed to visualize and calculate indices representing the pattern of ecological networks among prey and predators. Berger-Parker dominance index was also calculated to determine whether babblers are specialized in food choice or polyphagous. Species diversity and evenness were assessed using Shannon (H') and Pielou's (J) evenness indices (Oksanen et al. 2013), respectively, whereas overlaps of prey items among babbler species were assessed using Pianka index (EcoSimR package; Gotelli & Ellison 2013). The outputs of prey item overlap analysis are a histogram of which its skewness represents the degree of overlap, i.e., left-skewed indicating a low overlap in the diet and right-skewed if otherwise. This is followed by two graphical plots with circles indicating the observed and simulated diet segregation pattern, i.e., a circle represents the relative consumption of prey category and its size is proportional to the level of such consumption. In other words, if there is no overlap of prey items among the babbler species, no circle will be present. Analyses were performed using R version 3.3.1 (R Core Team 2016).

RESULTS AND DISCUSSION

Species diversity and foraging strata

Over 4,800 net-hours, a total of 222 individuals representing 15 babbler species (nine from Pellorneidae and six from Timaliidae) were caught during this study (Table 1). This represents more than 50% of the babblers recorded in Sarawak. The Black-throated Babbler (*Stachyris nigricollis*, n = 32) was the most common species caught for all sites, followed by Short-tailed Babbler (*Trichastoma malaccense*, n = 25). The most common abundant species recorded for each site was White-chested Babbler (*Trichastoma rostratum*, n = 11) in Pelagus, Rufous-crowned Babbler (*Malacopteron magnum*, n = 18) in Ulu Baleh and Chestnut-winged Babbler (*Stachyris erythroptera*, n = 12) in Baram. Based on the Shannon diversity index, Ulu Baleh had the highest species diversity (*H'* = 2.314), followed by Baram (*H'* = 2.238) and Pelagus (*H'* = 2.193). The distribution of individuals among species was more even in Ulu Baleh and Baram compared to Pelagus (Table 1).

The babblers showed a segregation in foraging strata, with half of the species captured frequenting low strata while only three were at mid strata and four at high strata. Both, species richness and abundance were found to decrease when the foraging height increased. All species were found foraging mostly at a height of less than two meters, while others such as the Babbler Fluffy-backed Tit-babbler, Ferruginous, Scaly-crowned, Chestnut-rumped, Black-throated, Grey-hooded Babblers only occasionally go higher (2.5–3.6 m), whereas the Black-capped Babbler is strictly below one meter. This implies some form of niche segregation among the sympatric babbler species. It should be noted that the foraging height recorded in this study was solely based on the vertical capture location of double-stacked mist-nets, which may not entirely represent the foraging height. It also covered flying height of the babblers.

Diet composition

A total of 136 prey items were retrieved from regurgitated and faecal samples of 13 babbler species which comprised eight insect orders, plus one arachnid and one gastropod. Of those identifiable prey items, Coleoptera (41.5%), Hymenoptera (36.2%), and Araneae (12.3%) formed the major diet of babblers (Table 2). Based on analysis of bipartite ecological webs (Figure 2), Sooty-capped and Black-capped Babblers are specialists that feed solely on Coleoptera. Among all the babbler species, Fluffy-backed Tit-babbler seems to have the most generalized diet, covering seven insect orders. With respect to diet overlap analysis (Figure 3), the histogram was skewed to the left indicating that the diet overlap among the 13 babbler species was low. The prey items that heavily overlapped were from Categories 1 (for Araneae), 2 (Caterpillar), and 3 (Cicaedae). On the other hand, prey items that did not overlapped were from Categories 6 (Diptera), 9 (Hymenoptera), 10 (Orthoptera), and 11 (Phasmidae).

Being terrestrial, foliage and/or bark gleaning insectivores, the major prey groups of the babblers comprises of relatively more terrestrial (i.e., Coleoptera, Hymenopter,a and Araneae of understory level, similar to Mansor et al. (2018), except Blattodea) rather than aerial arthropods (but see Mansor et al. 2021). The abundance of Hymenoptera such as ants and Araneae (spiders) on the forest floor (Griffiths et al. 2018; Hartshorn et al. 2021) as well as those in the aerial leaf litter (Mansor et al. 2019) might be a reason that they formed a major portion of the babblers' diet. With respect to nutritional composition, Coleoptera and Araneae were found to contain higher portions of crude protein and lipids than Hymenoptera (Razeng & Watson 2015). Both protein and lipids (e.g., fats) are crucial for bird growth

Table 1. Species and number of individuals of babblers caught in Pelagus, Ulu Baleh, and Baram.

Common name	Species name	Study sites			Foraging strata		
		Pelagus	Ulu Baleh	Baram	Understorey	Mid-storey	Sub-canopy
Pellorneidae							
Rufous-crowned Babbler	*Malacopteron magnum*	3	18	0	11	10	0
Salvadori's Babbler	*Malacocincla sepiaria*	0	16	2	16	2	0
Scaly-crowned Babbler	*Malacopteron cinereum*	1	11	3	11	2	2
Sooty-capped Babbler	*Malacopteron affine*	1	4	0	2	3	0
Moustached Babbler	*Malacopteron magnirostre*	1	0	0	1	0	0
White-chested Babbler	*Trichastoma rostratum*	11	11	1	17	6	0
Short-tailed Babbler	*Trichastoma malaccense*	10	5	10	18	7	0
Ferruginous Babbler	*Trichastoma bicolor*	7	7	3	13	3	1
Black-capped Babbler	*Pellorneum nigrocapitatum*	1	0	3	4	0	0
Timaliidae							
Black-throated Babbler	*Stachyris nigricollis*	8	13	11	15	15	2
Grey-headed Babbler	*Stachyris poliocephala*	6	3	5	11	3	0
Chestnut-rumped Babbler	*Stachyris maculata*	1	2	4	4	2	1
Grey-hooded Babbler	*Cyanoderma bicolor*	1	5	12	12	4	2
Fluffy-backed Tit-babbler	*Macronous ptilosus*	3	8	5	7	8	1
Bold-striped Tit-babbler	*Mixornis bornensis*	1	0	6	6	1	0
Shannon index (*H'*)		2.193	2.314	2.238			
Species evenness (*J*)		0.867	0.941	0.919			
Total individual		55	103	65			
Total species		14	12	12			

Table 2. Prey item composition identified up to order.

Taxa	Pelagus	Ulu Baleh	Baram	Total
Coleoptera	21	14	19	54
Hymenoptera	8	24	15	47
Araneae	8	6	2	16
Orthoptera	0	2	2	4
Hemiptera	1	1	0	2
Phasmida	1	1	0	2
Dictyoptera	0	1	1	2
Diptera	1	0	0	1
Cicaedae	0	1	0	1
Gastropods	1	0	0	1
Unidentified	5	0	1	6

(Klasing 2000). Diet overlaps among babblers in this study were relatively low, consistent with reports from central Peninsular Malaysia (Mansor et al. 2018, 2021). The differences noted in foraging tactics might be one of the factors influencing the diet of the babbler species and vice versa. In addition, low diet overlaps of these birds could also be due to potential shifts in foraging behaviour when joining heterospecific feeding flocks (Mansor et al. 2020), which awaits further investigation in the case of Bornean babblers.

CONCLUSION

In the tropics where species diversity is high, resource partitioning and niche differentiation are essential evolutionary adaptions that lead to character displacement and reduce the competition among sympatric species (Wiens 1989). The use of different forest strata, either vertically or horizontally, and food resources by birds are common ecological strategies to reduce interspecific competition. Our study demonstrated the possible presence of spatial and trophic niche segregation among 15 babbler species in eastern Malaysia, some of which are likely to be specialists while others are generalists. Similar to other more localised

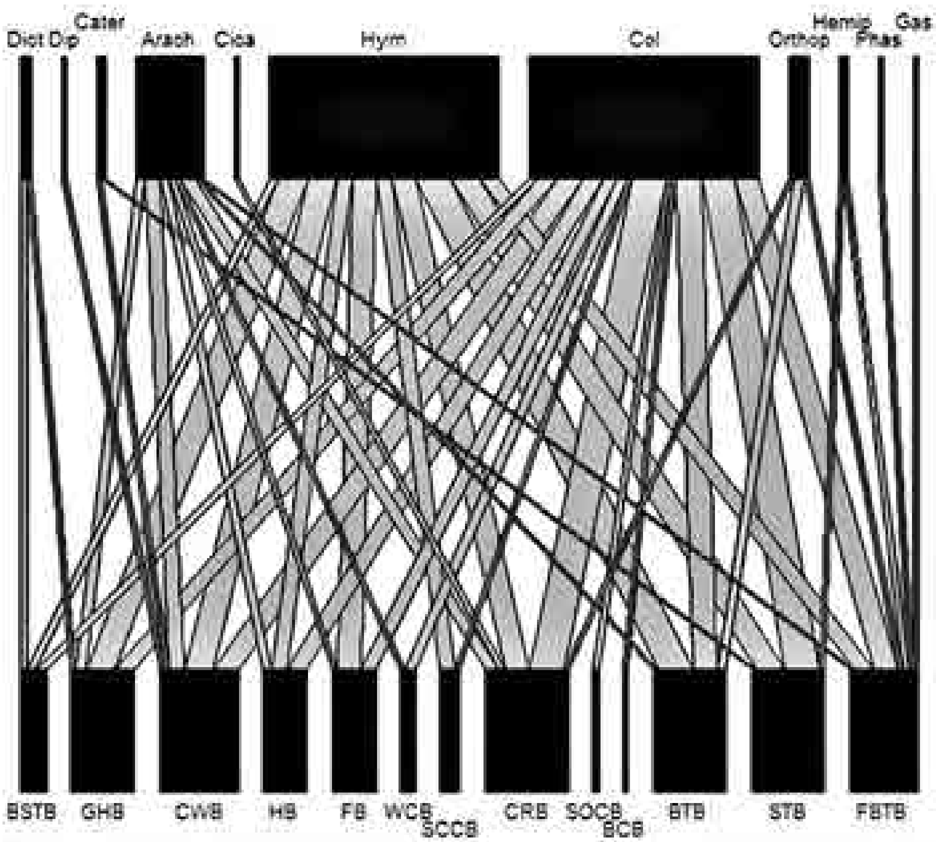

Figure 2. Analysis of babbler diets according to prey taxa. Widths of links are scaled to reflect interaction frequencies, while bar sizes indicate total interaction frequencies (Voon et al. 2014): BSTB—Bold-striped tit-babbler | GHB—Grey-headed Babbler | CWB—Chestnut-winged Babbler | HB—Horsfield's Babbler | FB—Ferruginous Babbler | WCB—White-chested Babbler | SCCB—Scaly-crowned Babbler | CRB—Chestnut-rumped Babbler | SOCB—Sooty-capped Babbler | BCB—Black-capped Babbler | BTB—Black-throated Babbler | STB—Short-tailed Babbler | FBTB—Fluffy-backed Tit-babbler | Dict—Dictyoptera | Dip—Diptera | Cater—Caterpillar | Arach—Araneae | Cica—Cicaedae | Hym—Hymenoptera | Col—Coleoptera | Orthop—Orthoptera | Hemip—Hemiptera | Phas—Phasmida | Gas—Gastropoda.

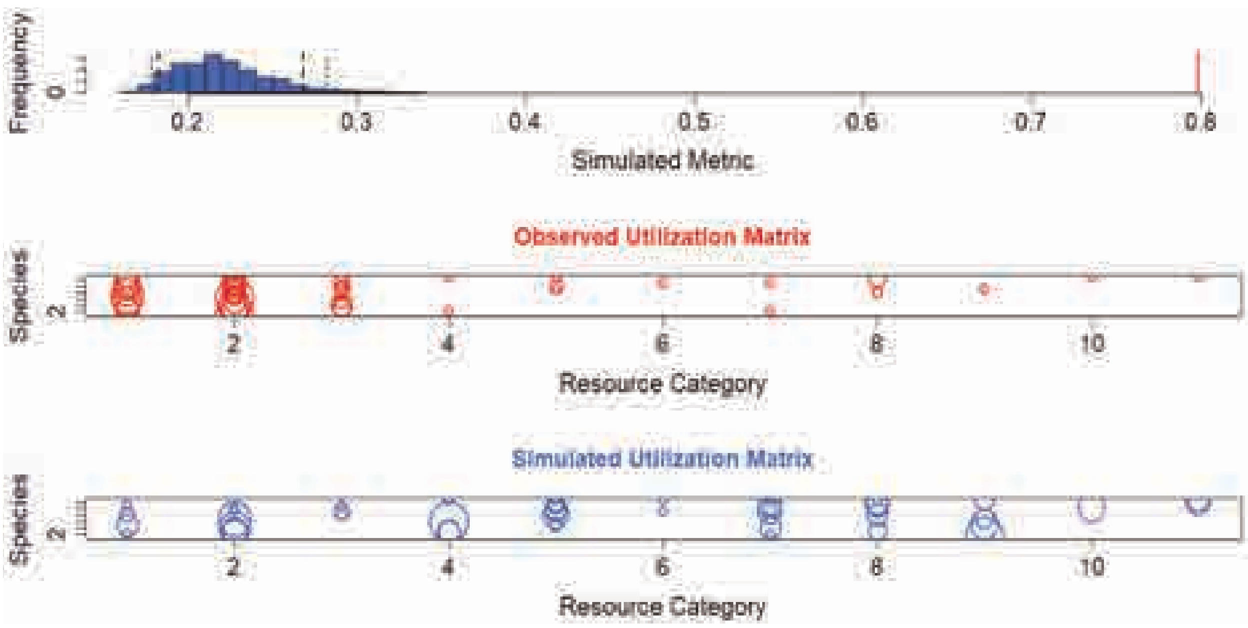

Figure 3. Diet overlap analysis (resource category input: 1—Araneae | 2—Caterpillar | 3—Cicaedae | 4—Coleoptera | 5—Dictyoptera | 6—Diptera | 7—Gastropoda | 8—Hemiptera | 9—Hymenoptera | 10—Orthoptera | 11—Phasmidae.

studies conducted in Malaysia, our study supported that different foraging tactics (Mansor & Mohd Sah 2012; Mansor et al. 2015, 2018; Styring et al. 2016; Mansor & Ramli 2017), foraging area and prey preference may have contributed to the difference in the diet of babblers (both Timaliidae and Pellornidae). Furthermore, prey size and type preference of the babblers in the Malaysian forests is believed to be influenced by predation and anti-predation strategies (Sherry et al. 2020) as well as possibly nutritional composition of the prey which deserve further investigation.

Having a feeding guild that is more terrestrial, foliage and/or bark gleaning in nature at the understory strata may render babblers, particularly those with specific spatial and trophic niches, exceptionally sensitive to habitat disturbance and fragmentation (Zakaria & Nordin 1998; Yong 2009). This implies that protection of this bird group, among others, is essential when forest management practices are being made. Their ecological role as indicators of forest ecosystem health (Lambert & Collar 2002; Hamer et al. 2015) is supported by our findings. It is also worth mentioning that two Near Threatened babbler species, i.e., White-necked Babbler (*Stachyris leucotis,* a rare slope specialist) and Grey-breasted Babbler (*Malacopteron albogulare,* an uncommon peat-swamp and heath forest specialist; Yong et al. 2014) are also found on Borneo, although not recorded in our study. Both species deserve more research and protective measures pertaining to their ecological requirements, trophic and spatial niches.

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COMMUNICATION

Effects of wind farm on land bird composition at Kachchh District, Gujarat, India

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Abstract: Bird assemblages in wind farm areas tend to change during the construction and operational phases, causing significant impacts in addition to collision mortality. Most existing studies on this issue are reported from North America and Europe, and it is largely under reported in Asian countries. We assessed patterns of bird assemblage in a wind farm and control areas in Kachchh, India, from October 2012 to May 2014, using point count method (79 sampling points with a 50 m radius). We recorded 54 species of land birds, mainly passerines. Species richness and diversity were higher in the control site, and the abundance of most passerine species was lower in the wind farm area, although the abundance of larks and wheatears was higher in the wind farm areas. Species composition was significantly different in both the sites. This difference is attributed to the presence of wind turbines and a difference in land use pattern.

Keywords: Bird sensitivity, collision mortality. displacement, habitat loss, renewable energy.

Tamil: காற்றாலைகள் அமைக்கும் போதும் அதற்கு பிறகும், அப்பகுதியில் உள்ள பறவைகளின் எண்ணிக்கையும் இன அமைப்பும் மாறுகிறது . இதுகுறித்தான ஆய்வுகள் பெரும்பாலாக வட அமெரிக்கா மற்றும் ஐரோப்பிய நாடுகளிலே நடத்தப்பட்டுள்ளன, ஆசிய பகுதிகளில் இதுகுறித்த ஆய்வுகள் மிகக் குறைவாகும் . அக்டோபர் 2012 முதல் ஏப்ரல் 2014 வரை, புள்ளி எண்ணிக்கை முறையைப் பயன்படுத்தி (50 மீ ஆரம் கொண்ட 79 மாதிரிப் புள்ளிகள்) இந்தியாவின் கட்ச் மாவட்டத்தில் உள்ள ஒரு காற்றாலை பகுதியில் இதுகுறித்து ஆய்வு நடத்தினோம். அதில் காற்றாலை உள்ள இடங்களிலும், அதற்கு அருகாமையில், காற்றாலை இல்லாத இடங்களிலும் உள்ள பறவை இனங்களின் தன்மையை ஆய்ந்தோம். இங்கு , 54 வகையான நிலப்பறவைகளை பதிவு செய்தோம். இவற்றில் பல பறவைகள் காற்றாலை இல்லாத பகுதிகளில் அதிகமான எண்ணிக்கையில் காணப்பட்டது. ஒரிரு வானம்பாடி மற்றும் புதர்ச்சிட்டு குருவியினங்கள் மட்டும் காற்றாலை பகுதியில் அதிக எண்ணிக்கையில் காணப்பட்டது. பொதுவாக இந்த இரு பகுதிகளின் இன அமைப்பில் குறிப்பிடத்தக்க மாற்றங்கள் உள்ளதை அறிந்தோம். இம்மாற்றதிற்கு காற்றாலைகளும் , நிலப்பரப்பில் ஏற்படுத்தப்படும் மாற்றங்களுமே காரணமாக உள்ளது.

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Author contributions: PRA conceived the idea. SRK and AMSA involved in the field data collection. All three were involved in writing the manuscript.

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INTRODUCTION

Wind energy is promoted worldwide (GWEC 2017), and the negative impacts of wind farms, especially on wildlife, have been well documented (Leddy et al. 1999; Villegas-Patraca et al. 2012). The major impacts of turbines on avifauna include: 1) Bird mortality and injury from collisions with rotating wind turbine blades, 2) Displacement of birds from the windfarm area due to the disturbance caused by the installation and operation of wind turbines, 3) Disruption of bird movements due to barrier effects (Drewitt & Langston 2006). Injuries to birds can also be caused by collisions with towers, nacelles and associated infrastructure of wind farms. (Drewitt & Langston 2006).

The displacement effect of wind farms on avifaunal assemblages have been extensively studied (Leddy et al. 1999; Pearce-higgins et al. 2009; Villegas-Patraca et al. 2012; Campedelli et al. 2014). For instance, the effects of wind turbines on grassland passerines of southwestern Minnesota, USA, were studied by Leddy et al. (1999), and it was found that grasslands located away from wind turbines have richer bird assemblages. Similarly, a study by Villegas-Patraca et al. (2012) in Mexico found high species richness of birds in surrounding croplands and secondary forests, intermediate richness values at 200 m from the turbines, and lowest species richness beneath turbines. A long-term study by Shaffer & Buhl (2016) using BACI (Before After Control Impact) design showed displacement in seven of nine species studied, while one species was unaffected, and one species exhibited attraction to the turbine site. They also found displacement and attraction were generally within 100 m. At times, the displacement extended even beyond 300 m. Garcia et al. (2015) studied breeding passerines in wind farms and reported that 12 out of 15 species decreased during the construction phase, and 10 of them showed an apparent increase in the population after the construction of the Valbormida wind farm in Italy.

In India, wind energy contributes about ten percent of total power generation (MNRE 2022). India is the 4th largest producer of wind energy, with an installed capacity of 39.25 GW (as of 31 March 2021 (MNRE 2022)). Existing studies mostly pertain to Europe and USA, whereas there is limited knowledge on this aspect from India (Pande et al. 2013; Arun et al. 2014; Thaker et al. 2018; Kumar et al. 2019). This study is an attempt to understand and evaluate the impacts of wind farms on the diversity and assemblage of terrestrial birds in the Kachchh region of Gujarat.

METHODS

Study Area

The study was conducted at the Samakhiali region (23.25–23.18 °N to 70.05–70.64 °E) in Kachchh district of Gujarat (Figure 1). The study area is close to the Little Rann of Kachchh, an Important Bird and Biodiversity Area (IBA) (Rahmani et al. 2016). The region is a 'stopover' and 'wintering' site for birds using the Central Asian Flyway and African Eurasian Flyway (Balachandran et al. 2018). The high winds and flat terrain close to the sea make it a suitable location for wind power generation (NIWE 2022) and have resulted in a large number of wind turbines coming up in this area. The region is generally dry and arid, dotted with many wetlands. Barren lands with the invasive tree species *Prosopis juliflora* predominate the landscape, with a small number of rain-fed agricultural fields. Most of the rainfall is received from July to September. Our total study area covers around 200 km^2. There are 200 turbines in the turbine site area that were installed since 2003. Most of the turbines are of 1.8 MW capacity with 95 m hub height and a rotor diameter of 100 m.

Bird Surveys

The study area was divided into a turbine site (~120 km^2) and a control site (~80 km^2) where there are no turbines. Land use pattern in the turbine site was similar to that of the control site except for the presence of turbines. The most suitable area available with similar vegetation and land use pattern to that of the turbine site was selected as the control site. We used the point count method with a 50 m radius for bird surveys as the area had more open habitats (Petit et al. 1995; Ralph et al. 1995). A total of 79 sampling points were fixed: 48 points in the turbine site and 31 points in the control site. All control points were at least 1 km away from the nearest wind turbine. To avoid repetitive counts of the same birds, we maintained a minimum 500 m distance between each sampling point. Every single count was conducted for 10 min duration and counted all the land birds except raptors. All bird surveys were carried out from 0600 h to 0900 h.

We conducted our survey from October 2012 to May 2014. The sampling period was divided as summer (March–September) and winter (October–February) for analysis. In winter, many species of migratory birds visited the area. Among eight temporal replications, five visits were made in winter and three in summer. We could not do eight replications in all 79 points, but a minimum of three replications were done at each

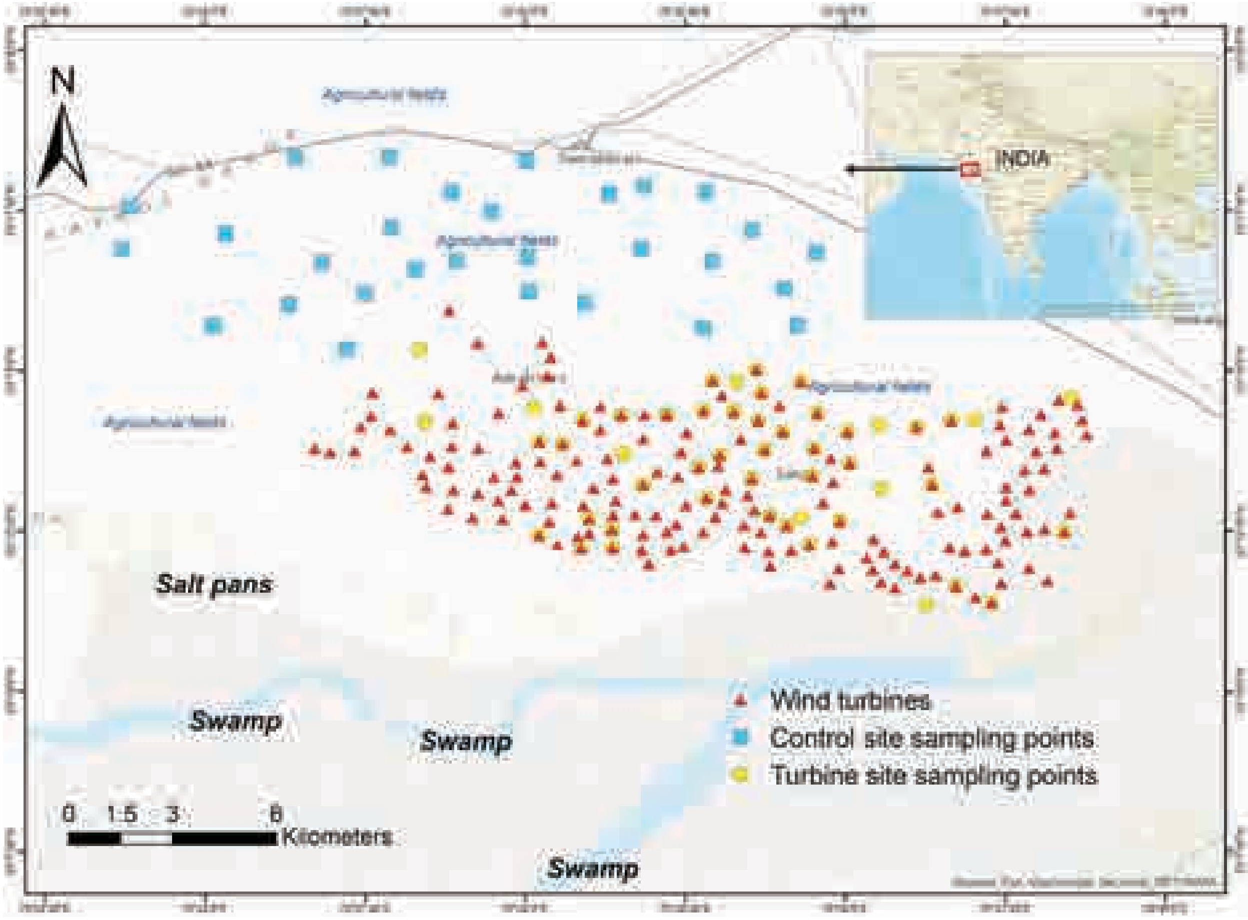

Figure 1. Location of the wind farm at Samakhiali, Gujarat, India.

point, with a total of 430 individual point counts during the study period. Identification of birds was done using standard guides (Ali & Ripley 2001; Grimmett et al. 2011), and the nomenclature of birds was followed according to del Hoyo et al. (2014).

Statistical Analysis

The bird assemblages were compared between sites and seasons using statistical measures. Relative abundance (Fr_i = number of individuals of i^{th} species / Total number of individual) of each species for all four assemblages, i.e., control and turbine sites both in summer and winter was calculated. The species with Fr_i >0.05 are considered as dominant species. This analysis was done to determine the dominant species (abundant) in each assemblage following Battisti et al. (2014). Species richness (S), Simpson diversity index, Simpson's measure of evenness, and Shannon diversity index (H') for each assemblage were also calculated. The effects of difference in sampling efforts are very minimal as the minimum samples required for representing the population have been drawn (completeness of sampling effort was tested by plotting species accumulation curves plotted using Estimate S) (Figure 2). Each assemblage's sampling points were pooled separately, and averages of each sampling point were used for estimating the diversity.

To test the spatial autocorrelation between sampling points, we performed the Mantel test with 9,999 permutations (Hammer et al. 2001). For this test we used the Euclidean similarity measure based on the geographical distance between sampling points, and Bray Curtis similarity measure based on the species composition of birds. To assess the difference in overall species composition between control and turbine sites, Non-metric Multi-Dimensional Scaling (NMDS) analysis followed by one-way PERMANOVA (NPMANOVA) test, both using Bray-Curtis similarity measure, was performed. NMDS ordinates sampling sites by their similarity in species composition. This algorithm attempts to place the data points in a two-dimensional coordinate system to preserve the ranked

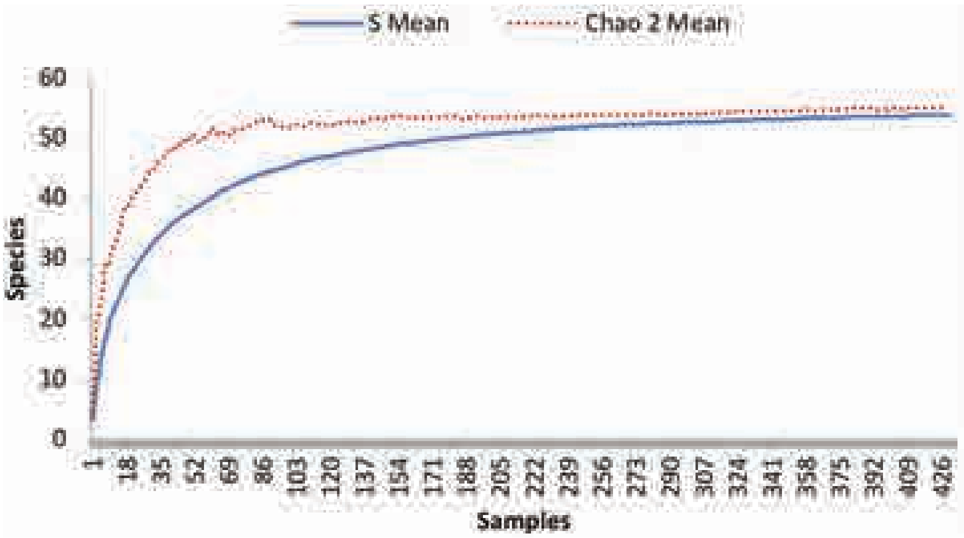

Figure 2. Speies accumulation curve shows the completeness of sampling efforts.

differences. PERMANOVA (Non-Parametric MANOVA, also known as NPMANOVA) is a non-parametric test of significant differences between two or more groups based on distance measures (Anderson et al. 2013). PERMANOVA calculates an F value in analogy with ANOVA. The significance is computed by permutation of group membership, with 9,999 replicates. To test the species most affected by wind turbines, the difference in mean abundance between control and turbine site for species with >20 sightings (including both sites) were tested using independent t-test. In order to overcome the differences in sampling efforts, the mean abundance of each sampling point was calculated and used to analyze the difference in abundance. Data for summer and winter were tested separately. Analyses such as PERMANOVA, Mantel test, and Diversity indices calculation were performed using 'Past 3.10' (Hammer et al. 2001). NMDS was performed using 'CANOCO-5' (ter Braak & Šmilauer 2012).

The Generalized Linear Models (GLM) was used to infer which factors among habitat variables influences bird species richness and diversity. Two GLMs were run, one with point-wise species richness (cumulative species richness at each sampling point) as the response variable and another with point-wise diversity index (Shannon diversity index). The explanatory variable included turbine variables such as the density of turbines (hereafter referred as 'turbine density') and distance to the nearest wind turbine from sampling points. The turbine density (number of turbines within one km radius) for each sampling point was calculated using QGIS 2.10.1. Among the variables, 'turbine density' and 'distance to the nearest turbine' strongly correlated with each other; hence only turbine density was included in the analysis. Habitat variables include normalised differential vegetation index (NDVI), distance (in km) from each sampling point to the nearest freshwater body (ponds, lakes, and check dams), human habitation, road (tarred), and salt marsh (salt pans).

NDVI for each sampling point corresponding to the months in which bird samplings were done was extracted from Google Earth Engine, a repository for geospatial data (this NDVI is calculated using Landsat-7 Satellite Imagery with 30 m resolution). NDVI is measured every 32 days. For this analysis, only values for the month in which the bird survey was conducted were extracted and the mean of this was included in the analysis (Mean of 8 temporal replications). NDVI is considered as the measure of plant productivity and a major determinant of bird species richness (Ding et al. 2006; Qian et al. 2009).

Precipitation for all the sampling points was collected from Worldclim global climatic data repository (http://www.worldclim.org/bioclim) (Fick & Hijmans 2017*).* Precipitation data is an average of 50 years from 1950 to 2000. The spatial resolution of this data is 30 seconds (~1 sq km). Though it may not be accurate and predicted based on the available historical data, this data set is readily available and widely used by biologists. This data is used to see whether precipitation plays any role in changing bird assemblage between sampling points.

Other variables such as distance (in km) from each sampling point to the nearest freshwater body (Ponds, Lakes, and Check dams), human habitation, road (tarred), and salt marsh (salt pans) were measured using Google Earth 2013 imagery & QGIS 2.10.1.

RESULTS

We recorded 54 species of birds belonging to 25 families, among which Muscicapidae had a maximum number of species (8 species, 34%), followed by Cisticolidae (6 species, 24%) (Table 1). Forty species were residents to the area, 12 were winter migrants, and two were passage migrants. All 54 species were categorized as Least Concern by IUCN (2018), however, 51 species were categorized as Schedule IV as per the Indian Wildlife Protection Act 1972. We recorded 53 species in the control site and 46 in the turbine site (Table 1). Species such as Greater Coucal, Dusky Crag Martin, Chestnut-shouldered Petronia, Brahminy Starling, Sykes Warbler, Black Redstart, and Blue throat were recorded only in the control site, however, the frequency of their sightings was very low (<4). The Great Grey Shrike was recorded only in the turbine site during the survey period (with 11 sightings).

In summer, species such as Rock Dove, Grey-breasted Prinia, House Sparrow, Red-vented Bulbul, and Rosy Starling were dominant (Fr_i >0.05) in control site and Ashy-crowned Sparrow Lark, Eurasian Collared Dove, and Rosy Starling were dominant in turbine site. In winter, House Sparrow, Rosy Starling, and Common Babbler were dominant in the control site and Ashy-crowned Sparrow Lark, House Sparrow and Rosy Starling were dominant in the turbine site (Table 1).

There was no significant spatial autocorrelation of species composition between the sampling points (Mantle test: R = 0.028; p = 0.204). Simpson Diversity and Evenness index values were lower in turbine site than in the control site in all two seasons (Table 2).

The first two axis of NMDS plot for summer explained 73.27 % of variation and showed distinction between the control and the turbine sampling points. Similarly, the NMDS plot for winter explained 71.3 % of variation, and it followed a similar pattern as that of summer (Figure 3). Overall (two seasons combined), species composition in both the sites were significantly different (PERMANOVA: F = 6.531; p = 0.001) and this pattern existed across the seasons (summer: F = 6.721; p = 0.001 and winter: F = 5.883; p = 0.001). In summer, 11 species had more than 20 sightings, and its abundance tested for significant differences between control and turbine sites. Among these, Asian Koel, Common Babbler, Eurasian Collared-dove, Grey-breasted Prinia, House Crow, House Sparrow,

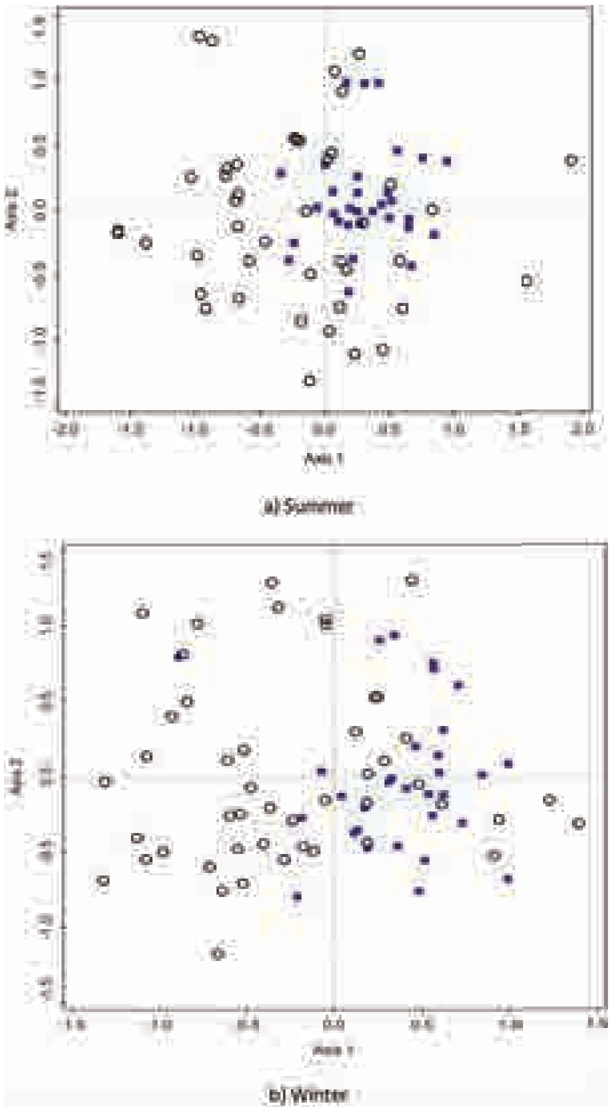

Figure 3a and b. Non-metric MDS plots show overlapping of control and turbine sampling points (Circles: Turbine site sampling points; Squares: Control sampling points). The plot is created using Bray Curtis dissimilarity distance with 499 permutations.

Indian Robin, Laughing Dove, Purple Sunbird, and Red-vented Bulbul had significantly lower abundance in the turbine site (Table 3). In winter, 15 species of birds were recorded with more than 20 sightings wherein, Black Drongo, Eurasian Collared-dove, Grey-breasted Prinia, House Crow, House Sparrow, Indian Robin, Laughing Dove, Purple Sunbird, and Red-rumped Swallow had lower abundance in the turbine site. However, birds like Rufous-tailed Lark and Variable Wheatear had a higher abundance in the turbine site (Table 3).

The GLM model with plot wise species richness as response variable was significant (F = 15.39, p = 0.001). The species richness was positively influenced by NDVI

Table 1. List of bird species recorded and their relative abundance at the control and turbine sites in summer and winter.

	Family name	Common name	Scientific name	Relative abundance in summer		Relative abundance in winter	
				Control (n = 35)	Turbine (n = 25)	Control (n = 47)	Turbine (n = 43)
1	Alaudidae	Ashy-crowned Sparrow-Lark	*Eremopterix grisea*	0.029	**0.080**	0.047	**0.153**
2	Alaudidae	Crested Lark	*Galerida cristata*	-	0.008	0.002	0.008
3	Alaudidae	Rufous-tailed Lark	*Ammomanes phoenicura*	0.005	0.014	0.014	0.046
4	Alcedinidae	White-breasted Kingfisher	*Halcyon smyrnensis*	0.016	-	0.019	0.007
5	Columbidae	Rock Dove	*Columba livia*	**0.114**	0.002	0.045	0.019
6	Columbidae	Eurasian Collared-dove	*Streptopelia decaocto*	0.040	**0.057**	0.045	0.033
7	Columbidae	Laughing Dove	*Spilopelia senegalensis*	0.043	0.040	0.035	0.020
8	Columbidae	Red Turtle Dove	*Streptopelia tranquebarica*	0.005	0.028	0.005	0.009
9	Coraciidae	European Roller**	*Coracias garrulus*	0.000	0.000	0.004	0.005
10	Coraciidae	Indian Roller	*Coracias benghalensis*	0.001	0.000	0.002	0.001
11	Corvidae	House Crow	*Corvus splendens*	0.044	0.024	0.028	0.014
12	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	0.033	0.004	0.010	0.003
13	Cuculidae	Greater Coucal	*Centropus sinensis*	0.003	0.000	0.000	0.000
14	Cisticolidae	Ashy Prinia	*Prinia socialis*	0.000	0.000	0.002	0.003
15	Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	0.005	0.000	0.003	0.002
16	Cisticolidae	Grey-breasted Prinia	*Prinia hodgsonii*	**0.053**	0.025	0.040	0.013
17	Cisticolidae	Jungle Prinia	*Prinia sylvatica*	0.002	0.000	0.014	0.004
18	Cisticolidae	Plain Prinia	*Prinia inornata*	0.000	0.000	0.002	0.001
19	Cisticolidae	Rufous-fronted Prinia	*Prinia buchanani*	0.003	0.000	0.001	0.000
20	Dicruridae	Black Drongo	*Dicrurus macrocercus*	0.000	0.001	0.005	0.009
21	Estrildidae	Indian Silverbill	*Euodice malabarica*	0.004	0.038	0.010	0.000
22	Hirundinidae	Barn Swallow*	*Hirundo rustica*	0.004	0.000	0.017	0.005
23	Hirundinidae	Dusky Crag-martin	*Ptyonoprogne concolor*	0.003	0.000	0.000	0.000
24	Hirundinidae	Red-rumped Swallow	*Cecropis daurica*	0.019	0.003	0.017	0.008
25	Hirundinidae	Wire-tailed Swallow	*Hirundo smithii*	0.000	0.001	0.003	0.000
26	Laniidae	Bay-backed Shrike	*Lanius vittatus*	0.000	0.000	0.007	0.003
27	Laniidae	Long-tailed Shrike	*Lanius schach*	0.000	0.000	0.003	0.005
28	Laniidae	Isabelline Shrike*	*Lanius isabellinus*	0.000	0.000	0.011	0.004
29	Laniidae	Great Grey Shrike	*Lanius meridionalis*	0.000	0.000	0.000	0.007
30	Meropidae	Asian Green Bee-eater	*Merops orientalis*	0.021	0.014	0.024	0.036
31	Motacillidae	Paddyfield Pipit	*Anthus rufulus*	0.003	0.000	0.008	0.004
32	Nectariniidae	Purple Sunbird	*Cinnyris asiaticus*	0.039	0.028	0.030	0.011
33	Passeridae	House Sparrow	*Passer domesticus*	**0.066**	0.010	**0.189**	**0.098**
34	Passeridae	Chestnut-shouldered Petronia	*Petronia xanthocollis*	0.001	0.000	0.000	0.000
35	Phasianidae	Grey Francolin	*Francolinus pondicerianus*	0.008	0.033	0.000	0.011
36	Phasianidae	Indian Peafowl	*Pavo cristatus*	0.021	0.003	0.000	0.000
37	Ploceidae	Baya Weaver	*Ploceus philippinus*	0.013	0.008	0.004	0.000
38	Psittacidae	Rose-ringed Parakeet	*Psittacula krameri*	0.017	0.000	0.002	0.002
39	Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	**0.071**	0.049	0.039	0.036
40	Sturnidae	Brahminy Starling	*Sturnia pagadarum*	0.004	0.000	0.002	0.000
41	Sturnidae	Rosy Starling*	*Pastor roseus*	**0.190**	**0.410**	**0.145**	**0.249**
42	Sylviidae	Hume's Whitethroat**	*Sylvia althaea*	0.002	0.000	0.000	0.001

	Family name	Common name	Scientific name	Relative abundance in summer		Relative abundance in winter	
				Control (n = 35)	Turbine (n = 25)	Control (n = 47)	Turbine (n = 43)
43	Sylviidae	Lesser White-throat*	*Sylvia curruca*	0.000	0.000	0.006	0.001
44	Acrocephalidae	Sykes's Warbler*	*Iduna rama*	0.000	0.000	0.003	0.000
45	Leiothrichidae	Common Babbler	*Turdoides caudatus*	**0.074**	0.071	**0.088**	0.114
46	Muscicapidae	Black Redstart*	*Phoenicurus ochruros*	0.000	0.000	0.001	0.000
47	Muscicapidae	Bluethroat*	*Luscinia svecica*	0.000	0.000	0.005	0.000
48	Muscicapidae	Common Stonechat *	*Saxicola torquatus*	0.000	0.000	0.003	0.002
49	Muscicapidae	Desert Wheatear*	*Oenanthe deserti*	0.000	0.000	0.002	0.003
50	Muscicapidae	Indian Robin	*Saxicoloides fulicatus*	0.041	0.046	0.035	0.024
51	Muscicapidae	Isabelline Wheatear*	*Oenanthe isabellina*	0.000	0.000	0.008	0.005
52	Muscicapidae	Pied Bush Chat*	*Saxicola caprata*	0.005	0.000	0.009	0.002
53	Muscicapidae	Variable Wheatear*	*Oenanthe picata*	0.000	0.001	0.004	0.020
54	Upupidae	Eurasian Hoopoe	*Upupa epops*	0.000	0.000	0.005	0.002

*—winter visitor | **—Passage migrant. The bold letter indicates the dominant species (with relative abundance >0.05).

Table 2. Diversity indices of bird assemblages of control and turbine sites in winter and summer. Sampling effort, i.e., number of independent point counts surveyed for each season, is given in parenthesis. Annual samplings were distributed as two visits in 2012 (winter: 2 visits), four in 2013 (summer: 2; winter: 2) and two in 2014 (summer: 1; winter: 1).

Diversity indices	Summer (155)		Winter (275)		Overall (430)	
	Control (84)	Turbine (71)	Control (111)	Turbine (164)	Control (195)	Turbine (235)
Species richness	35	25	47	42	53	46
Simpson diversity index	0.920	0.805	0.919	0.883	0.921	0.896
Simpson's evenness	0.359	0.205	0.263	0.204	0.241	0.210
Shannon diversity index	2.892	2.299	3.02	2.687	3.077	2.819

(t = 3.74, p = 0.001) and negatively influenced by turbine density (t = -2.65, p = 0.01) (Table 4). The model with Shannon diversity index as response variable was also significant (F = 3.33, p = 0.008). Shannon diversity was positively influenced by NDVI (t = 2.25, p = 0.028).

DISCUSSION

The study area supports typical land birds of a semi-arid region of India. We detected evidence for the effects of wind turbines on bird assemblage at Kachchh, Gujarat. The overall species richness and diversity were higher at the control site than the turbine site in both seasons. The majority of the species showed lower abundance in the wind farm area; however, a few species had higher abundance in the wind farm. A similar pattern of low species richness in wind farm in comparison to adjacent areas was also reported by Villegas-Patraca et al. (2012) in Mexico; they found increasing species richness as one moves away from the base of the wind turbine.

Species richness as an indicator of habitat quality can be misleading, since degraded habitats can be occupied by generalist species, thereby increasing the overall species richness (Magurran 2016). Hence, it is recommended to consider species composition to reflect habitat quality and habitat degradation (Magurran 2016). In the present study species composition of birds was different in turbine and control areas. Generalist species like Common Babbler, Rosy Starling, and House Sparrow were present abundantly in both sites. However, certain species of larks and wheatear, including Variable Wheatear, Ashy-crowned Sparrow-Lark, Crested Lark, and Rufous-tailed Lark were found to be more abundant in turbine area. Generally, the abundance of most species except the above-mentioned larks was low in the turbine area.

Species which prefer trees and shrubs, such as Asian

Table 3. Difference in the abundance of species with more than 20 sightings between control and turbine site in summer and winter. Compared using independent t test; (n = 79 sampling points).

Common name	Scientific name	Summer		Winter	
		t- value	p-value	t- value	p-value
Asian Koel	*Eudynamys scolopaceus*	4.530	**0.000**	-	-
Ashy-crowned Sparrow-Lark	*Eremopterix grisea*	-0.355	0.724	-1.944	0.056
Black Drongo	*Dicrurus macrocercus*	-	-	2.343	**0.022**
Common Babbler	*Turdoides caudate*	3.577	**0.001**	0.661	0.511
Eurasian Collared-dove	*Streptopelia decaocto*	2.064	**0.042**	2.867	**0.005**
Asian Green Bee-eater	*Merops orientalis*			0.017	0.987
Grey-breasted Prinia	*Prinia hodgsonii*	5.804	**0.000**	4.991	**0.000**
House Crow	*Corvus splendens*	3.972	**0.000**	3.639	**0.000**
House Sparrow	*Passer domesticus*	4.651	**0.000**	2.573	**0.012**
Indian Robin	*Saxicoloides fulicatus*	3.212	**0.002**	3.307	**0.001**
Laughing Dove	*Spilopelia senegalensis*	3.634	**0.001**	3.482	**0.001**
Purple Sunbird	*Cinnyris asiaticus*	4.707	**0.000**	4.737	**0.000**
Red-rumped Swallow	*Cecropis daurica*	-	-	2.047	**0.044**
Red-vented Bulbul	*Pycnonotus cafer*	2.970	**0.004**	1.862	0.066
Rufous-tailed Lark	*Ammomanes phoenicura*	-	-	-2.056	**0.043**
Variable Wheatear*	*Oenanthe picata*	-	-	**-3.049**	**0.003**

*—winter visitors. Bold letters indicate species with a significant difference.

Table 4. GLM Models explaining the influence of turbine and habitat variables on bird assemblage. (Model 1 = Species Richness as response variable; Model 2 = Shannon diversity as response variable). Bold letters indicate P value <0.05.

Variables	Model 1: Species Richness				Model 2: Shannon Diversity			
	AIC = 481.2, F = 15.399, p = 0.001				AIC = 156.93, F = 3.33, p = 0.008			
	beta	SE	t value	p -value	beta	SE	t value	p value
Intercept	7.848	2.141	3.670	0.000	11.010	4.765	2.310	**0.024**
Turbine Density (in 1 km^2 radius)	-0.060	0.022	-2.650	**0.010**	-0.036	0.043	-0.850	0.400
Distance to Human Habitation (km)	-0.025	0.041	-0.610	0.541	0.061	0.084	0.730	0.470
Distance to Ponds/Lakes (km)	-0.099	0.062	-1.610	0.112	-0.186	0.130	-1.430	0.157
Distance to Road (km)	-0.019	0.035	-0.550	0.585	-0.039	0.080	-0.490	0.629
NDVI	3.220	0.861	3.740	**0.000**	4.393	1.955	2.250	**0.028**
Distance to Salt Pans (km)	0.020	0.017	1.180	0.244	0.019	0.036	0.540	0.592
Precipitation	-0.014	0.005	-2.650	**0.010**	-0.023	0.011	-2.010	**0.048**

Koel, Grey-breasted Prinia, Indian Robin, Red-vented Bulbul, and Purple Sunbird were found in low numbers in the turbine site. This was evident from the individual 't' test conducted for differences in the abundance of individual species . Most species tested had a lower abundance in the wind farm area. Similar avoidance of wind turbine by a majority of birds was also reported from Mexico by Villegas-Patraca et al. (2012).

GLM analysis revealed that the diversity of birds was influenced by turbine presence along with NDVI. From the above pattern, the regular clearing of vegetation which alters the habitat in the turbine site may be one of the reasons for lower abundance of shrub preferring birds in the turbine area, along with the disturbance caused by the turbine's presence. This may be the reason for the high abundance of birds preferring open habitats like Larks and Wheatears in turbine site. The increased number of Larks and Wheatears in turbine sites might be due to the alteration of the landscape during the development of wind farms. The supply roads, trenches, and cleared open areas below the turbine which had not existed before, maybe the causatives for this change (Hötker 2006). The negative influence of precipitation on bird richness as per GLM might be a random result as the study area is small the effect of variation in rainfall on bird community may not be strong.

Our study confirms that there is an effect of wind turbines and its related habitat alteration on the birds of the Kachchh region is evident. A combined effect of presence of turbine, alteration of habitats by clearing vegetation and disturbances has contributed to this low abundance of bird species. Although attempts were made to correct the bias due to difference in the sampling size, to certain extant habitat, there is a possibility that this bias might have some influence on the results.

India has varied geographical and climatic conditions, and results from the semi-arid landscape at Gujarat may not apply to other habitats. The wind farms located in Western Ghats and East-coast may have different impacts on birds based on varied bird composition of those areas. In order to reduce the carbon footprint, the Indian government provides huge subsidies for establishing renewable energy production; especially for wind energy (MNRE 2022) and with a very few studies on the impact of wind farms on birds in India, it is difficult to measure the magnitude of its impacts on bird populations and their habitats. The findings of this study can be taken as an indicative result that some species tend to avoid turbine areas; further, a more comprehensive study is required to confirm our results by looking into the various other relevant variables such as predator-prey interaction, vegetation diversity and nesting success of birds in wind farms must be studied to gain a better understanding of the dynamics of bird assemblages in the wind farms.

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COMMUNICATION

New records of odonates from Trongsa and Zhemgang, central Bhutan with a checklist of Jigme Singye Wangchuck National Park

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Abstract: New records of 43 species of dragonflies and damselflies from Trongsa and Zhemgang districts in central Bhutan are provided. Two of these, *Watanabeopetalia atkinsoni* (Selys, 1878) and *Tetrathemis platyptera* (Selys, 1878), are new to Bhutan bringing the number of species known from Bhutan to 125. A checklist of the 60 species known from Trongsa district, Zhemgang district and the Jigme Singye Wangchuck National Park is provided.

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Author contributions: MMG—carried fieldwork and drafted the manuscript; CD—carried fieldwork with first author and reviewed the manuscript; AMS—supported the fieldwork and logistics and reviewed the manuscript; SKR—escorted the fieldwork in Nabji Korphu with first author; KCD—escorted the entire fieldwork, arranged the logistics and reviewed the manuscript; VJK—provided the critical review and supplemented with useful literatures.

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INTRODUCTION

In the last few years, an increasing number of studies were published on the dragonflies and damselflies of Bhutan with numerous species being reported new to the country. The checklist published by Gyeltshen et al. (2017) included 92 species and that of Kalkman et al. (2020) contained 114 species. A further nine species were recorded by Gurung et al (2021) bringing the total to 123 species. Rasaily et al. (2021) provided an overview of the odonates of Bhutan with a checklist, distribution maps, data on phenology, and altitudinal distribution for all species. The dragonfly and damselfly fauna of Bhutan compared to adjacent region in the eastern Himalaya, is relatively well known although it is likely that more species remain to be discovered. Most of the studies on Bhutanese odonates were carried out in non-protected areas with limited field survey periods and proximity to the main roads. Data on the occurrence of dragonflies and damselflies in the protected areas is scant in Bhutan. Here, we present distribution data collected in 2021 of 43 species of odonates from Trongsa and Zhemgang districts. Part of these records originate from the Jigme Singye Wangchuck National Park (JSWNP). These records include two species new to Bhutan.

MATERIALS AND METHOD

Opportunistic sampling was carried out from 23 April 2021 to 20 May 2021 during the pre-monsoon and 18 October 2021 to 05 November 2021 during the post-monsoon season in two districts—Trongsa and Zhemgang in central Bhutan (Figure 1)—along an altitudinal gradient stretching from 400 m to 2,800 m. The survey was conducted from 0900–1500 h in suitable habitats such as brooks, wetlands, ponds, paddy fields, and rivers. Odonates were photographed using a Nikon D5600 DSLR camera attached to Nikkor 70–300 mm zoom lens during the survey. Common species were identified in the field following Gyeltshen et al. (2017). Species which could not be identified in the field were captured using an insect sweep net and brought to the College of Natural Resources, Royal University of Bhutan lab for examination. All specimens collected from this study were deposited in the College of Natural Resources Museum. The specimens were examined under the microscope and were identified using the taxonomic monograph of Fraser (1933, 1934, 1936) and Karube (2002). All species identifications are based upon adult specimens except for two records of *Perissogomphus stevensi* and one records of *Neurobasis chinensis* which were identified from larvae.

Abbreviations

DoFPS: Department of Forest and Park Services; FR: forest ranger; FW: forewing; HW: hindwing; JSWNP: Jigme Singye Wangchuck National Park; MG1–37: Locality 1 to 37; pt: pterostigma; S1–10: abdominal segment 1 to 10.

List of localities (Figure 1)

All observations were made by the first author unless specified otherwise. Some localities were visited multiple times and in these cases a, b, c, or d indicates the date on which they were visited (see list of localities). 'X' denotes those cases where a locality was visited multiple times but the date on which a species was recorded is unknown.

(MG1) Zhemgang district, Tingtibi, Dakpay Chhu, shallow stream with thick vegetation by the side of marshy land, (27.152121°N, 90.693088°E, altitude 555 m), 25 October 2021.

(MG2) Zhemgang district, Tingtibi, streams with thick lowland vegetations, (27.142237°N, 90.692395°E, altitude 558 m), (a) 26 April 2021; (b) 25 October 2021.

(MG3) Zhemgang district, Takabi Chhu stream, tall tree canopies with thick riparian vegetation, (27.146026°N, 90.687720°E, altitude 561 m), 21 October 2021.

(MG4) Zhemgang, Tingtibi, Takabi Chhu, stream with thick vegetation and tall tree canopy habitat, (27.144651°N, 90.687412°E, altitude 483 m), (a) 12 May 2021; (b) 21 October 2021.

(MG5) Zhemgang district, Tingtibi, Maidagang Chhu streams with dense riparian vegetation, (27.127601°N 90.715601°E, altitude 534 m), (a) 25 April 2021; (b) 22 October 2021.

(MG6) Zhemgang district, way to Berti from Tingtibi, along the roadside pools with bushy vegetation, (27.150037°N, 90.684622°E, altitude 599 m), (a) 27 March 2021; (b) 25 October 2021.

(MG7) Zhemgang district, Tingtibi, common along stream side vegetation, (27.139521°N, 90.698527°E, altitude 789 m), 26 October 2021.

(MG8) Zhemgang district, way to Berti from Tingtibi, wetlands and slow flowing streams, (27.150343°N, 90.670788°E, altitude 571 m), (a) 25 April 2021; (b) 25 October 2021.

(MG9) Zhemgang, Berti, slow flowing stream near the Berti fishing community, (27.160623°N, 90.654518°E, altitude 662 m), 25 October 2021.

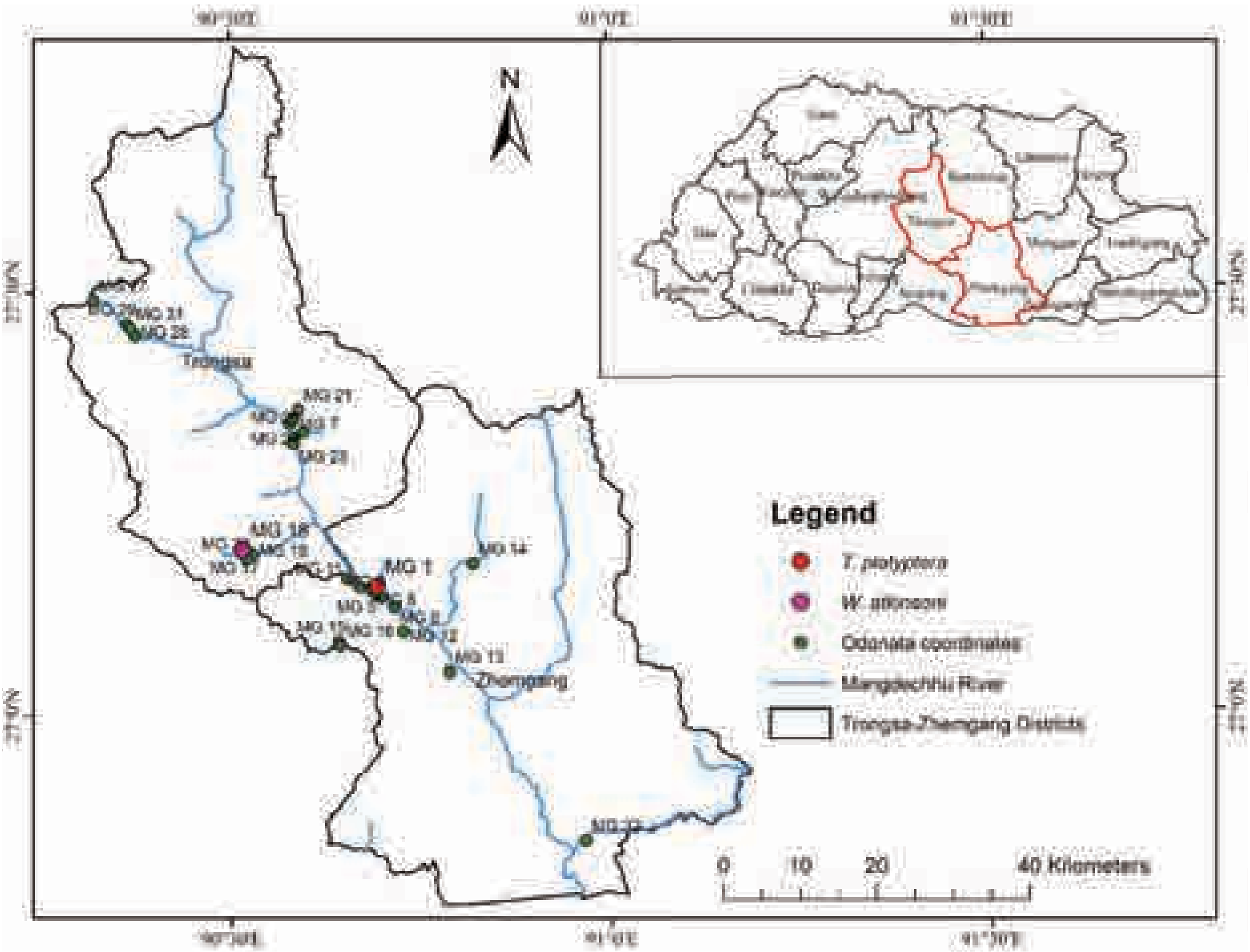

Figure 1. Survey localities along Mangdechhu basin, Jigme Singye Wangchuck National Park, Trongsa and Zhemgang districts.

(MG10) Zhemgang district, way to Manas, standing water, wetland and slow flowing streams, (27.049563°N, 90.787988°E, altitude 1,476 m), (a) 28 April 2021; (b) 23 October 2021.

(MG11) Zhemgang district, on stream side riparian vegetation, (27.177540°N, 90.819670°E, altitude 1,539 m), (a) 26 April 2021; (b) 24 October 2021.

(MG12) Zhemgang district, Tamala, standing water and mountain brooks, (27.085926°N, 90.642640°E, altitude 2,181 m), 25 April 2021.

(MG13) Zhemgang district, Tamala passes, lake below Tamala check post, thick tree canopies, and permanent standing water, (27.081386°N, 90.643579°E, altitude 1,397 m), 25 April 2021.

(MG14) Trongsa district, Nabji Korphu, fast flowing montane streams along the thick forest canopy, (27.190785°N, 90.526465°E, altitude 1,223 m), 16 May 2021.

(MG15) Trongsa district, Nabji Korphu, thick vegetation along forest streams, (27.195754°N, 90.515107°E, altitude 1,416 m), 19 May 2021.

(MG16) Trongsa district, Nabji Korphu, wetland with thick vegetation, (27.189306°N, 90.529591°E, altitude 1,187 m), 16 May 2021.

(MG17) Trongsa district, Nabji Korphu, streams with thick riparian vegetation and tree canopies, (27.184594°N, 90.521300°E, altitude 1,218 m), 16 May 2021.

(MG18) Trongsa district, Langthel, forest along the streams, (27.360582°N, 90.590122°E, altitude 1,571 m), (a) 16 May 2021; (b) 22 October 2021.

(MG19) Trongsa district, Langthel, stream with thick vegetation and tree canopies, (27.349298°N, 90.581241°E, altitude 1,140 m), (a) 16 May 2021; (b) 22 October 2021.

(MG20) Trongsa district, Langthel, above Bayzam bridge, grasslands and bushes by the wetland, (27.320119°N, 90.583442°E, altitude 1,082 m), (a) 14 April 2020; (b) 23 October 2021.

(MG21) Trongsa district, Langthel, wetland, water channels, and paddy fields, (27.343525°N, 90.578323°E, altitude 1,002 m), (a) 20 April 2021; (b) 22 October 2021.

(MG22) Trongsa district, Langthel, streams along the forest, (27.348525°N, 90.582566°E, altitude 1,251 m), (a) 10 May 2021; (b) 22 October 2021.

(MG23) Trongsa district, Langthel, fast flowing streams with tree canopies, (27.334342°N, 90.596369°E, altitude 1,151 m), 10 May 2021.

(MG24) Trongsa district, Chendebji, wetland and brooks, (27.489954°N, 90.319323°E, altitude 2,712 m), (a) 14 May 2021; (b) 18 October 2021.

(MG25) Trongsa district, Nika Chhu stream with thick undisturbed riparian vegetation (27.44833°N, 90.37397°E, altitude 2,251 m), 01 December 2021.

(MG26) Samdrupjongkhar district, Jomotshangkha, stagnant pool side in Jangsa area with low land vegetation, (26.884801°N, 92.096801°E, altitude 280 m), 26 September 2020.

(MG27) Trongsa district, Kartigang Chhu, stream with thick vegetation and tall canopies away from settlements, on the way to Langthel from Tingtibi, (27.278597°N, 90.629933°E, altitude 1,355 m), 22 October 2021.

Other observations

(MG28) Zhemgang district, Buli, wetland by the forest, (27.206561°N, 90.711347°E, altitude 1,510 m), 30 November 2021, leg. Sherub D. Jamtsho.

(MG29) Zhemgang district, Kikhar, stream with thick fern growth, (27.171210°N 90.698348°E, altitude 698 m) 25 September 2019, leg. Reta Bdr.

(MG30) Zhemgang district, tandem flight capture over the grassland, (27.053908°N 90.847121°E, altitude 1,459 m), 23 March 2020, leg. Sherub D. Jamtsho.

(MG31) Zhemgang district, Nimshong Shingkhar, vegetation by the forest side, (27.246188°N 90.947851°E, altitude 1,252 m), (a) 14 May 2020; (b) 18 July 2020; (c) 25 August 2020, leg. Sherub D. Jamtsho.

(MG32) Zhemgang district, Therang, Shingkhar, perching by the forest, (27.278504°N 90.945818°E, altitude 1,911 m), (a) 30 May 2019; (b) 01 June 2019, leg. Sherub D. Jamtsho

(MG33) Zhemgang, Nimshong Shingkhar, thick vegetation near a steam, (27.191413°N 90.966913°E, altitude 1,464 m), (a) 26 July 2020; (b) 18 August 2019, leg. Sherub D. Jamtsho.

(MG34) Zhemgang, Nimshong Shingkhar, perching by the forest side, (27.225310°N 90.955527°E, altitude 1,544 m), 21 July 2018, leg. Sherub D. Jamtsho.

(MG35) Zhemgang district, Radhi Shingkhar, by the forest side, (27.271882°N 90.944047°E, altitude 1,881 m), 21 June 2019, leg. Sherub D. Jamtsho.

(MG36) Trongsa district, Jigme Singye Wangchuck National Park, bamboo dominated forest (27.194522°N 90.479680°E, altitude 1,525 m), 18 November 2020, leg. Kado Rinchen.

(MG37) Trongsa district, Langthel, woodland by the standing water habitat, (27.326706°N, 90.583657°E, altitude 1,069 m), 11 July 2019, leg. Kado Rinchen.

RESULTS

Our survey resulted in 43 new species records of from Trongsa and Zhemgang, Central Bhutan. In addition, 17 other species were recorded from these dzongkhags (provinces) in previous publications bringing the total to 60 species belonging to 16 genera and 11 families (Table 1). Two of the species recorded by us, *Watanabeopetalia atkinsoni* and *Tetrathemis platyptera*, are new to Bhutan bringing the total number of species known from the country to 125.

All 37 localities from which we present records are in Trongsa and Zhemgang districts with the exception of locality 26 which is in Samdrupjongkhar district. This is however included here in order to include a second record of *T. platyptera.*

List of species recorded

Anisoptera (dragonfly)

Family Aeshnidae

1. *Aeshna petalura* (Martin, 1908), MG27, MG35, MG36.

2. *Cephalaeschna* sp. Selys, 1883, MG27.

3. *Gynacantha* sp. Rambur, 1842, MG27.

4. *Polycanthagyna erythromelas* (McLachlan, 1896), MG37.

Family Chlorogomphidae

5. *Watanabeopetalia atkinsoni** (Selys, 1878), MG15.

Family Cordulegasteridae

6. *Anotogaster nipalensis* (Selys, 1854), MG30.

Family Gomphidae

7. *Davidius* sp. Selys 1878, MG30.

8. *Lamelligomphus risi* (Fraser, 1922), MG1, MG2b, MG3, MG5b, MG6b.

9. *Perissogomphus stevensi* Laidlaw, 1922, MG2a, MG5b (3 larvae), MG6b (3 larvae), MG15, MG16, MG17.

10. *Scalmogomphus bistrigatus* Hagen, 1854. MG31c.

Family Libellulidae

11. Crocothemis sp. Brauer, 1868, MG1, MG2x, MG6x, MG7, MG25, MG32x.

12. Diplacodes trivialis (Rambur, 1842), MG2x, MG4x, MG10x, MG20a, MG24x.

13. Orthetrum glaucum (Brauer, 1865), MG2x, MG3, MG4x, MG11b, MG18x, MG22x.

14. Orthetrum internum MacLachlan, 1894, MG15, MG19a, MG20b, MG21x.

15. Orthetrum luzonicum (Brauer, 1868), MG2x, MG3, MG4x, MG10x.

16. Orthetrum pruinosum (Burmeister, 1839), MG1, MG2x, MG11a, MG12, MG23.

17. Orthetrum sabina (Drury, 1773), MG1, MG2x, MG11x, MG12, MG22a.

18. Orthetrum triangulare (Selys, 1878), MG1, MG3, MG4x, MG9, MG18b, MG23.

19. Palpopleura sexmaculata (Fabricius, 1787), MG1, MG2, MG6x, MG18x, MG22b.

20. Pantala flavescens (Fanricius, 1798), MG2x, MG3, MG14, MG16, MG19x.

21. Sympetrum commixtum (Selys, 1884), MG20x, MG24a, MG30.

*22. Tetrathemis platyptera** (Selys, 1878), MG1, MG26.

23. Trithemis aurora (Burmeister, 1839), MG2b, MG3, MG5a, MG9, MG19b

24. Trithemis festiva (Rambur, 1842), MG2x, MG5x, MG7, MG8x, MG10a, MG21b.

25. Trithemis pallidinervis (Kirby, 1889), MG1, MG2.

Family Macromidae

26. Macromia moorei Selys, 1874, MG2x, MG3, MG5x, MG7, MG8x, MG14, MG15.

Zygoptera (damselfly)

Family Calopterygidae

27. Caliphaea confusa Hagen in Selys, 1859, MG3, MG15, MG17, MG32a.

28. Neurobasis chinensis (Linnaeus, 1758), MG1, MG4x, MG5b (2 larvae), MG15, MG17.

Family Chlorocyphidae,

29. Aristocypha cuneata (Selys, 1853), MG1, MG2b, MG4b, MG5b, M7, MG9, MG10b.

Family Coenagrionidae

30. Aciagrion olympicum Laidlaw, 1919, MG31a.

31. Agriocnemis pygmaea Rambur, 1842, MG8b.

32. Ceriagrion fallax Ris, 1914, MG4, MG10b, MG11x.

33. Ischnura rubilio (Selys, 1876), MG2b, MG3, MG6b, MG8b, MG32b.

34. Pseudagrion rubriceps (Selys, 1876), MG6a, MG8a.

Family Euphaeidae

35. Anisopleura comes Hagen, 1880, MG14, MG15, MG16, MG17, MG33a & b.

36. Anisopleura subplatystyla Fraser, 1927, MG28, MG29, MG33b.

37. Bayadera indica Selys, 1853, MG23.

Family Lestidae

38. Indolestes cyaneus (Selys, 1862), MG12, MG13, MG24b, MG25.

39. Lestes dorothea Fraser, 1924, MG34.

Family Platystictidae

40. Protosticta sp. Selys, 1885, MG31b.

Family Platycnemididae

41. Calicnemia eximia Selys, 1863, MG13, MG15, MG18a, MG21a & b.

42. Calicnemia miniata (Selys, 1886), MG35.

43. Copera vitatta (Laidlaw, 1914) MG1, MG5x.

New records for Bhutan

Chlorogomphidae: *Watanabeopetalia atkinsoni* Selys, 1878 (Image 1A–E)

Specimens examined. Two males were collected from Nabji Korphu, locality MG15, (27.195754°N, 90.515107°E, altitude 1,416 m), Trongsa district, 19 May 2021, leg. Mer Man Gurung.

The members of the family Chlorogomphidae resembles those of Cordulegastridae in being large black and yellow dragonflies. The easiest character in the hand to distinguish members Chlorogomphidae from those of Cordulegastridae is the presence of one (*Chloropetalia*, *Watanabeopetalia*) or more (*Chlorogomphus*) cross veins in the median space or both fore and hindwing (none in members of Cordulegastridae). *Watanbeopetalia* can be distinguished from other species of Chlorogomphidae occurring in the eastern Himalayan region by the presence of two broad yellow stripes, one on mesepimeron and one on metepimeron, on the side of the thorax and by the front of face being light brown without well-defined yellow markings. Four *Watanabeopetalia* species have been described: *W. atkinsoni* (Selys, 1878), *W. ojisan* (Karube, 2013), *W. uenoi* (Asahina, 1995) and *W. usignata* (Chao, 1999) (Paulson et al. 2021). From these four species only *W.*

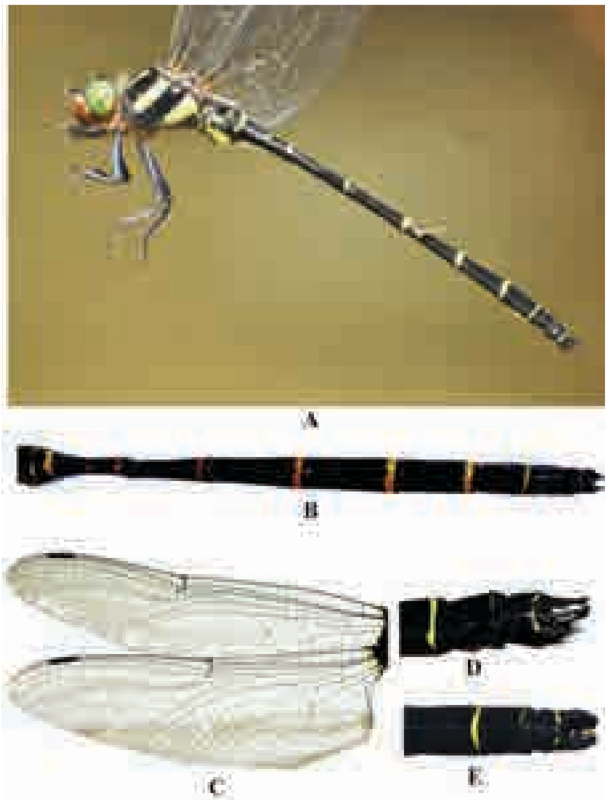

Image 1. Features of *Watanabeopetalia atkinsoni* (Selys, 1878), two males: A—Habitus, lateral view | B—Abdomen, dorsal view | C––Wings | D––Anal appendages, lateral | E—Anal appendages, dorsal leg. © Mer Man Gurung.

atkinsoni is known to occur in the Indian sub-continent where it has been found in India (west Bengal & Sikkim) and Nepal (Darjeeling & Shiva Puri, north Kathmandu valley) (Karen Conniff pers. comm. 01.x.2021).

The characters and body coloration of the two male specimens of Bhutanese *Watanabeopetalia atkinsoni* match well with the original description (Karube 2002). As this species is poorly known we provide additional figures of the species in life and details of the abdomen, wings and appendages (Image 1). Karube (2002) mentions that abdomen S1–8 is black with yellow markings and that S9–10 is either completely black or black with narrow yellow rings (Image 1B). This is also true for the Bhutanese specimens as one of the specimens has S9–10 black without yellow rings and other has yellow markings in last two segments (Image 1D–E). Karube (2002) describes the thorax as dark-brown to black marked on front with a bright citron-yellow oblique antehumeral stripe and on the side with two broad yellow stripes with in between them a small yellow upper spot. One of the specimens collected from Bhutan also has second yellow spot between the oblique antehumeral stripes (Image 1A).

Watanabeopetalia atkinsoni specimens were collected from a fast-flowing mountain stream on a sunny day. The riparian vegetation consisted of dense grasses with a tall tree canopy and the streambed consisted mostly of cobbles and sand. The water flow was obstructed frequently by rocks forming pools, cascades, and falls at several sites over which males were observed patrolling. Females were not observed. Other species found in this habitat include *Anisopleura comes*, *Caliphaea confusa*, *Macromia moorei*, and *Perissogomphus stevensi*.

Libellulidae: *Tetrathemis platyptera* Selys, 1878 **(Image 2A–C)**

Specimens examined. Two males and two females were collected from locality MG1, Tingtibi, Dakpay Chhu (27.152121°N, 90.693088°E, altitude 555 m), Zhemgang district, 25 October 2021, leg. Mer Man Gurung; 1 m#, locality MG26, Jangsa, Jomotshangkha (26.8848°N, 92.0968°E, altitude 280 m), Samdrupjongkhar, 26 September 2020, leg. Ghana S. Bhandari.

This species is distributed throughout wet montane

Image 2. Feature of *Tetrathemis platyptera* (Selys, 1878), two males and two females: A—Habitus, lateral view, male from Zhemgang leg. © Mer Man Gurung | B—Habitus, lateral view, male from Samdrupjongkhar. © Ghana S. Bhandari.

Table 1. Checklist of dragonflies and damselflies of central Bhutan, Trongsa (Tro), Zhemgang (Zhe) and Jigme Singye Wangchuck National Park (JSWNP), References (Ref). Of these 43 species were recorded during the present study and 17 species are only known from previous publications.

Species	Tro	Zhe	JSWNP	Ref
Order Anisoptera				
Family Aeshnidae				
1. *Aeshna petalura* (Martin, 1908)		x	x	
2. *Anax nigrofasciatus* (Oguma, 1915)		x	x	3
3. *Cephalaeschna* sp. Selys, 1883	x		x	
4. *Gynacantha* sp. Rambur, 1842		x	x	
5. *Polycanthagyna erythromelas* (McLachlan, 1896)	x		x	
Family Corduliidae				
6. *Somatochlora daviesi* Lieftinck, 1977	x		x	3
Family Chlorogomphidae				
7. *Chlorogomphus mortoni* (Fraser, 1936)		x	x	4
8. *Watanabeopetalia atkinsoni* (Selys, 1878) *	x		x	
Family Cordulegasteridae				
9. *Anotogester nipalensis* (Selys, 1854)				
Family Gomphidae				
10. *Anisogomphus* sp. (Selys, 1854)	x		x	3
11. *Davidius* sp. Selys, 1878		x	x	
12. *Davidius boronii* Lieftinck, 1977	x		x	1
13. *Lamelligomphus risi* (Fraser, 1922)		x	x	
14. *Perissogomphus stevensi* Laidlaw, 1922	x	x	x	
15. *Scalmogomphus bistrigatus* Hegen, 1854		x	x	
Family Libellulidae				
16. *Crocothemis* sp. Brauer, 1868	x		x	
17. *Diplacodes nebulosa* (Fabricius, 1793)		x		4
18. *Diplacodes trivialis* (Rambur, 1842)	x	x	x	
19. *Lyriothemis bivittata* (Rambur, 1824)		x	x	4
20. *Orthetrum glaucum* (Brauer, 1865)	x	x	x	
21. *Orthetrum internum* MacLachlan, 1894	x	x	x	
22. *Orthetrum luzonicum* (Brauer, 1868)	x	x	x	
23. *Orthetrum pruinosum* (Burmeister, 1839)	x	x	x	
24. *Orthetrum sabina* (Drury, 1773)	x	x	x	
25. *Orthetrum triangulare* (Selys, 1878)	x	x	x	
26. *Palpopleura sexmaculata* (Fabricius, 1787)	x	x	x	
27. *Pantala flavescens* (Fanricius, 1798)	x	x	x	
28. *Sympetrum commixtum* (Selys, 1884)	x		x	
29. *Sympetrum hypomelas* (Selys, 1884)	x	x	x	3
30. *Tetrathemis platyptera* (Selys, 1878) *		x	x	
31. *Tramea virginia* (Rambur, 1842)		x	x	5
32. *Trithemis aurora* (Burmeister, 1839)	x	x	x	
33. *Trithemis festiva* (Rambur, 1842)	x	x	x	
34. *Trithemis pallidinervis* (Kirby, 1889)		x	x	
Family Macromiidae				
35. *Macromia moorei* Selys, 1874	x	x	x	

Species	Tro	Zhe	JSWNP	Ref
Order Anisozygoptera				
Family Epiophlebiidae				
36. Epiophlebia laidlawi Tillyard, 1921	x		x	2
Order Zygoptera				
Family Calopterygidae				
37. Caliphaea confusa Hagen in Selys, 1859	x	x	x	
38. Neurobasis chinensis (Linnaeus, 1758)	x	x	x	
Family Chlorocyphidae				
39. Aristocypha cuneata (Selys, 1853)	x	x	x	
40. Aristocypha quadrimaculata (Selys, 1853)		x		4
41. Libellago lineata (Burmeister, 1839)		x		
42. Paracypha unimaculata Selys, 1853		x		4
Family Coenagrionidae				
43. Aciagrion pallidum Selys, 1891	x		x	3
44. Aciagrion olympicum Laidlawi, 1919	x		x	3
45. Agriocnemis pygmaea Rambur, 1842		x	x	
46. Ceriagrion fallax Ris, 1914		x	x	
47. Ischnura rubilio (Selys, 1876)	x	x	x	
48. Pseudagrion rubriceps (Selys, 1876)		x	x	
Family Euphaeidae				
49. Anisopleura comes Hagen, 1880	x		x	
50. Anisopleura subplatystyla (Fraser, 1927)	x		x	3
51. Bayadera indica Selys, 1853	x		x	
Family Synlestidae				
52. Megalestes major (Selys, 1862)	x		x	
53. Megalestes gyalsey (Gyeltshen, Kalkman & Orr, 2017)	x		x	5
Family Lestidae				
54. Indolestes cyaneus (Selys, 1862)	x	x	x	
55. Lestes dorothea Fraser, 1924				
Family Platystictidae				
56. Protosticta sp. Selys, 1885				
Family Platycnemididae				
57. Calicnemia eximia Selys, 1863	x	x	x	
58. Calicnemia miniata (Selys, 1886)				
59. Calicnemia mortoni Laidlawi, 1917		x	x	6
60. Copera vitatta (Laidlaw, 1914)		x		

1—Lieftinck (1977) | 2—Dorji (2015) | 3—Kalkman & Gyeltshen (2016) | 4—Gyeltshen (2017) | 5—Gyeltshen et al. (2017) | 6—Gurung et al. (2021).

lowlands of tropical southern regions and southeastern Asia occurring as far south as Java. Males were encountered at MG1 patrolling over a small pool with thick riparian vegetation. The bottom consisted mostly of debris with the water being just 50 cm deep. Only few females were spotted ovipositing on the twigs above the pond, but males were quite abundant. *Copera vitatta* (Laidlaw, 1914), *Orthetrum triangulare* (Selys, 1878), *Orthetrum glaucum* (Brauer, 1865), *Trithemis festiva* (Rambur, 1842), and *Trithemis aroura* (Burmeister, 1839) were co-occupying the habitat.

Image 3. *Lamelligomphus risi* (Fraser, 1922), one male: Habitus, lateral view, male leg. © Mer Man Gurung.

DISCUSSION

With this study the number of species known from Bhutan becomes 125 but it is likely that with the present speed of discovery this number will steadily continue to increase. The Bhutanese odonate fauna is expected to contain at least 150 species. The occurrence of both species found new to Bhutan, *Watanabeopetalia atkinsoni* and *Tetrathemis platyptera*, is no surprise as they were known from adjacent areas. Where *T. platyptera* is mainly found in the lowland, however, *W. atkinsoni* is confined to mountains occurring from Nepal to the north of Thailand. *W. atkinsoni* has not been recorded from Burma but undoubtedly occurs there as well. Although the knowledge on the fauna of northeast of the Indian peninsula is clearly increasing there are still many genera which are poorly known and in need of further study and/or revision. These include several genera also found in central Bhutan, such as *Cephalaeschna*, *Davidius*, *Gynacantha*, and *Anisogomphus*. In many cases more material is needed and comparison with types and/or material from southeastern Asia or China is needed. An increase in number of DNA barcodes available from different regions would make it easier to test if species might be identical or are clearly different.

With 60 species the central part of Bhutan is moderately well explored and more field work is likely to show that the area holds at least 100 species. Especially the lowland areas of Royal Manas National Park (RMNP) are likely to hold many Oriental species not known from Trongsa and Zhemgang districts or even completely new to Bhutan.

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COMMUNICATION

Land snails of Guwahati, Assam, India

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Abstract: Assam is located in the Indo-Burma global biodiversity hotspot, and contains many animals and plants that have not been investigated scientifically. Increasing urbanization and destruction of forest cover have created threats to the survival of many species, hence scientific investigation is important to support conservation efforts. I undertook this study to evaluate the status of land snails in Guwahati, the capital city of Assam, a fast-growing city 216 km^2 in area where shrinkage of natural forest cover has become a matter of great concern. A total of 12 species were recorded: *Cyclophorus pearsoni* (Benson, 1851), *C. zebrinus* (Benson, 1836), *Pterocyclus parvus* (Pearson, 1833), *Endothyrella affinis* (Gude, 1897), *Cryptaustenia silcharensis* (Godwin-Austen, 1907), *Macrochlamys atricolor* (Godwin-Austen, 1875), *M. hengdanensis* Godwin-Austen, 1899, *Sitala rimicola* (Benson, 1859), *Bradybaena cestus* (Benson, 1836), *Lissachatina fulica* (Bowdich, 1822), *Allopeas gracile* (Hutton, 1834), and *Rishetia hastula* (Benson, 1860). I have provided a detailed discussion of our findings.

Keywords: Diversity, Gastropoda, invertebrates, Mollusca, northeastern India, terrestrial mollusc.

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INTRODUCTION

Globally there are about 24,000 terrestrial mollusc species for which valid descriptions exist (Lydeard et al. 2004). Of these, India harbors 1,487 species under 140 Genera and 32 families (Magare 2015; Sajan et al. 2021). Land snails are found in moist and humid forest habitats where live or decomposed plant matter is available, such as damp walls and stones with algal growth in the crevices (Ramakrishna et al. 2010), domestic organic litter dumping areas, and areas where fungus-rich detritus is abundant. The existence of snails is often ignored due to their camouflaged colour, shape and size, slow movement and avoidance of daylight.

The northeastern region including Assam harbours a rich mixture of Indian and Burmese/Malayan snail groups, resulting in the highest species diversity in India (Mitra et al. 2005; Ramakrishna et al. 2010; Sen et al. 2012). Few studies have assessed their distribution and threats, with most of this information being based on the publications from 'Fauna of British' India volumes published during 1908 and 1914–1921 (Blanford & Godwin Austen 1908; Gude 1914, 1921), plus a few Zoological Survey of India reports (Sen et al. 2012). It is worthy to note that the state boundary of Assam (240,118 km^2) changed several times during 1960–1970, and many areas previously described as ranges of land snails in Assam are now in Nagaland, Meghalaya, Mizoram, and Arunachal Pradesh. Presently a 78,438 km^2 area including part of Brahmaputra and Barak valley in Assam requires urgent assessment of land snail status.

Increasing urbanization and destruction of forest cover has created threats to the survival of land snails in Assam. Guwahati is a fast urbanizing city, where loss of natural forest cover has become a matter of great concern. The objective of this study was to record the diversity of land snails in Guwahati city (Table 1), where I observed 12 species: *Cyclophorus pearsoni* (Benson, 1851), *C. zebrinus* (Benson, 1836), *Pterocyclus parvus* (Pearson, 1833), *Endothyrella affinis* (Gude, 1897), *Cryptaustenia silcharensis* (Godwin-Austen, 1907), *Macrochlamys atricolor* (Godwin-Austen, 1875), *M. hengdanensis* Godwin-Austen, 1899, *Sitala rimicola* (Benson, 1859), *Bradybaena cestus* (Benson, 1836), *Lissachatina fulica* (Bowdich, 1822), *Allopeas gracile* (Hutton, 1834), and *Rishetia hastula* (Benson, 1860). Morphometric characteristics of dry shells (Table 2) and the soil characteristics of their occurring areas (Table 3) were recorded and studied.

Description of the study area

Guwahati (26.179 °N & 91.750 °E) is situated on the southern bank of the Brahmaputra in Kamrup Metropolitan district of Assam. A part of the city has also expanded to the northern bank. The city is regarded as the gateway to northeastern India, and is the principal centre of socio-cultural, political, industrial, trade and commerce for the entire region. The total area of the city is ca 216.79 km^2. Current population is about 9.57 lakhs. The climate of Guwahati is warm-humid with a maximum temperature of 38 ^{0}C during summer and minimum of 10 ^{0}C during winter. The tropical monsoon climate of the city receives about 1,600 mm annual rainfall with maximum during the months of May to August. The southern and eastern sides of the city are surrounded by hills while, the central part of the city also has some small hillocks. Apart from the hilly tracts, swamps, marshes and small water bodies also cover the city. There are five reserved forest areas in the city and two wildlife sanctuaries namely, Amchang wildlife sanctuary and Deepor Beel Bird Sanctuary. The hills and hillocks, reserved forests and wildlife sanctuaries are home to many terrestrial wild animals.

Mollusc species in the present study were recorded from several hills: Kamakhys pahar, Kharghuli pahar, Nabagraha pahar and Basistha pahar in main Guwahati city, and Agiathuri pahar of northern Guwahati. Some of the residential areas with garden campus, public park, and nurseries were also considered for the study.

METHODS

A total of 10 sites were selected for the study. All the sites were marked with the help of a global positioning system marking device. The selected areas were searched in the months of March to September 2012 considering the ecological prerequisite of rain for land molluscs (Mitra et al. 2005). Places examined included stone pits and undersurface of stones, shady humid areas, under leaves of shrubs and herbs, tree-trunk, forest litters and vegetable garbage were carefully examined to collect the sample. Both the dry shells and living samples were collected during that time. Collected samples were then transferred to the departmental laboratory of Guwahati College for further investigations. Photographs were taken with the help of a digital camera. Majority of the species were identified following Mitra et al. (2005). Species status of some snails was also verified following Páll-Gergely (2015) and Budha (2017). The diversity of species and evenness was calculated using Shannon-Weiner diversity index (Shannon & Weaver 1949).

Table 1. Name of the recorded species with families, GPS location and total numbers of shell/specimen from different study sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Name of the Site	Kamakhya hill	Kharghuli areas	Basistha hill	Agiathuri hill	Nabagraha hill	Nehru park	Ulubari Nursery	Urban residential campus-1	Urban residential campus-2	Uttar Guwahati village area
Geographical (GPS) location	N 26.3333^0 E 91.8233^0	N 26.2055^0 E 91.9508^0	N 26.2597^0 E 91.0300^0	N 26.3122^0 E 91.1811^0	N 26.2769^0 E 91.0230^0	N 26.2625^0 E 91.9680^0	N 26.1877^0 E 91.8153^0	N 26.2136^0 E 91.8830^0	N 26.2405^0 E 91.8588^0	N 26.4364^0 E 91.7000^0
Habitat pattern	Natural forest, temples, human habitat	Natural forest, human habitat	Natural forest, temples	Natural forest	Natural forest, temples, human habitat	Public park, planned vegetations	Commercial nursery	Human habitat with kitchen litters	Human habitat with kitchen litters	Swampy habitat, village residence, damp soil
Name of the species with family	Total numbers of shell/specimen recorded in 100 m^2 area of each site									
Family: Cyclophoridae										
Cyclophorus pearsoni	17	5	79	52	4	0	0	0	0	0
Cyclophorus zebrinus	3	0	19	10	0	0	0	0	0	0
Pterocyclus parvus	0	0	0	215	0	0	0	0	0	32
Family: Plectopylididae										
Endothyrella affinis	0	0	5	0	0	0	0	0	0	0
Family: Ariophantidae										
Cryptoaustenia silcharensis	3	42	1	3	12	0	0	0	0	0
Macrochlamys atricolor	36	13	7	19	17	46	77	92	44	36
Macrochlamys hengdanensis	0	0	5	22	0	1	0	0	0	4
Sitala rimicola	36	88	0	9	78	0	0	0	0	0
Family: Bradybaenidae										
Bradybaenia cestus	0	0	0	0	0	0	0	0	0	8
Family: Achatinidae										
Lissachatina fulica	83	74	56	34	66	82	22	78	103	51
Family: Subulinidae										
Rishetia hastula	0	0	0	15	0	0	0	0	0	2
Allopeas gracile	12	3	26	11	18	7	18	3	4	25
Species Richness (S)	7	6	8	10	6	4	3	3	3	7
Shanon diversity (H)	1.514	1.353	1.546	1.805	1.417	0.861	0.878	0.765	0.716	1.617
Species evenness (J)	0.778	0.755	0.743	0.784	0.791	0.621	0.799	0.697	0.652	0.831

RESULT AND DISCUSSION

The occurrence of 12 snail species within ca. 216.79 km^2 thickly urbanized areas of a metropolitan city in Assam is considered significant. It appears that the diversity of land snails in hilly areas of Guwahati is relatively higher than in public parks, commercial nurseries, and residential campuses. *Macrochlamys atricolor* (Godwin-Austen), *Lissachatina fulica* (Bowdich), *Allopeas gracile* (Hutton), and *Rishetia hastula* (Benson) (Image 1–4) were recorded from public parks, commercial nurseries, and residential campuses. *Pterocyclus parvus* (Benson), *Cyclophorus zebrinus* Benson, *Macrochlamys hengdanensis* (Godwin-Austen), *Cryptaustenia silcharensis* (Godwin-Austen), *Sitala rimicola* (Benson), *Cyclophorus pearsoni* Benson, and *Endothyrella affinis* Gude (Image 5–11) were recorded from natural forest habitats of hill areas. Two samples of *Bradybaena cestus* (Benson) (Image 12) were recorded from a village residential campus of northern Guwahati, near a swampy habitat clinging over *Scirpus grossus* L. *Pterocyclus parvus*, *Cyclophorus pearsoni*, and *Rishetia hastula* was comparatively more abundant in the hills of northern Guwahati than in southern bank hills of the River Brahmaputra.

The morphometric measurements of the shells were found to be within already reported ranges (Mitra et al. 2005) (Image 13A–L). Species richness (S), Shannon diversity (H), and species evenness (J) of land molluscs in the studied areas of Guwahati is depicted in Figure 1. The species diversity index (H) fluctuated from 0.7164 to 1.8048 in the studied areas. The highest diversity was recorded in Agiathuri hills, where 10 of 12 recorded species were observed. The highest species evenness (J) was recorded as 0.83 in a village residential area of northern Guwahati near the Agiathuri hill.

Habitat loss and fragmentation as a result of anthropogenic activities is the root cause of low species diversity and community structure of land molluscs (Sen et al. 2012), which may also be influenced by factors like soil pH and moisture content (Bhattacharyya 1977; Clements et al. 2008). Among the recorded species only two, *Lissachatina fulica* and *Macrochlamys atricolor*, can be considered widely distributed. *Lissachatina fulica* is a general phytophagous mollusc found invading almost all types of garden vegetation, while *Macrochlamys atricolor* is chiefly found within kitchen wastes in damp places. It is discernible that the population of *L. fulica* is decreasing in the city, consistent with the findings of Bhattacharyya (1977). The record of low species diversity of snails in public parks, commercial nurseries, and

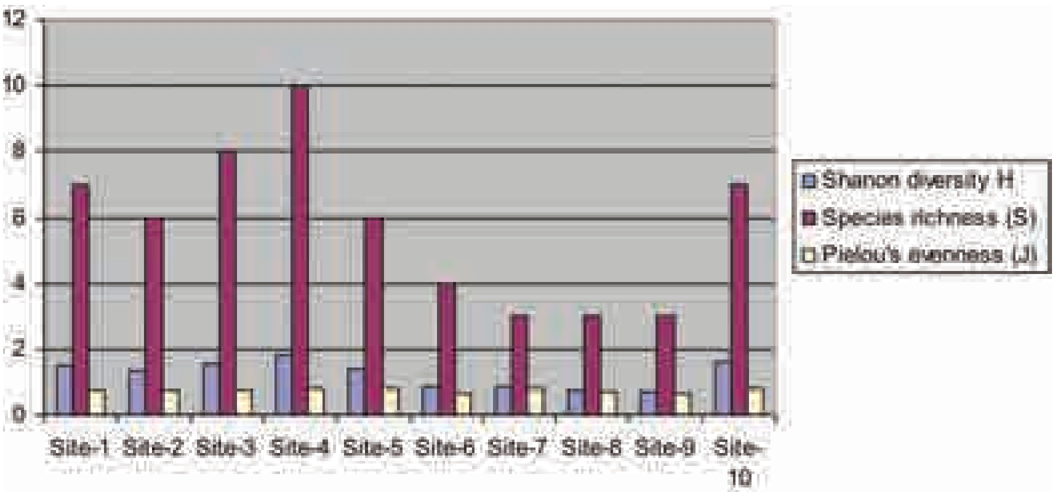

Figure 1. The species richness (S), Shannon diversity (H), and species evenness (J) of land molluscs in studied areas of Guwahati.

Table 2. Observed morphometry of the studied snails.

Name of the snail	Average length/ height of the shell (mm)	Average diameter of the shell (mm)	Average dry shell weight (g)
Cyclophorus pearsoni	30.0	31.0	6.560
Cyclophorus zebrinus	9.0	11.0	0.100
Pterocyclus parvus	4.0	12.0	0.155
Endothyrella affinis	4.0	7.0	0.045
Cryptoaustenia silcharensis	3.5	6.0	0.030
Macrochlamys atricolor	8.0	15.0	0.105
Macrochlamys hengdanensis	4.0	0.65	0.040
Sitala rimicola	7.0	7.0	0.025
Bradybaena cestus	8.0	12.0	0.125
Lissachatina fulica	65.8	34.1	8.79
Rishetia hastula	25.0	6.0	0.165
Allopeas gracile	14.2	3.7	0.075

Image 1. *Macrochlamys atricolor.* © Girindra Kalita

Image 2. *Lissachatina fulica.* © Girindra Kalita

Image 3. *Allopeas gracile.* © Girindra Kalita

Image 4. *Rishetia hastula.* © Girindra Kalita

Image 5. *Pterocyclus parvus.* © Girindra Kalita

Image 6. *Macrochlamys hengdanensis.* © Girindra Kalita

Table 3. Soil characterization of the studied area.

Sites	GPS location	Texture	pH	Organic Carbon (%)	Phosphorous P_2O_5 (Kg/Hac)	Calcium (CaO) %
1	N 26.3333^0 E 91.8233^0	Silty clay	7.2	0.68	33	0.56
2	N 26.2056^0 E 91.9508^0	Silty clay	7.6	0.76	31.3	0.46
3	N 26.2597^0 E 91.0300^0	Silty clay	7.4	0.9	30	1.56
4	N 26.3122^0 E 91.1811^0	Silty clay	7.5	1.04	32	0.46
5	N 26.2769^0 E 91.0230^0	Sandy	7.6	0.85	34.3	0.9
6	N 26.2625^0 E 91.9680^0	Clay loam	7.1	1.11	29.5	0.82
7	N 26.1877^0 E 91.8153^0	Clay loam	7.4	0.91	38	0.92
8	N 26.2136^0 E 91.8830^0	Clay loam	7.6	0.57	34	0.82
9	N 26.2405^0 E 918588^0	Clay loam	7.5	0.92	28	0.36
10	N 264364^0 E 91.7000^0	Clay loam	7.7	0.76	31	1.32

residential campuses in Guwahati may be due to the planned maintenance of the area. In managed forests, the abundance and diversity of snails has become low due to the removal of forest litter, and recently developed forest areas have only sparse leaf litter and less rotting logs (Sturm et al. 2006).

The human population of Guwahati has increased considerably in the past few decades, and the population density (population km^{-2}) rose from 2558 in 1981 to 3374 in 2001 (Kalita et al. 2011). The rising anthropogenic pressure has resulted in urban sprawl (Thakur & Goswami 1993) that has made the area less humid, with dryness making it less hospitable to land snails. Up to the 1970s, the invasive *L. fulica* and other species like *C. pearsoni*, *M. atricolor*, *S. rimicola*, and *A. gracile* were common, and villagers garlanded cattle with dry shells of *C. pearsoni* which also had traditional medicinal value. During that time it was difficult to protect gardens from the invasion of *L. fulica,* and people frequently used common salt (NaCl) to kill snails. Then as human habitats increased, a combination of loss of forest cover, increasing soil erosion, frequent rain-fed floods with high mud content and increasing temperatures led to the decline of land snail populations in the studied areas. The present government of Assam has taken steps towards protecting the local environment that include conservation of wetlands and hills, implementation of strict municipal laws to stop population sprawl, evictions from forest land, plantation programs to stop soil erosion, and improvement of drainage systems to stop floods. These measures are expected to have positive effects on protecting land snails.

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Image 7. *Cyclophorus zebrinus*. © Girindra Kalita

Image 8. *Cyclophorus pearsoni*. © Girindra Kalita

Image 9. *Cryptoaustenia silcharensis*. © Girindra Kalita

Image 10. *Sitala rimicola*. © Girindra Kalita

Image 11. *Endothyrella affinis*. © Girindra Kalita

Image 12. *Bradybaenia cestus*. © Girindra Kalita

Image 13A–L. A—*M. atricolor* (H 8.0 mm, D 15.0 mm, W 0.105 g) | B—*L. fulica* (L 65.8 mm, D 34.1 mm, W 8.79 g) | C—*A. gracile* (L 14.2 mm, D 3.7 mm, W 0.075 g) | D—*R. hastula* (L 25.0 mm, D 6.0 mm, W 0.165 g) | E—*P. parvus* (H 4.0 mm, D 12.0 mm, W 0.155 g) | F—*M. hengdanensis* (H 4.0 mm, D 0.65 mm, W 0.040 g) | G—*C. zebrinus* (H 9.0 mm, D 11.0 mm, W 0.100 g) | H—*C. pearsoni* (H30.0 mm, D 31.0 mm, W 6.560 g) | I—*C. silcharensis* (H 3.5 mm, D 6.0 mm, W 0.030 g) | J—*S. remicola* (H 7.0 mm, D 7.0 mm, W 0.025 g) | K—*E. affinis* (H 4.0 mm, D 7.0 mm, W 0.045 g) | L—*B. cestus* (H 8.0 mm, D 12.0 mm, W 0.125 g).
(H—average shell height | L—average shell length | D—average shell diameter | W—average shell weight). **© Girindra Kalita.**

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COMMUNICATION

Morphology characterization and phytochemical overview of the Moluccan Ironwood *Intsia bijuga* (Colebr.) Kuntze, a living collection of Purwodadi Botanic Garden, Indonesia

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Abstract: As one of the ex situ conservation sites, Purwodadi Botanic Garden (PBG) has *Intsia bijuga* as its collection with high economic value for its high quality wood. It is categorised as Near Threatened in the IUCN Red List. Its efficacy as herb is due to the presence of its various chemical compounds. The purpose of this study was to characterize the morphology of *I. bijuga* cultivated in PBG and to reveal its phytochemical compounds, as well as their health benefits. This research was conducted at the PBG in April–May 2020. The plant material was obtained from PBG collection. The plant morphology was characterized by direct observation in the field, while information regarding phytochemical compounds of *I. bijuga* along with their benefits was obtained by literature review. The data obtained was analyzed descriptively. The results showed that *I. bijuga* collected by PBG came from Maluku and Java. Both have morphological characteristics that are not very different, i.e., they are trees, they have compound leaves, pale stems with lenticels on their surface, panicle flowers, pod-shaped fruits, and buttress roots. *I. bijuga* contains polyphenol compounds that have medicinal benefits, such as anti-bacterial, anti-cancer, and anti-viral, hence it has enormous medicinal potential. Due to habitat shrinkage of the species, an effort to have it conserved ex situ is critical.

Keywords: Conservation site, Fabaceae, Merbau, plant morphology, phytochemical compounds.

Indonesian Abstrak: Sebagai salah satu kawasan konservasi ex situ, Kebun Raya Purwodadi (KRP) memiliki koleksi *Intsia bijuga* yang bernilai ekonomis tinggi karena kualitas kayunya. Spesies ini termasuk dalam kategori Near Threatened dalam IUCN Redlist. Efektivitasnya sebagai tanaman obat disebabkan oleh beragam senyawa kimia yang terkandung di dalamnya. Penelitian ini bertujuan untuk mengkarakterisasi secara morfologi *I. bijuga* yang berada di KRP dan mengungkap senyawa kimianya beserta manfaatnya untuk kesehatan. Penelitian ini dilakukan di KRP pada bulan April-Mei 2020. Material tumbuhan diperoleh dari koleksi KRP. Morfologi tumbuhan dikarakterisasi melalui pengamatan langsung di lapangan, sedangkan informasi mengenai senyawa fitokimia *I. bijuga* beserta manfaatnya diperoleh melalui tinjauan literatur. Data yang diperoleh dianalisis secara deskriptif. Hasil penelitian menunjukkan bahwa *I. bijuga* yang dikoleksi oleh KRP berasal dari Maluku dan Jawa. Keduanya memiliki karakteristik morfologi yang tidak jauh berbeda, yaitu keduanya memiliki habitus pohon, daunnya majemuk, batang pucat dengan lentisel pada permukaannya, bunga malai, buah polong, dan akar banir. *I. bijuga* mengandung senyawa polifenol yang bermanfaat bagi kesehatan, seperti anti-bakteri, anti-kanker, dan anti-virus sehingga memiliki potensial medis yang luar biasa. Karena adanya penyempitan habitat dari spesies ini, maka suatu upaya konservasinya secara ex situ menjadi hal yang sangat penting.

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BRIN

INTRODUCTION

Intsia is a woody plant genus of the family Fabaceae (Leguminosae) which has a natural habitat in lowland tropical rain forests (Heyne 1987). They grow in forests up to 1,000 m and are often found in zones behind mangrove forests, brackish forests, and river banks (Samingan 1975). Their distribution comprises from Tanzania, West Indian Ocean, Taiwan to tropical Asia, and southwestern Pacific. Based on The Plant List (2013), *Intsia* has eight accepted species, i.e., *Intsia africana*, *I. attenuata*, *I. bijuga*, *I. bijuga* var. *retusa*, *I. bracteata*, *I. cuanzensis*, *I. palembanica*, *I. petersiana*, and *I. rhombodea.* On the other hand, Plants of the World Online (2022) states that *Intsia* consists only of *I. bijuga* and *I. palembanica*, while other species are included in genus *Afzelia*.

Intsia bijuga (Colebr.) Kuntze is a tree up to 40 m height and is known as Merbau or Moluccan Ironwood. It is native to southeastern Asia, Oceania, Madagascar, and eastern Africa (Image 1), while in Indonesia it can be found in almost all islands, especially Maluku, Kalimantan, and Papua (Baskorowati & Pudjiono 2015; GTA 2019). It lives in lowland tropical rain forests, capable of growing in the altitude of 1,000 m, and is often found in the riverside zone and behind mangrove forests (Yudohartono & Ismail 2013).

Intsia bijuga has high economic value for its high quality wooden structure. Until now, it was one of the favorites of Indonesian natural forest entrepreneurs (Tokede et al. 2013) and is very well known for export because it is widely used as furniture, plywood or woodworking (Pudjiono 2017). This has led to an increase in demand and massive logging of *I. bijuga* (Sirami et al. 2019). Forest destruction has exacerbated this situation, causing a reduction in the abundance of this species and declining wild populations (Margono et al. 2012; Vincent et al. 2015; Sirami et al. 2019). Therefore since 1998 it has been included in IUCN Red List (IUCN 1998). Concerns about its extinction have led to the inclusion of this species on the CITES list with Appendix III status (limited trading) (Tokede et al. 2013). Hence various rescue actions need to be taken to reduce the risk of extinction, one of which is ex situ conservation efforts.

In addition to considering the risk of extinction, awareness of plant conservation can also be raised by increasing the useful value of the plants. So far, *I. bijuga* has been used as traditional medicines in various countries including Philippines, Madagascar, Vanuatu, and Papua New Guinea to treat various diseases such as rheumatism, dysentery, urinary tract infections, asthma, diabetes, ulcers, and fractures (Norscia 2006; Koch et al. 2015), while in Indonesia, its bark is used as a medicine for flatulence and liver (Widodo et al. 2018). These various benefits are of course related to its various chemical compounds. Thus, the disclosure of information on phytochemical compounds in *I. bijuga* as well as its health benefits is also necessary in order to further increase its beneficial value.

As an ex situ conservation area, Purwodadi Botanical Garden (BG) has a collection of *I. bijuga* from Java and Maluku. Nevertheless, information on the morphology and content of phytochemical compounds about *I. bijuga* originating from Indonesia has not been widely published. This study aimed to characterize the morphology of *I. bijuga* from Indonesia cultivated in the Purwodadi BG. In addition, this study also revealed the phytochemical compounds contained in *I. bijuga* and their health benefits.

METHODS

This study was conducted at Purwodadi BG from April to May 2020. The leaves, stems, fruit and seeds as the study materials were obtained from Purwodadi BG (Image 2). Morphological characters observed included habit, root type, shape and size of leaves, fruit, and seeds. The morphological characterization was carried out based on Harris & Harris (2001). In addition, information regarding the name of the collector, the location of the original habitat, and location of the collection was obtained from the Plant Collection Catalog Information System (SIKATAN) of Purwodadi BG.

The species identity confirmation was performed through morphological character approach of study material on herbarium specimen and morphology description from relevant articles and books. The references for herbarium were specimens from Herbarium Purwodadiense and Kew's Herbarium (The Herbarium Catalogue 2022), whilst the reference articles and books were "Studies in Malesian Caesalpinioideae (Leguminosae)", "The genera *Acrocarpus*, *Afzelia*, *Copaifera* and *Intsia*" (Hou 1994) and "Caesalpiniaceae (Leguminosae-Caesalpinioideae)" (Hou et al. 1996), a book chapter of Flora Malesiana.

Furthermore, the search for information on phytochemical compounds of *I. bijuga* and its benefits was carried out using the literature study method between 2010–2020 through Google Scholar, Mendeley, and Science Direct websites with the keywords "*Instia bijuga*", "phytochemical", and "natural compound". The

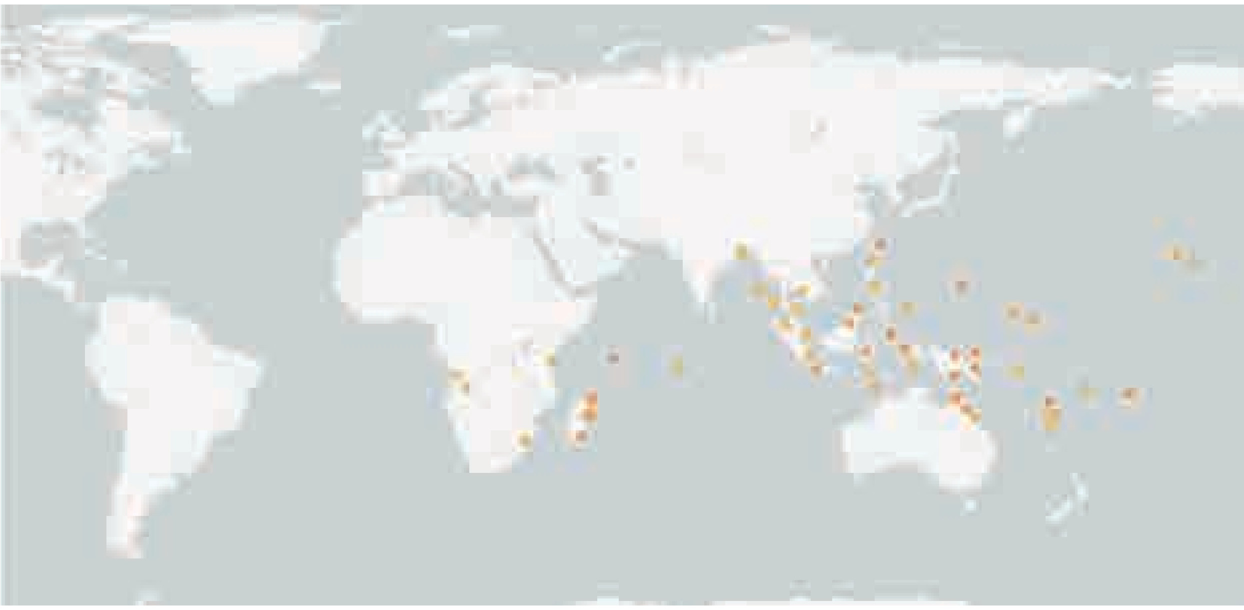

Image 1. World distribution of *Intsia bijuga* in wild population. [Source: GTA (2019)]

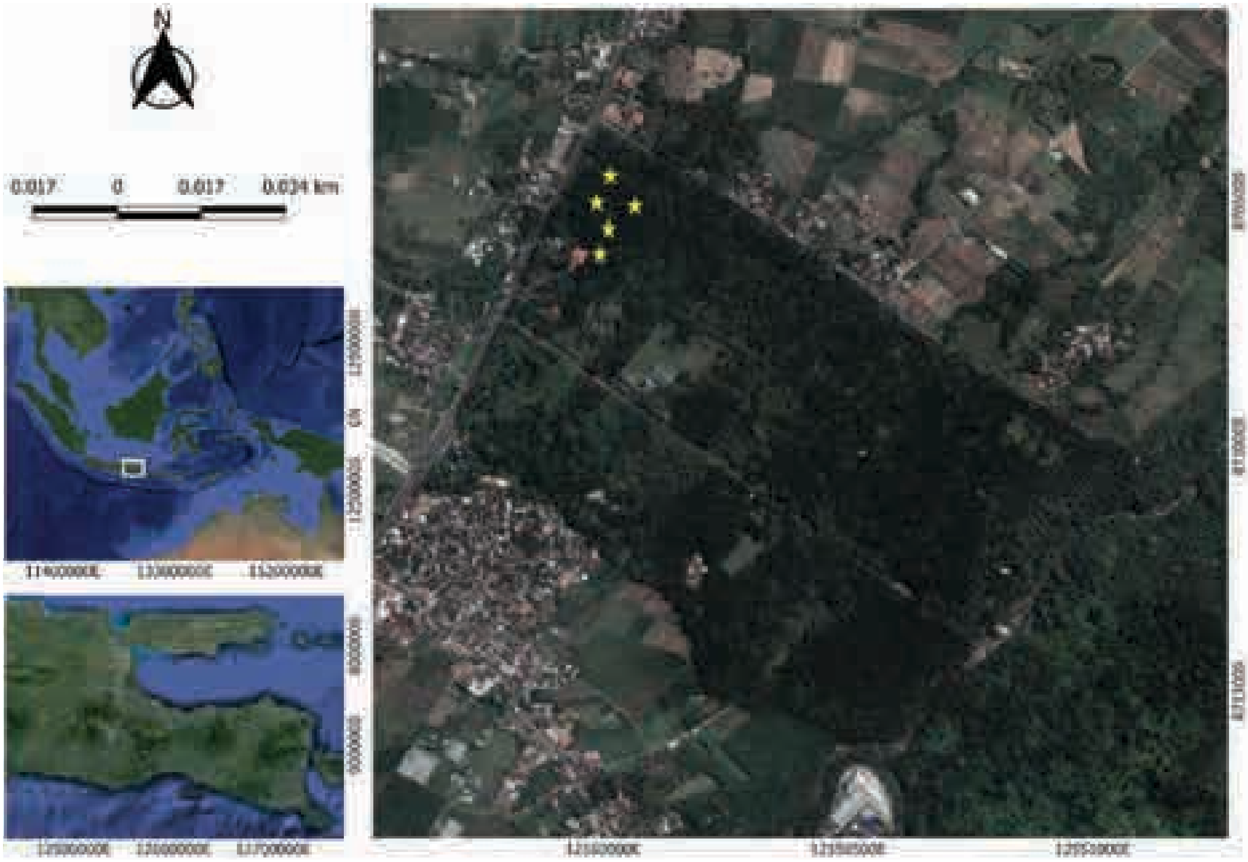

Image 2. Study site in Purwodadi Botanic Garden (the yellow asterisks indicate where *Intsia bijuga* collections are cultivated).

morphological character and phytochemical compounds data obtained were then analyzed descriptively to inform the potential of *I. bijuga* as a drug.

RESULTS AND DISCUSSION

Collection Database

Based on the database of PBG or Sistem Informasi Katalog Koleksi Tanaman Kebun Raya Purwodadi (2020), there are 12 collection numbers of the *I. bijuga* cultivated in five different locations/vak. The plants were the results of exploration in Indonesia (Maluku Islands and Java Island) and spontaneously collected. The age of the collection plants also varied, 24–65 years (Table 1).

Morphology of *Intsia bijuga*

So far, studies on morphology of *I. bijuga* in Indonesia have not been widely carried out and the information provided is still general and not specific (Rimbawanto & Widyatmoko 2006; Yudohartono & Ismail 2013; Pudjiono 2017). Based on direct observations, *I. bijuga* is a perennial tree with a height of about 15–23 m (Image 3A). This is slightly different from *I. bijuga* growing in Papua New Guinea, where at the age of eight it has reached a height of 12 meters with a trunk diameter of 15 cm (Gunn et al. 2004). The growing conditions and altitude factors were thought to have an indirect effect on plant growth, thus affecting plant height (Finkeldey & Hattemer 2007). The growth direction is erectus, hardwood and strong stems, elongated round shape like cylindrical, rough surface, showing lenticels on the surface of the stem and the length of the free stem before branching is about 7–10 m, releasing a little lymph and pale stems slightly greenish due to the lichen covering the stem surface (Image 3B).

Intsia bijuga has folium compositum consisting of 2–4 leaflets with a length of 7–12 cm per leaflet (Image 4A). The layout of the leaves is opposite and the shape is elipticus. The arrangement of penninervis with the costa is sloping so that the two parts of the leaf on the right and left of the leaf bone are asymmetric (Image 4B). The nerves lateralis are clearly visible and stop before reaching the leaf margins, the veins are smaller, forming a mesh and are not too prominent. Flat leaf edges are integer, thin but quite stiff with thickness of 0.05–0.1 mm, green leaf color with smooth abaxial and adaxial surface, hairless and not wrinkled. When compared with the leaves of *I. bijuga* in the Pacific Islands (Thaman et al. 2006), the leaf color of *I. bijuga* in Purwodadi BG is slightly darker. The shape of the tip of the leaf is acutus with the two edges of the leaf on the right and left of the costa gradually going upward and meeting at the tip of the leaf to form an acute angle. The base of the leaf is rotundatus and attached to the petiolus. Petiolus is cylindrical with slightly flattened upper side, green in color, thickened at the base with a diameter of 0.3-0.5 cm and does not show any wrinkles, hair, scales, lenticels or supporting leaves (Image 4C).

Direct observation of *I. bijuga* in Purwodadi BG showed that the cultivated plants had not yet entered the flowering season which usually occurs in January and lasts for 30–45 days. Slightly different from *I. bijuga* in the Northern territory where the cultivated plants flower in June and December, in its natural habitat, *I. bijuga* flowers in March (Cowie & Westaway 2012). Based on the observations conducted by Baskorowati & Pudjiono (2015), *I. bijuga* has unlimited bisexual inflorescentia centripetala and grows terminally and monopodially at the end of a branch. The peduncle grows steadily with branches that can branch again and the flowers bloom with acropetal type.

Although at the time of observation, *I. bijuga* had not yet entered the flowering season, part of the fruit was left over from the previous fertilization season. Fruit of *I. bijuga* is single true fruit dry pods with a length of 8–24 cm, smaller than the fruit of *I. bijuga* from Vanuatu which has a size of 10–30 cm (Thaman et al. 2006). The fruit is formed from one fruit leaf, it has a room with pseudo barriers where each fruit has a number of seeds, about 2–10 (Image 5). When young, the fruit is green and it is brown when ripe. Flat seeds, with 3–4 cm length

Table 1. *Intsia bijuga* cultivated in Purwodadi Botanic Garden.

Vak	Collection number	Access number	Collector	Date of cultivation	Origin	Note
XIII.E.I.	01-01abcd	P1986080306	LHP 08	1986-12-11	-	Spontaneous collection
XIII.F.	25	P1986070183	IS 221	1986-12-11	South west Maluku	Obtained from exploration
XIII.H.	48	P1955020044	-	1955-03-02	West Java	Obtained from exploration
XIII.I.	11-11a-11bc	P1995070068	IS 68	1996-11-11	Maluku: Halmahera	Obtained from exploration
XIII.K.	01-01a	P196002126	-	1962-01-11	Java	Obtained from exploration

Image 3. The habit (A) and stem (B) of *Intsia bijuga* cultivated in Purwodadi BG. © E. Renjana.

Image 4. Leaf morphology of *Intsia bijuga* cultivated in Purwodadi BG: A—folium compositum | B—penninervis | C—petiolus. © E. Renjana.

Image 5. Fruit and seed morphology of *Intsia bijuga* cultivated in Purwodadi BG. © E. Renjana.

with a black surface. The spermodermis is quite hard, where the tesla has a stiff texture and is like wood or stone. The hilus is clear, rough and brownish in color, slightly different from the surface color of the seed coat. The roots of *I. bijuga* are buttress type, where the roots grow high above the ground, and are flat like boards with a thickness of about 5–8 cm (Image 6). With the age of more than 20 years, the root of *I. bijuga* cultivated in Purwodadi BG is quite small compared to that of the root of *I. bijuga* growing in forests which can reach 4 m (Thaman et al. 2006). The root bark is pale, slightly greenish in color because it is covered by lichen and the surface is rough with scattered lenticels, and there are no spines near the roots.

In general, the plant morphology of *I. bijuga* does

Table 2. Phytochemical compunds in *I. bijuga* and their health benefits.

	Phytochemical compunds	Compound Group	Part of Plant used	Health Benefits	References
1	Dihydromyricetin (Ampelopsin)	Flavonoid	Stem	Provides neuroprotective effect on the brain injured by an ischemic stroke	Ye at al. 2017
				Induces cell growth inhibition and apoptosis in breast cancer cells	Zhou et al. 2014
				Acts as anti-bacterial, anti-inflammatory, anti-tumor, hepatoprotective, anti-hypertensive anti-oxidant, plasma lipid and blood sugar regulator; provides neuroprotection	Liu et al. 2019
2	Naringenin	Flavonoid	Stem	Acts as anti-hepatitis C, anti-aging, anti-Alzheimer's, anti-asthma, anti-chikungunya virus, anti-seizure epilepsy, anti-dengue virus, anti-diabetic, anti-edwardsiellosis, anti-hyperlipidemic, anti-inflammatory, anti-microbes, anti-oxidants, anti-platelets in cardiovascular disease, anti-damage due to stroke, cardioprotective, chronic kidney disease, expectorants, eye protective, hepatoprotective, radioprotective; provides aids against infertility, immunodepression, and constipation	Salehi et al. 2019
3	Myricetin	Flavonoid	Stem	Acts as anti-oxidant, anti-cancer, anti-inflammatory, anti-diabetic; provides protective effects against Parkisone and Alzheimer's	Semwal et al. 2016
4	Robinetin	Flavonoid	Stem	Acts as anti *Proteus vulgaris*, anti-tumor, anti-HIV-1	Kumar & Pandey 2013
5	3,5,3',4'-tetratrihydroxystilbene (Piceatannol)	Stilbene	Stem	Acts as anti-oxidant, anti-cancer, anti-parasitic, anti-bacterial; plays a role in cell signaling	Piotrowska et al. 2012
6	3,5,4'-trihydroxystilbene (Resveratrol)	Stilbene	Stem	Acts as anti-oxidant, cardioprotective, chemopreventive agent against cancer, anti-inflammatory, neuroprotective; has anti-viral properties	Liu et al. 2019

not vary too much in habit, stem growth direction, and root type between vaks/locations (Table 2). Although differences in morphological characters can be influenced by environmental factors, *I. bijuga* cultivated in Purwodadi BG do not significantly differ in morphology because they are in relatively the same environmental conditions. In addition, their vak/locations are quite close each other in Purwodadi BG area.

Quite different morphological variations can be seen in leaf size, where *I. bijuga* collected from Maluku, Halmahera planted in Vak XIII.I seems to have larger leaves than other *I. bijuga* planted in other vaks, with the ratio of length to width is 2: 1. Meanwhile, other leaf morphological characters such as leaf type, leaf layout, leaf shape, and leaf venation do not show clear differences (Image 7).

According to morphological characterization conducted in this study, the state character of *Intsia bijuga* lies in its compound leaves, which is 2-jugate leaf. This is in consonant with morphological descriptions of *I. bijuga* stated by Arifiani (2018), Hou et al. (1996), dan Hou (1994). Additionally, they also mentioned that another state character is the glabrous petiole.

Phytochemical compounds of *I. bijuga* and their benefits

From the identification of chemical compounds by Hillis & Yazaki (1973), it can be inferred that the wood of *I. bijuga* has six polyphenol compounds, consisting of four flavonoids and two stilbenes. The main polyphenol in this plant is flavonoid, namely robinetin, while the other three flavonoids are dihydromyricetin (ampelopsin), myricetin, naringenin. The two stilbenes in *I. bijuga* include 3,5,4'-trihydroxystilbene (resveratrol) and 3,5,3 ', 4'-tetratrihydroxystilbene (piceatannol). Based on literature studies, each of these chemical compounds has many health benefits (Table 2).

The variety of health benefits of *I. bijuga* is related to the role of each compound it contains at the organ and cellular levels. It's main potential is the prevention and treatment of tumors and cancer is due to its anti-oxidant, anti-tumor, and anti-cancer properties. According to Zhou et al. (2014) ampelopsin as one of the compounds contained in *I. bijuga* inhibited the growth of breast cancer cells as well as induced apoptosis. Furthermore, *I. bijuga* also plays a role in the maintenance of body organs such as the heart (cardioprotective), liver (hepatoprotective), eyes, and the nervous system (neuroprotective). Neuroprotective properties are very important for stroke, Alzheimer's, and Parkinson's patients in order to reduce the symptoms they suffer from.

The compounds of *I. bijuga* also have anti-inflammatory benefits. Inflammation is an immune system response to harmful stimuli, such as pathogens, damaged cells, toxic compounds, or irradiation.

Image 6. Root type of *I. bijuga* cultivated in Purwodadi BG. © E. Renjana.

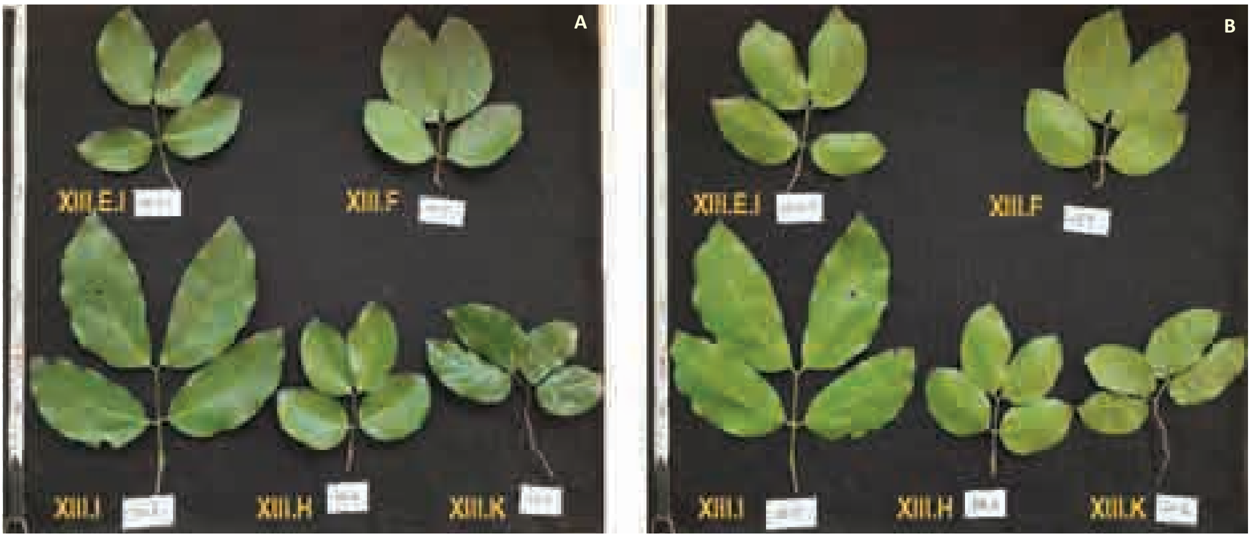

Image 7. Leaf shape and size of *I. bijuga* in various vak/locations of Purwodadi BG: A—abaxial | B—adaxial. © E. Renjana.

Inflammation causes discomfort since it causes swelling, redness, burning sensation, pain and reduced tissue function (Takeuchi & Akira 2010) so often anti-inflammatory drugs are used to reduce these symptoms. However, these drugs have many side effects, including gastric ulcers and cardiovascular complications, damage to kidney and the respiratory system (Henry 1988; Sostres et al. 2010). Various herbal plants have been developed to overcome the side effects of using synthetic anti-inflammatory drugs and *I. bijuga* can be a potential natural ingredient for this purpose with its anti-inflammatory components.

I. bijuga also has the potential to play a role in helping the body's immune system fight pathogens with its anti-bacterial, anti-parasitic, and anti-viral properties. One of the flavonoids of *I. bijuga* with anti-viral activity is robinetin. According to Kumar & Pandey (2013), robinetin is able to inhibit HIV-1 proteinase activity. In addition, *I. bijuga* might play a role in the maintenance of body homeostasis with its anti-hypertensive properties and its action in regulating blood sugar in diabetics and also its capacity as plasma lipids regulator. With all the active compounds that are useful and work synergistically for the health of the body, *I. bijuga* has the potential to be one of the leading medicinal plants.

Recent Conservation Status of *Intsia bijuga* and Prospective Research for its Conservation

Intsia bijuga is distributed across several regions of Indonesia, including Sumatra, Kalimantan, Sulawesi, Maluku, East Nusa Tenggara, and Papua. However, its distribution in Indonesia has begun to decrease due to illegal logging activities, so that it only remains in the Papua and Maluku regions (Rimbawanto & Widyatmoko

2006). With its superior quality of wood, this species has become a major production target for timber entrepreneurs in Papua, which raises concerns that it will face extinction in nature (Tokede et al. 2013). In 2020, it has been assessed into the category of Near Threatened (NT) with a decreasing population trend on the IUCN Red List v2.3 (Barstow 2020). Thus it can be inferred that it faces a high risk of extinction in the wild in the near future.

In addition to illegal logging activities, the decline in the population of *I. bijuga* is also caused by its natural growth factors. Naturally, this plant only bears fruit once a year from September to December (Baskorowati & Pudjiono 2015). In its natural habitat, seeds are very easy to obtain, but sometimes seedlings under the mother tree, especially on sandy and loamy soils, are difficult to find (Sirami et al. 2019). Thus, research on phenology and seed viability in ex situ conservation areas is expected to initiate a solution to this problem. Intensive maintenance and fertilization carried out in this area may have a positive impact on flowering and seed viability of *I. bijuga*.

Study on the propagation of *I. bijuga* can be done to increase the quantity of individuals. When deemed sufficient, the population of *I. bijuga* can be reintroduced in their natural habitat. Population reintroduction is henceforth a common practice in conservation to alleviate the loss of plant species. Generally, the aim of population reintroduction is to establish genetically variable populations, to increase gene flow and to minimize the probability of population extinction (Kaulfuß & Reisch 2017).

Based on the description of the medicinal potential of *I. bijuga*, the six active compounds of *I. bijuga* are mainly found in wood. However, if only the wood is used, then the sustainability of this species will be threatened. Therefore further research is needed on the content of its active compounds in other parts, such as leaves and seeds which are more abundant. In addition, the use of technology such as callus culture can be considered to produce the active compound in *I. bijuga* without having to extract it directly from nature. Callus cultures have gained commercial potential for the manufacture of secondary metabolites of therapeutic significance. Callus culture has been reported to be more reliable than collecting plant materials from the wild for extracting the therapeutic metabolites. They can be used for the generation of multiple clones of plants using micropropagation, and can also be used to develop single-cell suspension cultures employing either batch or continuous fermentation to produce the preferred secondary metabolites. Previous studies reported that callus cultures have been used for the production of tropane alkaloids, ajmaline, serpentine, reserpine, flavonoids, scopolamine, paclitaxel, stilbene, resveratrol and anthocyanins (Chandran et al. 2020).

CONCLUSION

Purwodadi Botanic Garden has a collection of *I. bijuga* originating from the Maluku Islands (Maluku: Halmahera) and Java. The results showed that all collections of *I. bijuga* observed had morphological characters that were not much different, namely tree habitus, compound leaves, pale stems with lenticels on the surface, panicle flowers, pod-shaped fruit and buttress roots. Based on literature studies, the wood of this species contains polyphenol compounds with medicinal benefits, such as anti-bacterial, anti-cancer, anti-viral, and so on. It shows that it has enormous medicinal potential. Therefore, ex situ conservation of these plants is very important considering that their numbers have decreased in their natural habitat

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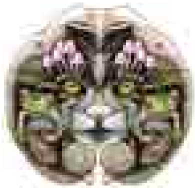

COMMUNICATION

Woody plant wealth of Therikadu Reserve Forest, Tuticorin, India: a checklist

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Abstract: A qualitative survey was conducted to record the woody plant wealth of Carnatic Umbrella Thorn Forest (CUTF) existing within the Therikadu Reserve Forest (TRF), Tuticorin district, southeastern Coast, Peninsular India. A sum of 35 man-days was spent on the field to prepare a woody plant checklist. All collected specimens were identified up to the species level with the help of floras. A sum of 105 species belonging to 83 genera in 37 families were recorded from the study area. The family Fabaceae represented by a large number of species (36 species) followed by Bignoniaceae (5) and Rubiaceae (4). Eight families represented by three species each, while 16 families represented by a single species each. CUTF acts as a home for one of the IUCN's endangered species, *Pterocarpus santalinus*. The reserve forest and sacred grove status are keeping TRF as an intact and relatively undisturbed ecosystem.

Keywords: Carnatic Umbrella Thorn Forest, CUTF, dry forest, endangered species, peninsular Indian forest, Tamil Nadu.

Tamil: தீபகற்ப இந்தியாவின் தென்கிழக்கு கடற்கரையில் அமைந்துள்ள தூத்துக்குடி மாவட்டத்தில் காணப்படும் கர்னாடிக் குடைவேல் முட்புதர் காட்டிலுள்ள கட்டைத்தன்மைவாய்ந்த தாவரங்களின் வளம் களஆய்வின் மூலம் கண்டறியப்பட்டது. முப்பத்தைந்து நாட்கள் களஆய்வு மேற்கொள்ளப்பட்டது. கண்டறியப்பட்ட அனைத்து தாவரங்களும் தாவரவளம் குறித்து வெளியிடப்பட்டுள்ள தரமான கையேடுகள் மூலம் உறுதிசெய்யப்பட்டன. களஆய்வின் மூலம் 105 சிற்றினங்கள், 83 பேரினங்கள் மற்றும் 37 தாவர குடும்பங்கள் பட்டியலிடப்பட்டுள்ளன. பேபேசி குடும்பம் 36 சிற்றினங்களுடன் அதிக அளவில் காணப்படுகின்றன, அதனை தொடர்ந்து பிக்னோனியேசி (5 சிற்றினங்கள்) மற்றும் ரூபியேசி (4 சிற்றினங்கள்) அதிக அளவில் காணப்படுகின்றன. எட்டு குடும்பங்கள் ஒவ்வொன்றும் தலா 3 சிற்றினங்களையும், 16 குடும்பங்கள் மிகவும் குறைவாக தலா ஒரு சிற்றினத்தையும் கொண்டுள்ளன. இந்த வகை காடுகள் அழிந்து வரக்கூடிய தாவரங்களின் பட்டியலிலுள்ள ஓர் மரவகைக்கு வாழிடமாக உள்ளது. இவ்வகை காடுகள் தமிழக அரசின் வனத்துறையால் பாதுகாக்கப்படுகின்றன, மேலும் கோவில்காடுகளாகவும் இவை உள்ளதால் இங்குள்ள உயிரினங்கள் நன்கு செழித்து வளர்ந்து, வெளிப்புற தொந்தரவுகளின்றி வாழ்கின்றன.

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Author contribution: MU designed and conceptualized the study. MU and VM conducted field surveys, collection, identification and documentation of woody plants from study area. VM prepared the first draft of the manuscript and MU corrected it.

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INTRODUCTION

Forests play a vital role in regulating the climate and provide a large number of ecosystem services to all living organisms including human beings (Montagnini & Jordan 2005). Thorn forest is one of the highly neglected forest ecosystems; information related to biodiversity wealth, carbon stock, and sequestration are very limited. Thorn forests act as a home for a large number of woody plant species (liana, shrub, and tree). The forests flourish in the larger part of dried regions in India. Thorn forest covers 16,491 km^2 of the geographical area in India. Indian states namely, Punjab, Haryana, Rajasthan, Gujarat, Tamil Nadu, Karnataka, Madhya Pradesh and Uttar Pradesh are endowed with thorn forest vegetation (Champion & Seth 1968). The thorn forest is characterized by short thorny bush and shrub vegetation and experiences dry season for about six to nine months in a year. Plants are leafless for the most part of the year, usually have very thin leaves protected by sharp structures such as spines, thorns or prickles. Sharp structures are part of the structural defence, protecting photosynthetic tissue from herbivores. Besides, the roots are predatory in nature and spreading near the soil surface as concentrations of essential macro and micronutrients are very limited in dry forests (e.g., Udayakumar & Sekar 2017). A type of thorn forest occurring in Dharmapuri, Kanyakumari, Krishnagiri, Madurai, Thoothukudi, Tirunelveli and Ramanathapuram districts has been designated as Carnatic Umbrella Thorn Forest by Champion & Seth (1968). A checklist of the species at national, state, district and ecosystem level is highly useful to estimate the plant wealth and habitat of species (Udayakumar & Parthasarathy 2012). Earlier, Nair & Srinivasan (1981) found *Acacia planifrons* and *Borassus flabellifer* as dominant species of CUTF in Ramanathapuram district, Tamil Nadu. Singh et al. (1999) found CUTF as one of the homes for slender Loris. Venkatesh et al. (2021) designated CUTF as the important habitat for mammalian small carnivores. Selvakumari & Rajakumar (2012) recorded wild edible plants from CUTF, Tuticorin. Recently, Venu & Velmayil (2021) investigated geochemistry, minerology and texture of Teri sediments. Information on plant diversity of CUTF in Tamil Nadu is scarce hence this study was conducted to record the woody plant wealth of Therikadu Reserve Forest located in Thoothukudi district, southern India.

MATERIALS AND METHODS

Study area

Therikadu forest ecosystem is protected as a reserve forest by the Department of Forests, Government of Tamil Nadu since 21 July 1982. Study area located in Tiruchendur taluk of Tuticorin district in Tamil Nadu. The geographical coordinates of the study area are 8.73345–8.74976 N & 77.98351–78.07294 E (Image 1). The altitude of the study area is 30 m, while the mean annual rainfall and minimum & maximum temperature are 750 mm and 28 & 32^{0}C. The study area receives a major proportion of the rainfall during the north-east monsoon (October to December), (Thoothukudi District Website 2021).

Field survey

As a part of the establishment of 50 ha forest dynamics plot in Therikadu Reserve Forest a qualitative survey was conducted to record the woody plant diversity. A sum of 35 man-days spent on the field to record woody plant wealth of TRF. About 10 sacred groves are located within the TRF. TRF housed large number of temples and local deities, among them Arunchunaikaththa ayyanar and Karukkuvel ayyanar temples (Tamil) are notable and visited by large number of people during festival seasons. All the woody plants, viz., shrubs, lianas and tree growing in TRF were collected and identified up to species level with the help of regional floras and available checklists (Gamble & Fischer 1921–1935; Nair & Henry 1983; Matthew 1991). Author citation followed The Plant List (http://theplantlist.org) and POWO (2021).

Reproductive phenophase of trees

A total of 525 individuals, five individuals each per species were marked with paint to record flowering, and fruiting phenophases of trees. All the marked individuals were observed monthly (during first week of the month) for the period of two years. Woody plants which had flowers and fruits (young, mature and dried) were considered as 'reproducing'.

RESULTS AND DISCUSSION

Species richness and lifeform

The qualitative plant survey allowed us to record a sum of 105 woody plant species spread in 83 genera and 37 families. The most speciose family in the study area is Fabaceae (36 species) followed by Bignoniaceae (5), and Rubiaceae (4). Ten families had two species each,

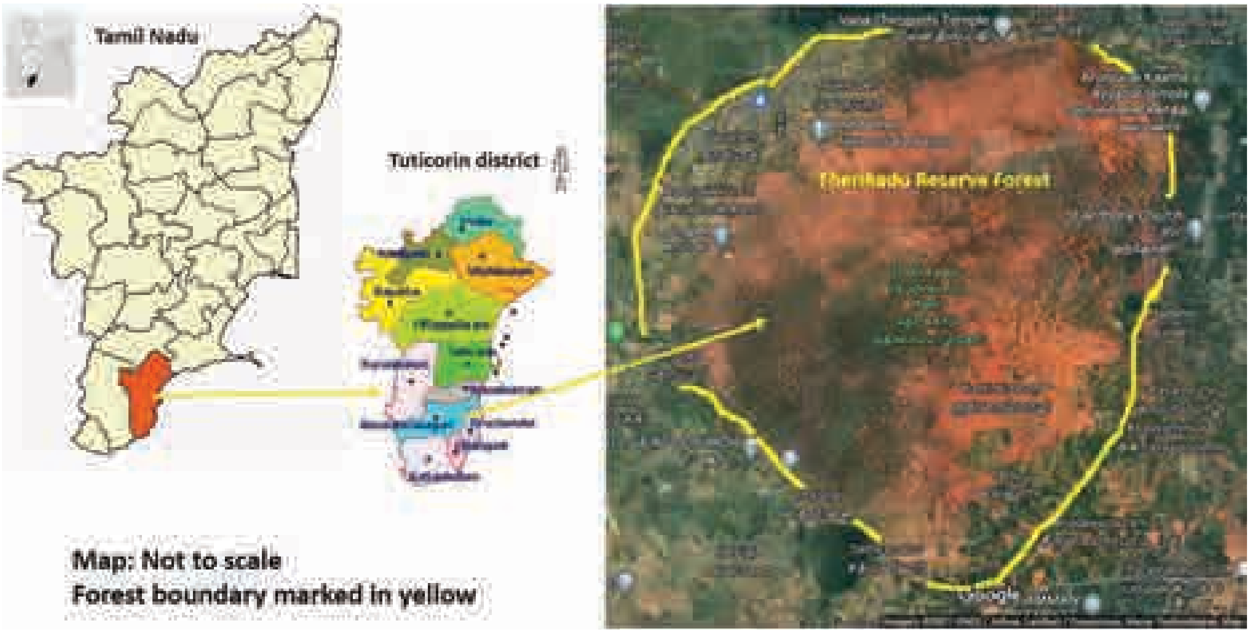

Image 1. Map of study area wherein qualitative study was conducted to record woody plant wealth.

eight families represented by three species each, while 16 families represented by just single species' each in CUTF (Table 1; Image 2, 3).

Of 105 woody species 78 are trees, 17 are shrubs and 10 lianas. One-third of the recorded species are introduced to the ecosystem by the forest department. The study area also had a significant number of economically important and cultivated species (Table 1). The forest department planted this species, and they are growing well within TRF.

Acacia planifrons, *Borassus flabellifer*, *Dalbergia spinosa*, *Dodonaea viscosa*, *Morinda coreia*, and *Tecomella undulata* are commonly present in the study area. Non-native species such as *Acacia auriculiformis*, *A. holosericea*, *A. melanoxylon, Cordia sebestena, Eucalyptus tereticornis, Millingtonia hortensis, Spathodea companulata, Senna siamea, Tabebuia rosea*, and *Tectona grandis* were planted by the forest department to enhance the green cover. Eleven non-native fruit yielding trees including *Anacardium occidentale*, *Annona squamosa*, *Carica papaya*, *Cocos nucifera*, and *Psidium guajava* were planted in and around the sacred groves.

Woody plant richness recorded from the study area is higher than in similar CUTF ecosystem (44 species including 17 trees, 8 lianas, and 19 shrubs) flourishing within Hosur Forest Division (Tiwari & Ravikumar 2018a) and Dharmapuri district of Tamil Nadu, India (21 trees, 7 lianas, and 25 shrubs) (Tiwari & Ravikumar 2018b). The CUTF of Thoothukudi endowed with a greater number of species than in other dry forests of Tamil Nadu. For example, Nagaraj & Udayakumar (2021) and Evitex-Izayas & Udayakumar (2021) recorded 18 (14 genera and 11 families) and 26 species (19 genera and 15 families) from southern thorn forest ecosystems in Vallanadu blackbuck sanctuary and Uthumalai reserve forest, respectively. The STF in Krishnagiri and Dharmapuri districts endowed with a sum of 52 woody species each (Tiwari & Ravikumar 2018a,b).

However, species richness of TRF is similar to that of southern dry mixed deciduous forest, Hosur, Tamil Nadu (56 trees, 7 lianas, and 42 shrubs, total 105 species; Tiwari & Ravikumar 2018a). Conversely, species richness of study area is lower than that of the tropical dry evergreen forest (TDEF) of Coromandel Coast, Tamil Nadu (86 trees and 44 lianas; as in Udayakumar & Parthasarathy 2012). The study also designated 149 woody species as core TDEF species.

Reproductive phenology of woody plants

Among 105 woody species, 23 species started to produce flowers and fruits during the month of February, gradually the number reduced in to one during the month of August. Notably, one-fourth of all the recorded species flowered and fruited throughout the year (Table 1). The length of the reproductive phenophase varied from two to twelve months. A sum of 26 species had 12 months of reproductive phenophase, three species had 10 months, while two species had just three months in study area. The mean length of reproductive

Table 1. Binomial, family, life form, flowering and fruiting seasons of woody plants recorded from CUTF of Therikadu Reserve Forest, southern India. (Introduced species are marked with an asterisk '*' symbol).

	Botanical name	Family	Life form	Flowering and fruiting seasons
1	*Abrus precatorius* L.	Fabaceae	Liana	Throughout the year
2	**Acacia auriculiformis* Benth.	Fabaceae	Tree	February–June
3	**Acacia chundra* (Rottler) Willd.	Fabaceae	Tree	Throughout the year
4	*Acacia horrida* (L.)Willd.	Fabaceae	Tree	July–November
5	**Acacia holosericea* G.Don	Fabaceae	Tree	June–October
6	*Acacia nilotica* (L.) Delile	Fabaceae	Tree	July–December
7	*Acacia planifrons* Wight & Arn.	Fabaceae	Tree	February–March
8	**Acacia senegal* (L.) Willd.	Fabaceae	Tree	July–February
9	**Acacia melanoxylon* R.Br.	Fabaceae	Tree	February–October
10	*Aegle marmelos* (L.) Correa	Rutaceae	Tree	Throughout the year
11	*Ailanthus excelsa* Roxb.	Simaroubaceae	Tree	January–April
12	*Albizia amara* (Roxb.) B.Boivin	Fabaceae	Tree	September–June
13	*Albizia lebbeck* (L.) Benth.	Fabaceae	Tree	February–May
14	**Anacardium occidentale* L.	Anacardiaceae	Tree	March–May
15	**Annona squamosa* L.	Annonaceae	Tree	April–July
16	*Anogeissus latifolia* (Roxb.ex DC.) Wall. ex Guillem. & Perr.	Combretaceae	Tree	August–February
17	*Azadirachta indica* A.Juss.	Meliaceae	Tree	April–July
18	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae	Tree	February–April
19	**Bauhinia malabarica* Roxb.	Fabaceae	Tree	November–April
20	*Bauhinia racemosa* Lam.	Fabaceae	Tree	September–January
21	**Borassus flabellifer* L.	Arecaceae	Tree	March–June
22	**Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	Tree	February–June
23	*Canthium coromandelicum* (Burm.f.) Alston	Rubiaceae	Shrub	January–June
24	**Carica papaya* L.	Caricaceae	Shrub	Throughout the year
25	**Cassia fistula* L.	Fabaceae	Tree	March–February
26	**Casuarina equisetifolia* L.	Casuarinaceae	Tree	June–December
27	*Catunaregam spinosa* (Thunb.) Tirveng.	Rubiaceae	Shrub	February–December
28	*Ceiba pentandra* (L.) Gaertn.	Malvaceae	Tree	February–June
29	*Cissus quadrangularis* L.	Vitaceae	Liana	February–October
30	*Cissus vitiginea* L.	Vitaceae	Liana	June–November
31	*Cissus heyneana* Planch.	Vitaceae	Liana	July–November
32	**Citrus aurantiifolia* (Christm.) Swingle	Rutaceae	Shrub	Throughout the year
33	**Citrus limon* (L.) Osbeck	Rutaceae	Shrub	February–September
34	**Cocos nucifera* L.	Arecaceae	Tree	Throughout the year
35	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	Liana	Throughout the year
36	*Cocculus hirsutus* (L.) W.Theob.	Minispermaceae	Liana	July–March
37	*Commiphora berryi* (Arn.) Engl.	Burseraceae	Shrub	Throughout the year
38	**Cordia sebestena* L.	Boraginaceae	Shrub	Throughout the year
39	*Ctenolepis garcini* (L.) C.B.Clarke	Cucurbitaceae	Liana	September–April
40	*Crateva religiosa* G.Forst.	Capparaceae	Tree	January–August
41	*Dalbergia spinosa* Roxb.	Fabaceae	Shrub	March–August
42	*Dalbergia sissoo* DC.	Fabaceae	Tree	February–May
43	*Delonix elata* (L.) Gamble	Fabaceae	Tree	April–August
44	**Delonix regia* (Hook.) Raf.	Fabaceae	Tree	April–August
45	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	Tree	February–June
46	*Dichrostachys santapaui* Sebast. & Ramam.	Fabaceae	Tree	May–December
47	*Erythrina variegata* L.	Fabaceae	Tree	April–July

	Botanical name	Family	Life form	Flowering and fruiting seasons
48	*_Eucalyptus tereticornis_ Sm.	Myrtaceae	Tree	April–August
49	_Ficus benghalensis_ L.	Moraceae	Tree	February–June
50	_Ficus mollis_ Vahl	Moraceae	Tree	May–August
51	_Ficus religiosa_ L.	Moraceae	Tree	March–May
52	_Flacourtia indica_ (Burm.f.) Merr.	Salicaceae	Shrub	December–August
53	_Flueggea virosa_ (Roxb.ex Willd.) Royle	Phyllanthaceae	Shrub	October–January
54	*_Gliricidia sepium_ (Jacq.) Walp.	Fabaceae	Tree	February–May
55	_Gmelina arborea_ Roxb.	Lamiaceae	Tree	Throughout the year
56	_Guettarda speciosa_ L.	Rubiaceae	Tree	February–June
57	_Hardwickia binata_ Roxb.	Fabaceae	Tree	June–April
58	_Holoptelea grandis_ (Hutch.) Mildbr.	Ulmaceae	Tree	February–March
59	_Lannea coromandelica_ (Houtt.) Merr.	Anacardiaceae	Tree	April–June
60	_Lawsonia inermis_ L.	Lythraceae	Shrub	January–June
61	*_Lysiloma latisiliquum_ (L.) Benth.	Fabaceae	Tree	Throughout the year
62	*_Leucaena leucocephala_ (Lam.) de Wit	Fabaceae	Tree	Throughout the year
63	_Madhuca longifolia_ (J.Koenig ex L.) J.F.Macbr.	Sapotaceae	Tree	October–April
64	_Mangifera indica_ L.	Anacaridiaceae	Tree	January–June
65	*_Manilkara zapota_ (L.) P.Royen	Sapotaceae	Tree	February - June
66	_Melia azedarach_ L.	Meliaceae	Tree	March–September
67	*_Millingtonia hortensis_ L.f.	Bigononiaceae	Tree	February–May
68	_Morinda coreia_ Buch.-Ham.	Rubiaceae	Tree	Throughout the year
69	_Moringa oleifera_ Lam.	Moringaceae	Tree	March–October
70	*_Muntingia calabura_ L.	Muntingiaceae	Tree	Throughout the year
71	*_Nyctanthes arbor-tristis_ L.	Oleaceae	Tree	Throughout the year
72	_Pandanus odorifer_ (Forssk.) Kuntze	Pandanaceae	Shrub	October–April
73	*_Parkinsonia aculeata_ L.	Fabaceae	Tree	Throughout the year
74	_Pergularia daemia_ (Forssk.) Chiov.	Apocynaceae	Liana	Throughout the year
75	_Peltophorum pterocarpum_ (DC.) K.Heyne	Fabaceae	Tree	January–April
76	_Pongamia pinnata_ (L.) Pierre	Fabaceae	Tree	February–October
77	*_Pterocarpus santalinus_ L.f.	Fabaceae	Tree	January–May
78	*_Phyllanthus acidus_ (L.) Skeels	Phyllanthaceae	Shrub	Throughout the year
79	_Phyllanthus emblica_ L.	Phyllanthaceae	Tree	March–June
80	_Pisonia grandis_ R.Br.	Nyctaginaceae	Shrub	September - October
81	*_Pithecellobium dulce_ (Roxb.) Benth.	Fabaceae	Tree	January–April
82	*_Plumeria rubra_ L.	Apocynaceae	Shrub	January–June
83	*_Polyalthia longifolia_ (Sonn.) Thwaites	Annonaceae	Tree	April–June
84	*_Prosopis chilensis_ (Molina) Stuntz	Fabaceae	Tree	Throughout the year
85	*_Prosopis juliflora_ (Sw.) DC	Fabaceae	Tree	Throughout the year
86	*_Psidium guajava_ L.	Myrtaceae	Tree	March–August
87	_Rivea hypocrateriformis_ Choisy	Convolvulaceae	Liana	Octobe–April
88	_Sapindus emarginatus_ Vahl	Sapindaceae	Tree	Throughout the year
89	_Sapindus trifoliatus_ L.	Sapindaceae	Tree	November–March
90	*_Spathodea campanulata_ P.Beauv.	Bignoniaceae	Tree	December–March
91	_Saraca asoca_ (Roxb.) Willd.	Fabaceae	Tree	Throughout the year
92	*_Senna siamea_ (Lam.) H.S.Irwin & Barneby	Fabaceae	Tree	Throughout the year
93	_Stereospermum chelonoides_ (L.f.) DC.	Bignoniaceae	Tree	April–June
94	_Syzygium cumini_ (L.) Skeels	Myrtaceae	Tree	May–November
95	*_Tabebuia rosea_ (Bertol.) Bertero ex A.DC.	Bigononiaceae	Tree	Throughout the year
96	*_Tamarindus indica_ L.	Fabaceae	Tree	December - June
97	_Tecomella undulata_ (Sm.) Seen.	Bigononiaceae	Tree	January–October
98	_Tectona grandis_ L.f.	Lamiaceae	Tree	February–August

	Botanical name	Family	Life form	Flowering and fruiting seasons
99	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	Tree	February–August
100	*Terminalia catappa* L.	Combretaceae	Tree	February–May
101	*Thespesia populnea* (L.) Sol. ex Correa	Malvaceae	Tree	Throughout the year
102	*Thespesia populneoides* (Roxb.) Kostel.	Malvaceae	Tree	Throughout the year
103	*Tinospora sinensis* (Lour.) Merr.	Menispermaceae	Liana	February–June
104	**Ziziphus jujuba* Mill.	Rhamanaceae	Shrub	November–July
105	*Ziziphus xylopyrus* (Retz.) Willd.	Rhamanaceae	Shrub	May–July

Image 2. A—Forest boundary with *Acacia* | B—Forest stand with palmyra | C—*Acacia holosericea* | D—*Tecomella undulata* | E—*Ficus benghalensis* | F—Forest stand | G—Trunk of *Acacia planifrons* | H—*Anacardium occidentale*. © A–C,D—V. Muneeswaran; E–G, H—M. Udayakumar.

Image 3. A—*Holoptelea grandis* | B—*Acacia holosericea* | C—*A. auriculiformis* | D—*Wrightia tinctoria* | E—*Borassus flabellifer* | F—*Barringtonia acutangular* | G—*Acacia planifrons* | H—*Hardwickia binata*. © A,C,E— M. Udayakumar; B,D,F,G,H—V. Muneeswaran.

phenophase recorded as 7.25±3.26months.

The TRF is relatively undisturbed compared to other forests. Reserve forest category and the presence of sacred groves within the TRF are reasons behind the protection. In addition, people dwelling around the TRF never collect any part of the plant for personal uses, they consider TRF as a home for their deity.

CONCLUSION

Woody plant wealth of CUTF existing within the Therikadu Reserve Forest is higher than in CUTF of Krishnagiri and Dharmapuri districts of Tamil Nadu. The forest flourishing in a dry environment and endowed with a moderate diversity of native trees. The occurrence of the larger specimens of *Acacia planifrons* indicates that TRF is relatively undisturbed for at least 50 years. Additionally, one can witness a large number of downed and decaying dead woods and trees within the forest, no one collect these deadwoods for any uses. The reserve forest and sacred grove statuses are keeping TRF as an intact and relatively undisturbed ecosystem.

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Invasive alien plant species of Hassan District, Karnataka, India

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Abstract: This study was undertaken to document alien and invasive flowering plant species in the Western Ghats (Hassan district, Karnataka, India), with background information on family, habit, habitat, longevity, nativity, and uses. A total of 312 alien species belonging to 236 genera in 79 families are listed. The majority belong to family Asteraceae (36 species), followed by Fabaceae (21 species), and Amaranthaceae (17 species). Herbs constitute the majority (59%) of alien species followed by shrubs (17 %). Around 36% the alien taxa are native to tropical America. Of 314 alien species, 122 were intentional introductions, with a majority (39%) introduced for ornamental purposes; 24% of species have naturalized, while 33% display as invasive. There is an urgent need to gather regional data on the diversity of invasive alien plant species in order to study the impact on native vegetation and biodiversity.

Keywords: Exotic, naturalized species, ornamental, plant diversity, threats, Western Ghats.

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Author contribution: GMP carried out the floristic study, collected the data and wrote the manuscript. SN identified the species, interpreted the data and designed the manuscript. Both authors have read and approved the final manuscript.

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INTRODUCTION

The increase in human activity and increased international trade, travel, and transport beyond biogeographic barriers has led to the introduction and establishment of invasive alien species in new regions (Dawson et al. 2017). Biological invasions have received much consideration due to the potential threats they impose on native species, natural systems, ecosystem processes & functioning, environmental quality, and human health (Pyšek & Richardson 2010; Simberloff et al. 2013; Jones & McDermott 2018; Pearson et al. 2018; Petruzzella et al. 2018; Bartz & Kowarik 2019; Rai & Singh 2020). Successful plant invasions are attributed to the interaction between the exotic plants and resident plant communities (Gallien & Carboni 2017). Many factors influence invasion success, including phenotypic plasticity, dispersal benefits from destructive foraging activities, wide geographic range, vegetative reproduction, fire tolerance, and superior competitive ability compared to native flora (Sharma et al. 2005). Invasive alien plants may outperform native species due to the absence of natural enemies in the introduced range (Aguilera 2011). Moreover, invasive plants display characteristics such as high competitive ability and efficient resource utilization (Baker 1965; Levine 2000; Petruzzella et al. 2018).

The introduction of non-native species into new habitats is largely due to short-term economic benefits (MeNeely 2001), therefore, most of the issues related to invasive plants can be linked to the intended or unintended consequences of economic activities (Perrings et al. 2002). Globalization and rapid modification of natural habitats have triggered a massive spread of plant species to areas outside their native ranges (van Kleunen et al. 2015). On the continental and global scale, species invasions have diminished the regional distinctiveness of flora and fauna (Vitousek et al. 1997). At least 10% of the world's vascular plants (300,000) have the potential to invade other ecosystems and affect native biota in direct or indirect ways (Singh et al. 2006). About 18% of the Indian flora are aliens, of which 55% are native to the Americas, 30% to Asia, and to 15% Europe & central Asia (Nayar 1977; Singh et al. 2010). Many invasive alien plants confer economic benefits; for example, *Lantana camara* is used by several local villages in India who use it for furniture and pulp making (Kannan et al. 2014); however, it remains a serious invader causing problems for indigenous flora and significant losses of ecosystem services compared to benefits.

Many invasive species have severe negative impacts. For example, *Ageratum conyzoides, Chromolaena odorata*, and *Parthenium hysterophorus* are considered invasive transformer species that lack natural enemies and have fast-spreading ability, allelopathic effects on other plants, and strong competitiveness with crops, while posing health hazard to humans and animals (Raghubanshi et al. 2005; Suthari et al. 2016). Some cultivated alien species provide food, medicine, fuel, & fodder to local communities (Kull et al. 2007) and some are used in the preparation of Ayurvedic formulations (Shiddamallayya et al. 2010). It is estimated that as many as 50% of invasive species, in general, can be classified as ecologically harmful, based on their actual impacts (Richardson et al. 2000).

There is a need for an authoritative database on alien and invasive alien plant species to monitor the spread and impact in various regions and for plan appropriate management strategies. State and regional floras in the country rarely indicate the native or alien status of the species listed therein. In some cases, naturalized alien species are treated as native in floristic documents (Khuroo et al. 2012). Many species recorded as aliens in different regions of the country, but whose native range falls within the country's political boundary, have been excluded in the present study. Example is the Himalayan Chir Pine *Pinus roxburghi* recorded as 'exotic' in southern India (Matthew 1969). Similarly, *Nyctanthes arbor-tristis* is a Himalayan native introduced for various reasons to the rest of the country, and many other species that have a within-the-country origin should also be regarded as alien. The present study reports on alien and invasive flowering plant species in the Hassan district of Karnataka.

MATERIALS AND METHODS

Study area

Hassan district is located in the southern part of Karnataka state in India, situated between 12^0 13', 13^0 33' N & 75^0 33', 76^0 38' E. Hassan district begins at the base of the steep Western Ghats and continues into the gently rolling Deccan plateau. The district shows wide variations in climate and vegetation. The evergreen and semi-evergreen forests in the district are concentrated in the Western Ghats region of Yeslur and Sakaleshpura, and are commonly known as wet evergreen tropical rain forest. Dry deciduous forests dominate the plains, also known as Maidan area (Figure 1).

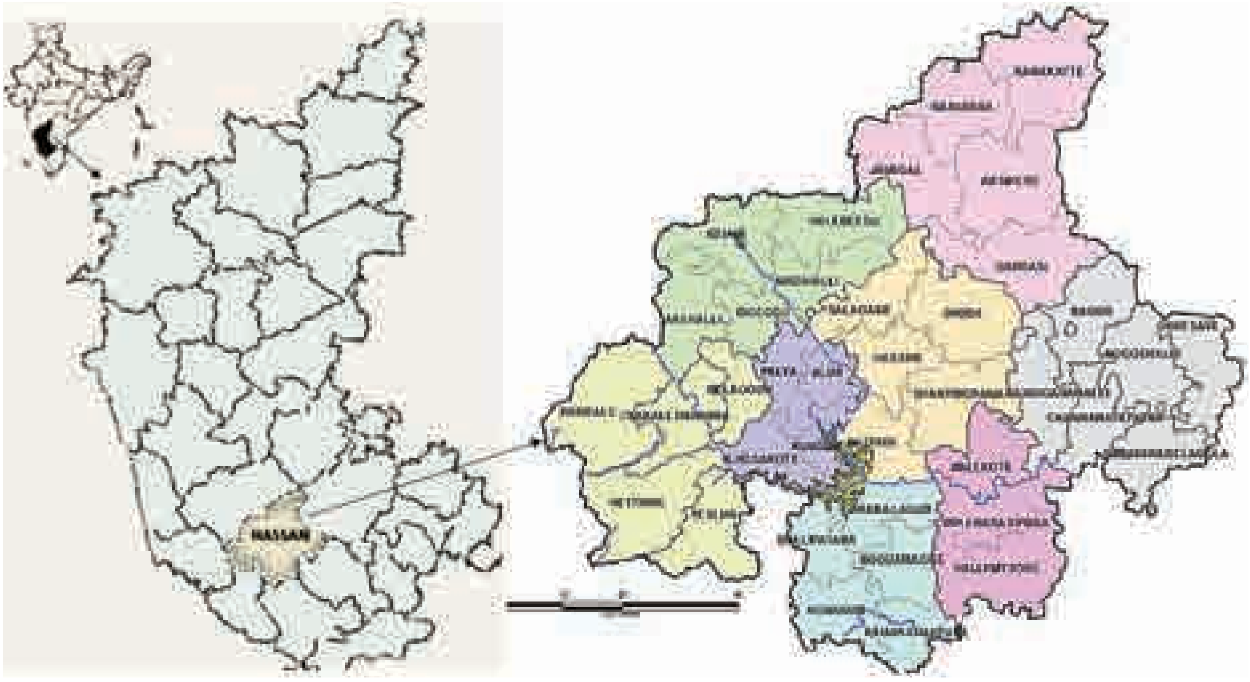

Figure 1. The study area of Hassan District of Karnataka.

Data collection

Extensive floristic surveys were conducted in a planned manner repeatedly in different seasons to get the maximum representation of alien and invasive alien species in Hassan District. Plant samples were collected from natural habitats, agricultural lands, aquatic, semi-aquatic habitats, marshes, open grasslands, wastelands, roadsides, village ponds, wetlands, railway tracks, riverbanks, reserve forests, slopes, and hilltops. The collected specimens were identified with the help of floras (Saldhana & Nicolson 1976; Saldhana 1984, 1996). Plants were categorized by habit (herb, shrub, climber, and tree) and by habitat (wasteland, cultivated field, aquatic, river & pond banks, forest, and roadside). The plant names were rechecked and authenticated using the plant list (www.theplantlist.org\) and GRIN taxonomy site (http://www.ars-grin.gov/npgs/aboutgrin.html), the synonyms were removed to avoid taxonomic inflation. We followed biogeographic approach in assigning the native ranges to all the species (Khuroo et al. 2012). Only those species whose native ranges fall outside the borders of the Indian subcontinent, namely 'alien' species (CBD 2000) were considered in this study. To minimize the error of judgement by earlier studies regarding the alien status, and to cross-check native range records, native ranges for all species were verified with data from the Germplasm Resources Information Network (www.grin.org, http://www.hear.org/pier/, http://www.iucngisd.org/gisd/) and some other published literature (Murthy et al. 2007; Negi & Hajra 2007; Reddy 2008; Reddy et al. 2008; Singh et al. 2010; Wu et al. 2010; Paul 2010; Khuroo et al. 2012; Pyšek et al. 2012).

To further document their status, alien plant species were categorized into casual (Ca), naturalized (Nt), invasive (In), casual or naturalized (Ca/Nt) and naturalized or invasive (Nt/In) as per the earlier studies (Richardson et al. 2000; Pysek et al. 2004; Khuroo et al. 2012). Alien species that may flourish and even reproduce occasionally in an area, but do not form self-replacing populations, and which rely on repeated introductions for their persistence are known as 'casual' (Ca). Alien species that reproduce and sustain populations over more than one life cycle and do not necessarily invade natural, semi-natural or human-made ecosystems are known as 'naturalized' (Nt). Naturalized alien species that produce reproductive offspring, often in large numbers, at considerable distances from parent plants and thus can spread over a considerable area are referred to as 'invasive' (In). Alien species grown or planted and have not yet escaped are referred to as 'cultivated' (Cl). Those casual alien species for which the current evidence is insufficient to be recognized as naturalized but have the potential to become naturalized in the near future are referred to as Ca/Nt. Those naturalized alien species for which the current evidence is insufficient to be recognized as invasive, but have the potential to become invasive in the near future are referred to as Nt/In. The purpose of intentional introduction (food, fodder, ornamental, plantation, horticulture, and medicinal) of the alien species were recorded from relevant literature (Sharma & Pandey 1984; Khuroo et al. 2007; Jaryan et al. 2013). Species that have come unintentionally were categorized as 'unintentional introductions' (Ui). Literature including unpublished (Singh et al. 2010; Kambhar & Kotresha 2011; Prakash & Balasubramanian 2018) and local communities were consulted for uses. The alien species were analyzed for taxa statistics, habit, habitat, nativity, purpose of introduction, invasive status and use-values. For analysis of habit, the number of species in a particular habit has been divided by the total number of alien species and multiplied by 100. The same follows for habitat, nativity, and invasion status analyses. For analyzing the purpose of introduction, number of species introduced for a particular purpose was divided by the total number of species for which the purpose of introduction is known (122) and then multiplied by hundred. We used Microsoft Excel (version 2013) for the data processing.

RESULTS AND DISCUSSION

A total of 312 species in 236 genera and under 79 families were documented as invasive alien plant species. They are shown along with the family name, habit, habitat, nativity, mode of introduction, invasive status, and uses in Table 1 and Images 1–5. The habit-wise distribution of alien species is represented in Figure 2.

Of the species 48% (n = 152) belong to just 10 families. Asteraceae was the dominant family with 36 species (23%) followed by Fabaceae 21 species (13%), Amaranthaceae 17 species (11%), and Poaceae 16 species (10%). Due to their dominance, most of these families have a high number of herbs. The dominance of Fabaceae, which has the ability to fix nitrogen, would aid their colonisation of empty niches. The proportion of alien species to the total species in the respective family in Hassan district is highest for Amaranthaceae (85%) followed by Solanaceae (83.3%) and Asteraceae (47.3%) (Table 2). For India, this is in agreement with Khuroo et al. (2012) and Jaryan et al. (2013). Similar patterns of family dominance in alien floras have been reported in studies from Europe (Lambdon et al. 2008) and China (Weber et al. 2008; Wu et al. 2010). Pysek (1998) found that these families also have the majority of alien species on a worldwide scale. In addition, studies on agricultural weeds found that the Asteraceae and Poaceae families account for the majority of weeds in terms of numbers (Heywood 1989). This could be due to the fact that these families have some of the highest species richness (Rao 1994) and hence have a higher chance of harboring more alien species. Such a family dominance pattern, as Khuroo et al. (2012) pointed out, is more of a depiction of sampling effect. These families are known to have a large number of species, hence an increase in the number of alien species belonging to these families is expected (Khuroo et al. 2012). In Himachal Pradesh also, proportion of alien species relative to the total species in Amaranthaceae (53.3%) followed by Solanaceae (52.9%) and Convolvulaceae (44%) is highest (Jaryan et al. 2013). This is in agreement to the results of Khuroo et al. (2012) for India and Wu et al. (2010) for China. In Kashmir, proportion of alien species relative to the total species in Amaranthaceae (83%) is highest (Khuroo et al. 2007). Interestingly, the Asteraceae and Convolvulaceae families have the biggest numerical contributions (47.3%) in this ranking for Hassan district (Table 2). In the top 10 list of families, Poaceae (11.4%) has the lowest alien species (Table 2). Remarkably, some families comprise only invasive species in Hassan district (e.g., Balsaminaceae, *Impatiens balsamina*; Ceratophyllaceae, *Ceratophyllum demersum*; Martyniaceae, *Martynia annua*). The following genera had highest number of alien species in Hassan district, *Solanum* (8 species), *Ipomoea* (7 species), and *Euphorbia* (6 species), *Amaranthus*, *Alternanthera*, & *Hibiscus* (4 species each). These genera also contribute a good number to the alien flora of India, Europe, and China (Lambdon et al. 2008; Weber et al. 2008; Wu et al. 2010; Khuroo et al. 2012).

Out of the 36 plant species that are globally recognised as the 'World's worst invasive alien species' (Lowe et al. 2000), 17 are present in India (Khuroo et al. 2012), of which we report the presence of eight in Hassan district: *Eichhornia crassipes*, *Spathodea campanulata*, *Imperata*

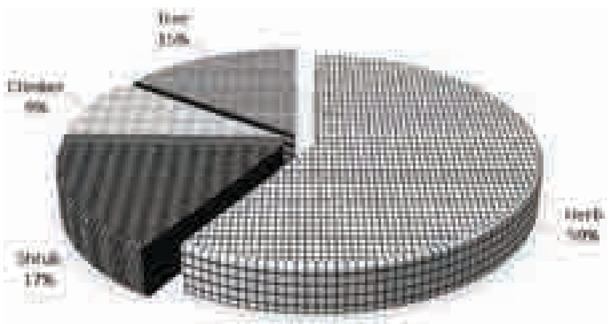

Figure 2. Habit-wise distribution of alien species of Hassan District.

Table 1. Alien plant species of Hassan District, their source region and uses.

	Accepted name of species	Family	Habit	Longevity	Habitat	Nativity	Purpose of introduction	Invasive status	Uses
1	*Abelmoschus esculentus* (L.) Moench	Malvaceae	H	A	CF	TAF	Fd	Cl	V
2	*Acacia auriculiformis* L.	Mimosaceae	T	P	AR	AU	Ui	Ca/Nt	W
3	*Acacia farnesiana* (L.) Willd.	Mimosaceae	T	P	AR	SAM	Ui	In	M
4	*Acanthospermum hispidum* DC.	Asteraceae	H	A	W	BR	Ui	In	M
5	*Achyranthes aspera* L.	Amaranthaceae	H	A	W	AS	Ui	In	M
6	*Achyranthes bidentata* Blume	Amaranthaceae	H	P	AR	AS	Ui	Nt	M
7	*Acmella uliginosa* (Sw.) Cass.	Asteraceae	H	A	W	TAM	Ui	Nt	Nk
8	*Adenostemma lavenia* (L.) Ktze.	Asteraceae	H	A	RB	SAM	Ui	In	Nk
9	*Aeschynomene indica* L.	Fabaceae	H	A	AQ	AU	Ui	In	Nk
10	*Agave americana* L.	Asparagaceae	S	P	AR	TAM	Ui	Nt	R
11	*Agave sisalana* Perrine.	Asparagaceae	S	P	W	MX	Ui	Cl	R
12	*Ageratum conyzoides* (L.) L.	Asteraceae	H	A	W	TAM	Or	In	M
13	*Ageratum houstonianum* Mill.	Asteraceae	H	A	W	TAM	Ui	In	Nk
14	*Albizia lebbeck* Benth.	Mimosaceae	T	P	F	AS	Pl	Nt	W
15	*Albizia saman* (Jacq.) Merr.	Mimosaceae	T	P	AR	TAM	Ui	Ca/Nt	W
16	*Allamanda cathartica* L.	Apocynaceae	C	P	CF	TAM	Or	Cl	Or
17	*Allium cepa* L.	Amaryllidaceae	H	A	CF	AS	Fd	Cl	V
18	*Allium sativum* L.	Amaryllidaceae	H	A	CF	AS	Fd	Cl	V
19	*Aloe vera* (L.) Burm.f.	Liliaceae	H	P	W	MR	M	Ca/Nt	M
20	*Alternanthera paronychioides* A.St.-Hil.	Amaranthaceae	H	P	RB	TAM	Ui	Nt/In	M
21	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	H	P	W	TAM	Ui	Nt/In	Nk
22	*Alternanthera pungens* Kunth	Amaranthaceae	H	P	W	TAM	Ui	Nt/In	M
23	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	H	P	RB	TAM	Ui	Nt	V
24	*Amaranthus caudatus* L.	Amaranthaceae	H	A	CF	SAM	Fd	In	V
25	*Amaranthus spinosus* L.	Amaranthaceae	H	A	CF	TAM	Ui	In	V
26	*Amaranthus tricolor* L.	Amaranthaceae	H	A	CF	AS	Fd	Ca	V
27	*Amaranthus viridis* L.	Amaranthaceae	H	A	CF	TAM	Ui	In	V
28	*Ammannia baccifera* L.	Lythraceae	H	A	RB	AU	Ui	Nt	Nk
29	*Anacardium occidentale* L.	Anacardiaceae	T	P	W	BR	Ht	Nt	M
30	*Anagallis arvensis* L.	Primulaceae	H	A	RB	EU	Ui	In	Nk
31	*Ananas comosus* (L.) Merr.	Bromeliaceae	H	P	CF	SAM	Ht	Cl	Ef
32	*Anethum graveolens* L.	Apiaceae	H	A	CF	AS	Or	Nt	V
33	*Annona muricata* L.	Annonaceae	T	P	CF	TAM	Ht	Cl	Ef
34	*Annona reticulata* L.	Annonaceae	T	P	F	TAM	Ht	Cl	Ef
35	*Annona squamosa* L.	Annonaceae	T	P	F	WI	Ht	Cl	Ef
36	*Antigonon leptopus* Hook. & Arn.	Polygonaceae	C	P	AR	TAM	Or	Ca/Nt	Or
37	*Arachis hypogaea* L.	Fabaceae	H	A	CF	BR	Fd	Cl	Ol
38	*Areca catechu* L.	Arecaceae	T	P	CF	AS	Pl	Nt	En
39	*Argemone mexicana* L.	Papaveraceae	H	A	W	NAM	M	In	M
40	*Aristolochia littoralis* Parodi	Aristolochiaceae	H	P	W	BR	Ui	Cl	Or
41	*Arthraxon lancifolius* (Trin.) Hochst.	Poaceae	H	A	W	TAF	Ui	Nt	V
42	*Artocarpus altilis* (Parkinson ex F.A.Zorn) Fosberg	Moraceae	T	P	W	SEA	Fd	Cl	Ef
43	*Asclepias curassavica* L.	Apocynaceae	H	P	AR	TAM	Ui	Ca/Nt	Nk
44	*Averrhoa bilimbi* L.	Oxalidaceae	T	P	AR	TAM	Ui	Cl	Ef

	Accepted name of species	Family	Habit	Longevity	Habitat	Nativity	Purpose of introduction	Invasive status	Uses
45	*Averrhoa carambola* L.	Oxalidaceae	T	P	AR	TAM	Ui	Cl	Ef
46	*Bacopa monnieri* Pennell	Scrophulariaceae	H	A	RB	TAM	Ui	In	V
47	*Balanites aegyptiaca* (L.) Delile	Zygophyllaceae	S	P	F	TAF	Ui	Nt	M
48	*Bambusa vulgaris* Schrad.	Poaceae	S	P	AR	SEA	Or	Ca/Nt	Or
49	*Basella alba* L.	Basellaceae	C	A	CF	TAF	M	Nt	M
50	*Benincasa hispida* (Thunb.) Cogn.	Cucurbitaceae	C	A	CF	SEA	Fd	Cl	V
51	*Beta vulgaris* L.	Amaranthaceae	H	A	CF	EU	Ht	Cl	V
52	*Bidens biternata* (Lour.) Merr. & Sherff	Asteraceae	H	A	CF	TAM	Ui	Ca/Nt	M
53	*Bidens pilosa* L.	Asteraceae	H	A	W	SAM	Ui	In	Nk
54	*Biophytum sensitivum* DC.	Oxalidaceae	H	A	W	SEA	Ui	In	M
55	*Bixa orellana* L.	Bixaceae	T	P	CF	BR	Ui	Cl	M
56	*Blainvillea acmella* (L.) Philipson	Asteraceae	H	A	W	TAM	Ui	In	M
57	*Blumea lacera* (Burm.f.) DC.	Asteraceae	H	A	W	TAM	Ui	In	M
58	*Blumea obliqua* (L.) Druce	Asteraceae	H	A	W	TAM	Ui	In	Nk
59	*Bougainvillea spectabilis* Willd.	Nyctaginaceae	S	P	AR	TAM	Or	Cl	Or
60	*Brassica nigra* (L.) K.Koch	Brassicaceae	H	A	CF	EU	Fd	Cl	Ol
61	*Brassica oleracea* L.	Brassicaceae	H	A	CF	EU	Fd	Cl	V
62	*Breynia vitis-idea* (Burn.f.) Fisch	Euphorbiaceae	S	A	CF	WI	Ui	Nt	Nk
63	*Brugmansia suaveolens* Bercht. & K.Presl.	Solanaceae	S	P	AR	BR	UI	Nt	Nk
64	*Bryophyllum pinnatum* (Lam.) Oken	Crassulaceae	H	A	W	TAF	Ui	Nt/In	M
65	*Caesalpinia pulcherrima* (L.) Sw.	Caesalpiniaceae	S	P	CF	TAM	Or	Cl	Or
66	*Cajanus cajan* (L.) Millsp.	Fabaceae	H	A	CF	TAF	Fd	Cl	ES
67	*Caladium bicolor* (Aiton) Vent.	Araceae	H	A	RB	TAM	Or	Cl	Or
68	*Callistemon viminalis* (Sol. ex Gaertn.) G.Don ex Loudon	Myrtaceae	T	P	CF	AU	Or	Ca/Nt	Or
69	*Calotropis gigantea* (L.) Dryand.	Apocynaceae	S	P	W	TAF	Ui	In	M
70	*Camellia sinensis* (L.) Kuntze	Theaceae	S	P	CF	AS	Fd	Ca/Nt	Br
71	*Canna indica* L.	Cannaceae	H	P	CF	TAM	M	Nt	M
72	*Capsicum annuum* L.	Solanaceae	H	P	CF	MX	Ht	Cl	V
73	*Cardiospermum halicacabum* L.	Sapindaceae	C	P	W	SAM	Ui	In	M
74	*Carica papaya* L.	Caricaceae	T	P	CF	SAM	Ht	Cl	Ef
75	*Carmona retusa* (Vahl) Masamune	Boraginaceae	H	A	F	SEA	Ui	Ca/Nt	M
76	*Cascabela thevetia* (L.) Lippold	Apocynaceae	T	P	CF	TAM	Or	Cl	Or
77	*Cassia fistula* L.	Caesalpiniaceae	T	P	F	AS	M	Nt	M
78	*Cassytha filiformis* L.	Lauraceae	C	P	P	AU	Ui	Nt	M
79	*Casuarina equisetifolia* L.	Casuarinaceae	T	P	CF	TAM	Ui	Nt	W
80	*Catharanthus pusillus* (Murray) G.Don	Apocynaceae	H	A	CF	TAM	Or	In	M
81	*Catharanthus roseus* (L.) G.Don	Apocynaceae	H	A	W	TAM	Or	In	M
82	*Celosia argentea* L.	Amaranthaceae	H	A	CF	TAM	Fd	Ca	V
83	*Ceratophyllum demersum* L.	Ceratophyllaceae	H	P	AQ	NAM	Ui	In	M
84	*Cereus repandus* (L.) Mill.	Cactaceae	S	P	AR	TAM	Ui	Nt	M
85	*Cestrum nocturnum* L.	Solanaceae	S	P	AR	WI	Or	Ca/Nt	Or
86	*Chenopodium album* L.	Amaranthaceae	H	A	CF	EU	Fd	In	V
87	*Chenopodium ambrosioides* L.	Amaranthaceae	H	A	W	TAM	Ui	In	Fo
88	*Chloris barbata* Sw.	Poaceae	H	A	W	TAM	Ui	Nt	Fo
89	*Chromolaena odorata* (L.) RM.King & H.Rob.	Asteraceae	H	P	W	TAM	Ui	In	M

	Accepted name of species	Family	Habit	Longevity	Habitat	Nativity	Purpose of introduction	Invasive status	Uses
90	*Cicer arietinum* L.	Fabaceae	H	A	CF	AS	Fd	Cl	Es
91	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	Cucurbitaceae	C	A	CF	SAM	Fd	Cl	Ef
92	*Cleome monophylla* L.	Cleomaceae	H	A	AR	TAF	Ui	Nt	M
93	*Cleome viscosa* L.	Cleomaceae	H	A	W	TAM	Ui	Nt	M
94	*Clidemia hirta* (L.) D. Don	Melastomataceae	H	P	W	TAM	Ui	Nt	M
95	*Clitoria ternatea* L.	Fabaceae	C	A	W	TAM	M	Nt	M
96	*Coffea arabica* L.	Rubiaceae	S	P	CF	TAF	Fd	Cl	Br
97	*Coldenia procumbens* L.	Boraginaceae	H	A	W	NAM	Ui	Nt/In	M
98	*Colocasia esculenta* (L.) Schott	Araceae	H	A	RB	AS	UI	Nt	V
99	*Corchorus aestuans* L.	Malvaceae	H	A	W	TAM	Ui	Nt	M
100	*Corchorus trilocularis* L.	Malvaceae	H	A	W	TAF	Ui	In	M
101	*Coriandrum sativum* L.	Apiaceae	H	A	CF	AS	Fd	Cl	V
102	*Cosmos bipinnatus* Cav.	Asteraceae	H	A	CF	TAM	Or	Nt/In	Nk
103	*Couroupita guianensis* Aubl.	Lecythidaceae	T	P	AR	SAM	Ui	Cl	M
104	*Crassocephalum crepidioides* (Benth.) S.Moore	Asteraceae	H	A	F	TAM	Ui	In	Nk
105	*Crotalaria pallida* Aiton	Fabaceae	H	A	CF	TAM	Ui	Nt	Nk
106	*Crotalaria retusa* L.	Fabaceae	H	A	CF	TAM	Ui	Nt	Nk
107	*Croton bonplandianus* Baill.	Euphorbiaceae	H	P	W	SAM	Ui	In	Nk
108	*Cucumis melo* L.	Cucurbitaceae	C	A	CF	AS	Fd	Cl	Ef
109	*Cucurbita maxima* Duchesne	Cucurbitaceae	C	A	CF	SAM	Fd	Cl	V
110	*Cucurbita pepo* L.	Cucurbitaceae	C	A	CF	SAM	Fd	Cl	V
111	*Cuscuta reflexa* Roxb.	Convolvulaceae	C	P	P	MR	Ui	In	M
112	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae	H	A	W	AS	Ui	Nt/In	M
113	*Cymbopogon citratus* (DC.) Stapf	Poaceae	H	A	CF	SEA	Ui	Ca	Ol
114	*Cyperus difformis* L.	Cyperaceae	H	A	CF	TAM	Ui	In	Nk
115	*Cyperus iria* L.	Cyperaceae	H	A	CF	TAM	Ui	Nt	Nk
116	*Cyperus rotundus* L.	Cyperaceae	H	A	CF	TAF	Ui	In	M
117	*Datura metel* L.	Solanaceae	S	P	W	TAM	Ui	Ca/Nt	M
118	*Datura stramonium* L.	Solanaceae	S	P	AR	TAM	Ui	In	M
119	*Daucus carota* L.	Apiaceae	H	A	CF	NAM	Fd	Cl	V
120	*Delonix regia* (Hook.) Raf.	Fabaceae	T	P	AR	TAF	Or	Cl	Or
121	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	S	P	F	AS	Ui	Nt	V
122	*Dentella repens* (L.) J.R.Forst. & G.Forst.	Rubiaceae	H	A	RB	AU	UI	Nt	Nk
123	*Dicoma tomentosa* Cass.	Asteraceae	H	A	W	TAM	Ui	In	M
124	*Digera muricata* (L.) Mart.	Amaranthaceae	H	A	CF	NAM	Ui	In	V
125	*Digitaria longiflora* (Retz.) Pers.	Poaceae	H	P	RB	TAF	Ui	Nt	Nk
126	*Dinebra retroflexa* (Vahl) Panz.	Poaceae	H	A	CF	TAM	Ui	Nt	NK
127	*Dioscorea bulbifera* L.	Dioscoreaceae	C	P	F	AS	M	Nt	V
128	*Duranta erecta* L.	Verbenaceae	S	P	CF	TAM	Or	Ca/Nt	Or
129	*Echinochloa colona* (L.) Link	Poaceae	H	A	W	EU	Fo	Nt	Fo
130	*Echinochloa crus-galli* (L.) P.Beauv.	Poaceae	H	A	CF	SAM	Fo	Nt	Fo
131	*Echinops echinatus* Roxb.	Asteraceae	H	A	W	TAF	Ui	Nt	M
132	*Eclipta prostrata* (L.) L.	Asteraceae	H	A	CF	TAM	Ui	In	M
133	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	H	P	AQ	TAM	Or	In	Nk
134	*Eleocharis atropurpurea* (Retz.) J.Presl & C.Presl	Cyperaceae	H	A	AQ	SAM	Ui	Nt	Nk

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135	*Emilia sonchifolia* (L.) DC. ex DC.	Asteraceae	H	A	RB	TAM	Ui	In	M
136	*Eragrostis pappose* (Desf. ex Roem. & Schult.) Steud.	Poaceae	H	A	W	TAF	Ui	Nt	Nk
137	*Eryngium foetidum* L.	Apiaceae	H	A	W	TAM	UI	Nt/In	V
138	*Eucalyptus citriodora* Hk	Myrtaceae	T	P	W	AU	Pl	Cl	Ol
139	*Euphorbia heterophylla* L.	Euphorbiaceae	H	A	CF	TAM	Ui	In	Or
140	*Euphorbia hirta* L.	Euphorbiaceae	H	A	CF	TAM	Ui	In	M
141	*Euphorbia pulcherrima* Willd. ex Klotzsch	Euphorbiaceae	S	P	W	MX	Or	Ca/Nt	M
142	*Euphorbia thymifolia* L	Euphorbiaceae	H	A	W	SAM	Ui	In	Nk
143	*Euphorbia tirucalli* L.	Euphorbiaceae	S	P	AR	TAM	Ui	Ca/Nt	M
144	*Euphorbia umbellata* (Pax) Bruyns.	Euphorbiacaeae	S	P	W	TAM	Ui	In	M
145	*Ficus carica* L.	Moraceae	T	P	CF	EU	Fd	Nt	Ef
146	*Fimbristylis dichotoma* (L.) Vahl	Cyperaceae	H	A	RB	AS	Ui	Nt	Nk
147	*Foeniculum vulgare* Mill.	Apiaceae	H	A	CF	MR	Fd	Cl	Es
148	*Galinsoga parviflora* Cav.	Asteraceae	H	A	RB	TAM	Ui	In	M
149	*Glossocardia bosvallia* (L.f.) DC.	Asteraceae	H	A	F	WI	Ui	Nt	V
150	*Gnaphalium polycaulon* Pers.	Asteraceae	H	A	RB	TAM	Ui	In	Nk
151	*Gomphrena celosioides* Mart.	Amaranthaceae	H	A	W	TAM	Ui	Nt	Nk
152	*Gomphrena globosa* L.	Amaranthaceae	H	A	CF	TAM	Ui	In	Nk
153	*Grangea maderaspatana* (L.) Poir.	Asteraceae	H	A	RB	SAM	Ui	In	M
154	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	T	P	CF	AU	Pl	Cl	W
155	*Guizotia abyssinica* (L. f.) Cass.	Asteraceae	H	A	CF	TAF	Ui	Cl	Ol
156	*Hamelia patens* Jacq	Rubiaceae	S	P	AR	BR	Or	Cl	Or
157	*Harrisia bonplandii* (Parm.) Britton & Rose	Cactaceae	S	P	W	SAM	Ui	Nt	Nk
158	*Helianthus annuus* L.	Asteraceae	H	A	CF	NAM	Ui	Cl	Ol
159	*Hibiscus cannabinus* L.	Malvaceae	S	P	CF	SAM	Ui	In	V
160	*Hibiscus rosa-sinensis* L.	Malvaceae	S	P	CF	AS	Or	Ca	Or
161	*Hibiscus sabdariffa* L.	Malvaceae	H	P	CF	SAM	Ui	Ca/Nt	V
162	*Hibiscus trionum* L.	Malvaceae	H	P	W	TAF	Ui	Nt	Nk
163	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	H	P	AR	SAM	Ui	In	Nk
164	*Impatiens balsamina* L.	Balsaminaceae	H	A	RB	TAM	Or	Cl	Or
165	*Imperata cylindrica* (L.) Raeusch.	Poaceae	H	P	W	TAM	Ui	Nt	R
166	*Indigofera linifolia* (L.f.) Retz.	Fabaceae	H	A	RB	SAM	Ui	Nt	M
167	*Indigofera linnaei* Ali	Fabaceae	H	A	F	TAF	Ui	In	Nk
168	*Ipomoea alba* L.	Convolvulaceae	C	A	W	MX	Ui	Cl	Nk
169	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	C	A	CF	BR	Fd	Cl	V
170	*Ipomoea cairica* (L.) Sweet	Convolvulaceae	C	A	W	TAF	Ui	Nt	Nk
171	*Ipomoea eriocarpa* R. Br.	Convolvulaceae	C	A	W	TAF	Or	Ca/Nt	Nk
172	*Ipomoea hederifolia* L.	Convolvulaceae	C	A	F	TAM	Ui	Nt	M
173	*Ipomoea nil* (L.) Roth	Convolvulaceae	C	A	W	NAM	Ui	In	Nk
174	*Ipomoea obscura* (L.) Ker Gawl.	Convolvulaceae	C	P	W	TAF	Ui	In	M
175	*Jatropha curcas* L.	Euphorbiaceae	S	P	AR	TAM	Or	Nt	Bf
176	*Jatropha gossypifolia* L.	Euphorbiaceae	S	P	W	TAM	Ui	Ca/Nt	Bf
177	*Kigelia pinnata* DC	Bignoniaceae	T	P	F	TAF	Or	Ca/Nt	Nk
178	*Lablab purpureus* (L.) Sweet	Fabaceae	H	A	CF	TAF	Fd	Cl	Ef
179	*Lagascea mollis* Cav.	Asteraceae	H	A	CF	TAM	Ui	In	Nk
180	*Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae	C	A	AR	TAF	Ui	Nt	V

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181	*Lantana camara* L.	Verbenaceae	S	P	F	TAM	Or	In	M
182	*Lawsonia inermis* L.	Lythraceae	S	P	W	TAF	Ui	Nt	M
183	*Leonotis nepetifolia* (L.) R.Br.	Lamiaceae	H	A	W	TAF	Ui	In	M
184	*Linum usitatissimum* L.	Linaceae	H	A	CF	EU	Fd	Cl	Es
185	*Ludwigia adscendens* (L.) H.Hara	Onagraceae	H	A	AQ	TAM	Ui	Nt	Nk
186	*Ludwigia octovalvis* (Jacq.) P.H.Raven	Onagraceae	H	A	RB	TAF	Ui	Nt	M
187	*Ludwigia perennis* L.	Onagraceae	H	A	RB	TAF	Ui	Nt	M
188	*Macrotyloma uniflorum* (Lam.) Verdc.	Fabaceae	H	A	CF	TAF	Fd	Cl	V
189	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae	H	A	W	TAM	Ui	In	M
190	*Manihot esculenta* Crantz.	Euphorbiaceae	T	P	CF	SAM	Fd	Cl	V
191	*Manihot glaziovii* Muell. Arg.	Euphorbiaceae	T	P	CF	BR	Ui	Ca/Nt	Nk
192	*Manilkara zapota* (L.) P.Royen	Sapotaceae	S	P	CF	TAM	Ht	Cl	Ef
193	*Martynia annua* L.	Martyniaceae	H	P	W	NAM	Or	In	M
194	*Mecardonia procumbens* (Mill.) Small	Plantaginaceae	H	A	W	TAM	Ui	In	Nk
195	*Melia azedarach* L.	Meliaceae	T	P	AR	AS	M	Nt	W
196	*Melochia corchorifolia* L.	Sterculiaceae	H	P	F	TAM	Ui	In	V
197	*Mentha arvensis* L.	Lamiaceae	H	A	W	AS	Ui	Ca/Nt	M
198	*Merremia gangetica* Cufod.	Convolvulaceae	H	A	W	TAF	Ui	Nt	M
199	*Millingtonia hortensis* L. f.	Bignoniaceae	T	P	AR	AS	Ui	Ca/Nt	Or
200	*Mimosa pudica* L.	Mimosaceae	H	P	CF	BR	Ui	In	M
201	*Mirabilis jalapa* L.	Nyctaginaceae	H	A	W	SAM	Or	Nt	Or
202	*Monochoria vaginalis* (Burm.f.) C.Presl.	Pontederiaceae	H	P	RB	TAM	Ui	In	M
203	*Moringa oleifera* Lam.	Moringaceae	T	P	CF	NAM	Ht	Ca/Nt	V
204	*Morus alba* L.	Moraceae	S	P	CF	AS	Ht	Nt	Ef
205	*Muntingia calabura* L.	Muntingiaceae	T	P	AR	TAM	Or	Cl	Ef
206	*Mussaenda frondosa* L.	Rubiaceae	S	P	F	TAF	Ui	Cl	M
207	*Nerium oleander* L.	Apocynaceae	S	P	CF	EU	Or	Ca/Nt	Or
208	*Nicandra physalodes* (L.) Gaertn.	Solanaceae	H	A	W	SAM	Or	Ca	M
209	*Ocimum americanum* L.	Lamiaceae	H	A	W	TAM	Ui	In	M
210	*Opuntia ficus-indica* (L.) Mill.	Cactaceae	S	P	F	NAM	Ui	Nt/In	Ef
211	*Opuntia stricta* Haw. Var. *dillenii* (Ker Gawl.)	Cactaceae	S	P	F	TAM	Ui	Ca/Nt	Ef
212	*Oxalis corniculata* L.	Oxalidiaceae	H	P	CF	EU	Ui	In	M
213	*Oxalis latifolia* Kunth	Oxalidaceae	H	A	W	BR	Ui	In	V
214	*Pandanus odorifer* (Forssk.) Kuntze	Pandanaceae	S	P	RB	SEA	Ui	Cl	M
215	*Parthenium hysterophorus* L.	Asteraceae	H	A	W	TAM	Ui	In	Nk
216	*Passiflora foetida* L.	Passifloraceae	C	P	W	SAM	Or	Cl	Or
217	*Passiflora subpeltata* Ortega	Passifloraceae	C	A	W	TAM	Ui	Nt	Nk
218	*Peltophorum pterocarpum* (DC.) Backer ex K. Heyne	Caesalpiniaceae	T	P	AR	AS	Ui	Ca/Nt	W
219	*Persicaria hydropiper* (L.) Delarbre	Polygonaceae	H	P	RB	EU	Fd	In	Nk
220	*Phaseolus vulgaris* L.	Fabaceae	H	A	CF	SAM	Fd	Cl	Es
221	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	T	P	RB	TAM	Ui	Ca/Nt	Ef
222	*Phyla nodiflora* (L.) Greene	Verbenaceae	H	A	AQ	SAM	Ui	Ca/Nt	Nk
223	*Phyllanthus acidus* (L.) Skeels	Phyllanthaceae	T	P	AR	BR	Ui	Cl	Ef
224	*Phyllanthus amarus* Schumach. & Thonn.	Phyllanthaceae	H	A	W	TAM	Ui	Nt	M
225	*Physalis minima* L.	Solanaceae	H	A	W	NAM	M	In	Ef
226	*Pistia stratiotes* L.	Araceae	H	P	AQ	TAM	Ui	In	M

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227	*Pisum sativum* L.	Fabaceae	H	A	CF	TAM	Ht	Cl	Es
228	*Pithecellobium dulce* (Roxb.) Benth.	Mimosaceae	T	P	W	TAM	Ui	Nt	Ef
229	*Plumbago zeylanica* L.	Plumbaginaceae	S	P	W	TAF	Or	Cl	M
230	*Plumeria alba* L.	Apocynaceae	T	P	W	TAM	Or	Cl	Or
231	*Portulaca oleracea* L	Portulacaceae	H	A	W	SAM	Fd	In	V
232	*Portulaca pilosa* L.	Portulacaceae	H	A	W	SAM	Or	In	M
233	*Portulaca quadrifida* L.	Portulacaceae	H	A	W	TAM	Ui	In	M
234	*Potamogeton nodosus* Poir.	Potamogetonaceae	H	P	AQ	TAM	Ui	Nt	V
235	*Prosopis juliflora* (S.w.) DC	Mimosaceae	T	P	W	TAM	UI	Nt	M
236	*Psidium guajava* L.	Myrtaceae	S	P	CF	SAM	Ht	Nt	Ef
237	*Punica granatum* L.	Lythraceae	T	P	CF	AS	Ht	Cl	Ef
238	*Pyrostegia venusta* (Ker Gawl.) Miers	Bignoniaceae	C	P	AR	BR	Or	Cl	Or
239	*Raphanus sativus* L.	Brassicaceae	H	A	CF	TAF	Fd	Cl	V
240	*Ricinus communis* L	Euphorbiaceae	S	A	W	TAF	Fd	In	Ol
241	*Rosa multiflora* Thunb.	Rosaceae	S	P	RB	AS	Or	Ca/Nt	M
242	*Rotala densiflora* (Roth) Koehne	Lythraceae	H	A	RB	AS	Ui	Nt	M
243	*Rubia cordifolia* L.	Rubiaceae	H	P	F	TAF	Ui	Nt	M
244	*Rubus ellipticus* Smith	Rosaceae	S	P	RB	TAM	Ui	Nt	Ef
245	*Ruellia prostrata* Poir.	Acanthaceae	H	A	W	TAF	Ui	In	M
246	*Ruta graveolens* L.	Rutaceae	H	A	W	MR	M	Cl	M
247	*Saccharum spontaneum* L.	Poaceae	S	P	RB	SEA	Ui	In	Fo
248	*Salvia coccinea* Buc'hoz ex Etl.	Lamiaceae	H	A	W	SAM	UI	Ca	Nk
249	*Scoparia dulcis* L.	Plantaginaceae	H	A	RB	TAM	M	In	Fo
250	*Sechium edule* (Jacq.) Sw.	Cucurbitaceae	C	A	CF	TAM	Ui	Cl	V
251	*Senna alata* (L.) Roxb.	Caesalpiniaceae	S	A	W	WI	Ui	In	M
252	*Senna occidentalis* (L.) Link	Caesalpiniaceae	S	P	W	SAM	Ui	In	M
253	*Senna sophera* (L.) Roxb.	Caesalpiniaceae	H	A	AR	WI	Ui	Nt/In	M
254	*Senna surattensis* (Burm.f.) H.S.Irwin & Barneby	Caesalpiniaceae	T	P	F	SEA	Ui	Cl	Nk
255	*Senna tora* (L.) Roxb.	Caesalpiniaceae	H	A	W	SAM	Ui	In	M
256	*Sesamum indicum* L.	Pedaliaceae	H	A	CF	TAF	Ui	Cl	Es
257	*Sesbania sesban* (L.)	Fabaceae	T	P	W	TAF	Ui	Nt	V
258	*Setaria italica* (L.) P.Beauv.	Poaceae	H	A	CF	TAF	Fo	In	Fo
259	*Sida acuta* Burm.f.	Malvaceae	H	A	W	TAM	Ui	Nt	M
260	*Sida cordata* (Burm. f.) Waalk.	Malvaceae	H	A	AR	SAM	Ui	Nt	M
261	*Siegesbeckia orientalis* L.	Asteraceae	H	A	AR	TAF	Ui	Ca/Nt	Nk
262	*Simarouba glauca* DC.	Simaroubaceae	T	P	AR	SAM	Pl	Cl	M
263	*Solanum americanum* Mill.	Solanaceae	H	A	CF	TAM	Ui	In	V
264	*Solanum erianthum* D.Don	Solanaceae	H	P	F	TAM	Ui	In	M
265	*Solanum lycopersicum* L.	Solanaceae	H	P	CF	TAM	Ui	In	V
266	*Solanum melongena* L.	Solanaceae	H	A	CF	TAF	Fd	Cl	V
267	*Solanum pimpinellifolium* L.	Solanaceae	H	A	W	SAM	Ui	Cl	V
268	*Solanum seaforthianum* Andrews	Solanaceae	C	P	W	BR	Ui	In	Nk
269	*Solanum torvum* Sw.	Solanaceae	S	P	AR	WI	Ui	In	M
270	*Solanum tuberosum* L.	Solanaceae	H	P	CF	SAM	Fd	Cl	V
271	*Sonchus oleraceus* (L.) L.	Asteraceae	H	A	AR	MR	Ui	In	Nk
272	*Sonchus wightianus* DC.	Asteraceae	H	A	W	EU	Ui	Nt/In	M

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273	*Spathodea campanulata* Beauv.	Bignoniaceae	T	P	AR	TAF	Or	Ca/Nt	Or
274	*Spermacoce hispida* L.	Rubiaceae	H	A	W	TAM	Ui	In	M
275	*Sphagneticola calendulacea* (L.) Pruski	Asteraceae	H	A	W	AU	Ui	Nt	Or
276	*Sporobolus diander* (Retz.) P. Beauv.	Poaceae	H	A	W	AS	Ui	In	Fo
277	*Stachytarpheta jamaicensis* (L.) Vahl	Verbenaceae	S	P	F	TAM	Ui	In	M
278	*Stachytarpheta mutabilis* (Jacq.) Vahl.	Verbenaceae	S	P	W	SAM	Ui	Ca/Nt	Nk
279	*Stylosanthes fruticosa* (Retz.) Alston	Fabaceae	H	P	W	TAM	Ui	In	Fo
280	*Swietenia mahagoni* (L.) Jack.	Meliaceae	T	P	AR	WI	Ui	Nt	M
281	*Synadenium grantii* Hook. f.	Euphorbiaceae	S	P	W	TAM	Or	In	M
282	*Synedrella nodiflora* (L.) Gaertn.	Asteraceae	H	A	W	WI	Ui	In	Nk
283	*Tabebuia aurea* (Silva Manso) Benth. & Hook.f. ex S.Moore	Bignoniaceae	T	P	AR	TAM	Or	Ca/Nt	Or
284	*Tabebuia rosea* (Bertol.) Bertero ex A.DC.	Bignoniaceae	T	P	AR	TAM	Or	Cl	Or
285	*Tagetes erecta* L.	Asteraceae	H	P	CF	TAM	Or	Cl	Or
286	*Tagetes patula* L.	Asteraceae	H	A	W	MX	Or	Ca	Or
287	*Talinum portulacifolium* (Forssk.) Asch. ex Schweinf.	Portulacaceae	H	A	W	TAM	Ui	Nt/In	V
288	*Tamarindus indica* L.	Fabaceae	T	P	AR	TAF	Ht	Ca/Nt	Ef
289	*Tecoma capensis* (Thunb.) Lindl.	Bignoniaceae	S	P	CF	EU	Or	Cl	Or
290	*Tecoma gaudichandi* DC.	Bignoniaceae	S	P	AR	SAM	Or	Cl	Or
291	*Tecoma stans* (L.) Juss. ex Kunth	Bignoniaceae	T	P	AR	TAM	Or	Cl	Or
292	*Thunbergia alata* Bojer ex Sims	Acanthaceae	C	P	AR	TAF	Or	In	Or
293	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	S	A	W	MX	Or	In	Or
294	*Torenia fournieri* Linden ex E. Fourn.	Linderniaceae	H	P	W	AU	Ui	In	Or
295	*Tradescantia spathacea* Sw.	Commelinaceae	H	A	W	TAM	Ui	Cl	Or
296	*Trapa natans* L.	Lythraceae	H	P	AQ	EU	Fd	In	Ef
297	*Tribulus terrestris* L.	Zygophyllaceae	H	P	W	TAM	Ui	In	M
298	*Tridax procumbens* (L.) L.	Asteraceae	H	P	W	TAM	Ui	In	M
299	*Trigonella foenum-graecum* L.	Fabaceae	H	A	CF	MR	Fd	Cl	Es
300	*Triumfetta rhomboidea* Jacq.	Malvaceae	H	A	W	TAM	Ui	In	M
301	*Typha angustifolia* L.	Typhaceae	H	P	RB	EU	Ui	In	Fo
302	*Typha domingensis* Pers	Typhaceae	H	P	AQ	SAM	Ui	In	Nk
303	*Urena lobata* L.	Malvaceae	S	P	AR	TAF	Ui	Ca/Nt	M
304	*Urochloa panicoides* P. Beauv.	Poaceae	H	A	W	TAF	Ui	In	Fo
305	*Vallisneria spiralis* L.	Hydrocharitaceae	H	A	AQ	MR	Ui	Nt/In	Nk
306	*Vigna trilobata* (L.) Verdc.	Fabaceae	C	A	W	TAF	UI	Nt	M
307	*Vigna umbellata* (Thunb.) Ohwi & H.Ohashi	Fabaceae	C	A	CF	SEA	Ui	Nt/In	Es
308	*Vigna unguiculata* (L.) Walp.	Fabaceae	H	A	CF	TAM	Fd	Cl	V
309	*Vitex negundo* L.	Verbenaceae	S	P	W	AS	UI	Ca/Nt	M
310	*Waltheria indica* L.	Sterculiaceae	H	P	F	TAM	Ui	In	M
311	*Xanthium strumarium* L.	Asteraceae	H	A	AR	TAM	Ui	In	M
312	*Zea mays* L.	Poaceae	H	A	CF	SAM	Fd	Cl	Fo, V

Habit: H—Herb | S—Shrub | C—Climber | T—Tree | **Longevity:** A—Annual | P—Perennial | **Habitat:** W—Wasteland | CF—Cultivated fields | RB—River or pond banks | F—Forests | AR—Roadsides | AQ—Aquatic | P—Parasite | **Nativity:** AS—Tropical Asia | AU—Australia | BR—Brazil | EU—Europe | MG—Madagascar; MR—Mediterranean region | MX—Mexico | NAM—North America | SAM—South America | SEA—South East Asia (Including Malaysia, Philippines & Indonesia); TAF—Tropical Africa | TAM—Tropical America | WI—West Indies | **Mode of introduction to India**: Fd—Food | Fo—Fodder | M—Medicine | O—Ornamental | Pl—Plantation | Ht—Horticultural; Ui—Unintentional | **Status:** Cl—Cultivated | Ca—Casual | Nt—Naturalized | In—Invasive | Ca/Nt—Casual or Naturalized | Nt/In—Naturalized or Invasive | **Uses:** Bf—Biofuel | Br—Beverages | Ef—Edible fruit | Es—Edible seed | Fo—Fodder | M—Medicinal | Nk—Not known | Ol—Oil | Or—Ornamental; R—Rope making | V—Vegetable | W—Wood.

cylindrica, *Opuntia stricta*, *Clidemia hirta*, *Lantana camara*, *Chromolaena odorata*, and *Rubus ellipticus*. Pysek et al. (2017) have identified 11 alien plant species that occur on one-third or more of the globe in terms of the number of regions where they are naturalized, and on at least 35% of the Earth's land surface. Of these, eight plant species are widely distributed in Hassan district: *Bidens pilosa, Chenopodium album, Datura stramonium, Echinochloa crus-galli, Oxalis corniculata, Portulaca oleracea, Ricinus communis*, and *Sonchus oleraceus.* The impact of these species on indigenous flora and invading ecosystems, however, has yet to be studied. The distribution of alien plant species was most abundant in wastelands (34%), followed by cultivated fields (30%), roadsides (14%), river or pond banks (9%), forests (8%), and aquatic systems (4%) (Figure 3). This pattern could be caused by the relative degree of disturbance in various environments, as well as other abiotic and biotic factors. Disturbance alters the physical environment creating open regions and disturbed environmental factors, such as, elevated soil nitrate and increased light and temperature changes, boost seed germination for many species, including exotics. This could allow alien species to establish themselves in ecosystems. Several researchers have discovered that the species composition after disturbance is reasonably predicted based on the seed bank before disturbance. As a result, sampling the pre-disturbance seed bank can provide insight into whether exotics will become abundant at a site in the event of a predicted disturbance (D'antonio & Meyerson 2002).

We categorized the origin of the reported invasive species into 12 regions, of which tropical America was found to be the origin for 36% (113 species), followed by tropical Africa 15% (48 species), South America 13% (41 species), and tropical Asia (28 species). The other regions, contribibute 2–5 % each to the overall alien flora (Figure 4). The possible explanation for the maximum proportion of species from tropical America can be the higher propagule pressure from different countries, such as Brazil and Mexico, to India via historical trade routes through the human agency of European colonisers and traders, and more or less matching of similar tropical climate (Khuroo et al. 2012). Considering that 36% of species originate in the Americas, the findings of this study are comparable to those reported for China, where 58% of species originate in the Americas (Wu et al. 2010). However, compared to the current study, the percentage of American species in the alien flora of Europe is lower at 34.8% (Lambdon et al. 2008). Because tropical climates have a higher impact on India and China than on Europe, this distinct pattern can be explained.

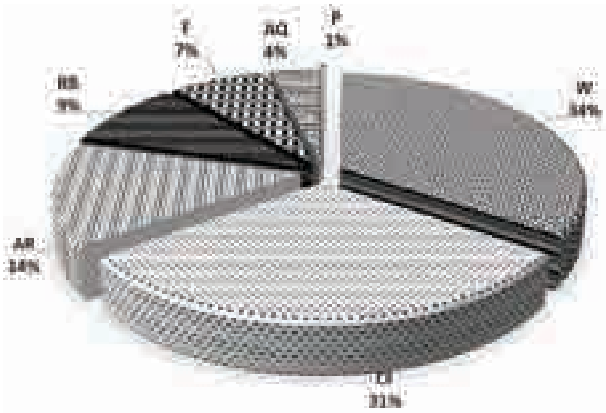

Figure 3. Habitat wise distribution of alien species in Hassan district. W—Wasteland | CF—Cultivated fields | RB—River or pond banks | F—Forests | AR—Roadsides | AQ—Aquatic | P—Parasite.

Table 2. Relative contribution of alien species in the top 10 alien species rich families in Hassan district of Karnataka.

	Family	Alien species	Total species in Hassan district	Alien plants (%)
1	Amaranthaceae	17	20	85
2	Solanaceae	15	18	83.3
3	Asteraceae	36	76	47.3
4	Convolvulaceae	9	19	47.3
5	Malvaceae	12	27	44.4
6	Caesalpinaceae	8	23	34.7
7	Fabaceae	21	97	33.3
8	Euphorbiaceae	14	51	27.4
9	Apocyanaceae	8	24	25
10	Poaceae	16	140	11.4

Some alien plant species, 36% of those listed for Hassan district, are used for medicinal purposes, followed by vegetables (16%), ornamentals (13%), edible fruits (8%), fodder (4%), timber (2%), and biofuel (1%). A large number of alien plant species benefit Indian agriculture, forestry, and pharmaceutical industries, as well as the Indian medical system (Ayurveda) (Shiddamallayya et al. 2010). Ornamental plants are an important component of the urban environment, as well as a substantial source of invasive species as a result of escapes from private or public gardens (Pyek & Chytr 2014; Pergl et al. 2016). Many taxa first escape and spread in spatially constrained areas around gardens, before spreading and colonising more distant vegetation. The combined impacts of local popularity of a specific taxon, regardless of invasion status, adequate natural & cultural conditions, abundant

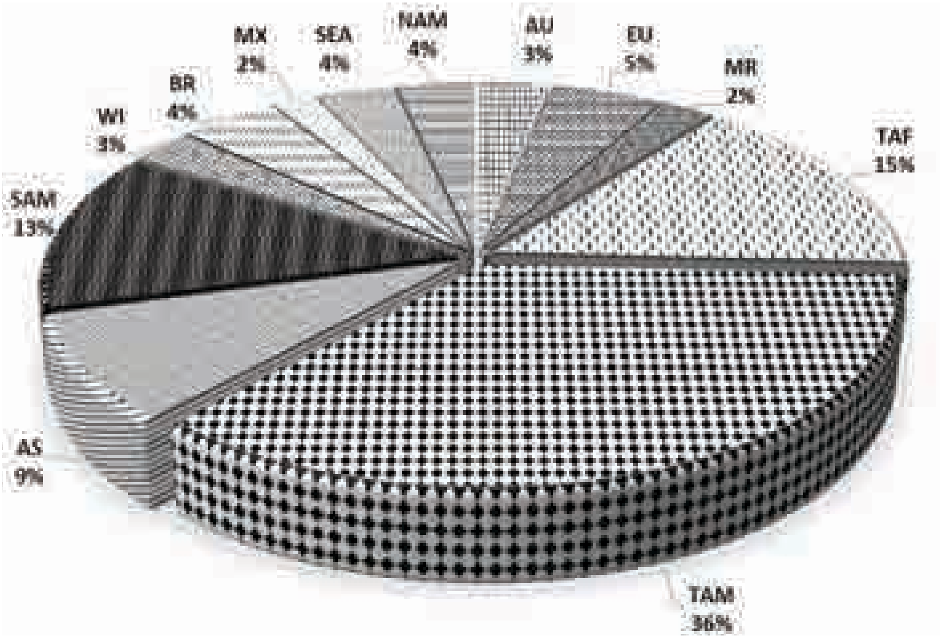

Figure 4. The Nativity of alien species of Hassan District.
SAM—South America | SEA—South East Asia | BR—Brazil | TAM—Tropical America | EU—Europe | TAF—Tropical Africa | AS—Tropical Asia | AU—Australia | WI—West Indies | MR—Mediterranean region | MX—Mexico | NAM—North America.

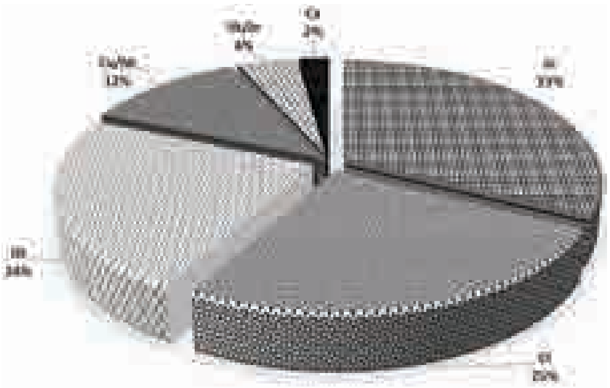

Figure 5. Invasive status of the alien species of Hassan district. Cl—Cultivated | Ca—Casual | Nt—Naturalized | In—Invasive | Ca/Nt—Casual or Naturalized | Nt/In—Naturalized or Invasive.

propagation in cultivation, and easy semi-spontaneous establishment in gardens may result in naturalisation foci (Petrik et al. 2019). Although the majority of alien species grown as garden ornamentals can only survive when planted under careful management, a significant proportion of them manage to escape and establish themselves outside of human control (Pergl et al. 2016). Pyek et al. (2012) found that 56% of the taxa in the Czech Republic's alien flora were recruited from escaping ornamental plants. Similarly, in the Karnataka district of Gadag, roughly 15% of alien species are employed as ornamentals (Kambhar & Kotresha 2011).

We found that 122 species were intentionally introduced, while the rest are unintentional introductions. The majority of species were introduced for ornamental purposes (47%), followed by food (30%), horticulture (10%), medicinal (9%), fodder (4%), and plantation (2%). The invasion status categorization of Hassan is represented in Figure 5.

Hassan district is the reservoir of rich flora, and is a significant segment of the global biodiversity hotspot of Western Ghats. Approximately 1,700 vascular plant species found in Hassan district accounts for 75% of the plant species of Karnataka state and 10% of India, which indicates the richness of biological diversity (Saldhana & Nicolson 1978). However, almost 18.4% of Hassan district flora comprises of alien species, which is higher than the 8% of alien plants in Western Ghats region of Karnataka and 6.5% alien species of Karnataka state (Ganeshaiah et al. 2002; Rao 2012). The majority of the alien species belong to the family Asteraceae, and it also contributed most of the exotic weed species in India (Singh et al. 2010; Kambhar & Kotresha 2011; Khuroo et al. 2012).

In concordance with the alien floras of Europe (Lambdon et al. 2008) and China (Wu et al. 2010), Asteraceae is the most species-rich family in the alien flora of India. At the global level, Pysek (1998) found these families to be having the majority of alien species. Studies on agricultural weeds concluded that, numerically, most weeds come from the families Asteraceae (Heywood 1989). Notably, Asteraceae is amongst the largest family in terms of species richness (Rao 1994). Hence, the possibility of contributing more to alien species is also higher (Mack & Erneberg 2002). The introduction of alien plants for ornamental purpose is common across the globe and especially species belongs to the genera *Amaranthus, Cascabela, Euphorbia, Ipomoea*, and *Solanum* are some of the commonly preferred ornamental alien species reported in India (Khuroo et al. 2012). *Alternanthera philoxeroides* powerful aquatic pest has been found in the lakes, ponds, puddles and waterways was considered a highly invasive and spread throughout the country (Maheshwari 1965). *Lantana camara, Chromolaena odorata,* and *Hyptis suaveolens* were the most concerning alien invasive plant species in terms of rapid growth, higher density, and frequency in forest areas.

Within the forest, these species were so gregarious in their growth and most ecologically destructive invaders in the Western Ghats region (Muniappan & Viraktamath 1993). The escape of these species into nature, on the other hand, may have serious consequences. *Chromolaena odorata* is an invasive transformer species in the Old World (Richardson et al. 2000), owing to its lack of natural enemies. It prefers areas of natural or human-induced disturbance, but it can even infiltrate untouched terrain. Subsistence and commercial agriculture, including crops and plantations, grazing pastures, and silviculture, are all affected by *Chromolaena odorata.* Awanyo et al. (2011) mentioned that the highly invasive *Chromolaena odorata* grows aggressively and suppresses other vegetation by easily forming a thick cover in a very short time. In another study, the high allelopathic properties of this weed support its gaining dominance in vegetation and in replacing other aggressive invaders such as *Lantana camara* and *Imperata cylindrica* in Asia and Africa (Mandal & Joshi 2014). The most common species of invasives in cultivated areas were *Celosia argentea* and *Argemone mexicana,* which were so aggressive and opportunistic in invasion that they could even penetrate flourishing crops if regular weeding was neglected. *Ageratum conyzoides, Cassia tora, Emilia sonchifolia, Oxalis corniculata, Scoparia dulci, Sonchus oleraceous*, and *Tridax procumbens* are some of the other invasive plant species commonly found in cultivated fields that require constant weeding in practices and act as vectors for transmitting pathogens. Parasitic dodders (*Cuscuta* spp.) are becoming a severe concern in south Indian agroecosystems, and are increasingly being detected on a wide range of plants across the country.

Ipomoea carnea, *Pistia stratiotes*, and *Eichhornia crassipes* have become a nuisance in aquatic ecosystems. They cause hindrance and block drainage and reduces the aesthetic value of open water bodies (Kambhar & Kotresha 2011). The invasion of *Eichhornia crassipes* into freshwater systems poses a threat to many human uses. Boating access, navigability, and recreation, as well as pipe systems for agriculture, industry, and municipal water supply, are the most direct impacts. Fish catchability and access to fishing grounds are also impacted. Furthermore, *Eichhornia crassipes* evapotranspiration rates can be higher than open-water evaporation rates. This can be a major issue in water-scarce places and small bodies of water. If it causes changes in fish community composition or modifies the catchability of fished species, it can have a significant impact on fishery (Villamagna & Murphy 2010).

Aside from the negative effects on native flora and the economy, certain alien species were useful to locals. Leafy vegetables included *Portulaca oleracea, Chenopodium album, Alternanthera sessilis, Amaranthus spinosus, Digera muricata*, and *Solanum americanum.* In its invaded area in India, *Prosopis juliflora* grows in forests, wastelands, and at the edges of crop fields, forming pure stands. Farmers retain trees in their fields because their crops grow better under them than in open fields, but they also provide fuel, fodder, charcoal, and lumber (Kaur et al. 2012). Invasive alien plant inventories are one of the most important components for assessing biodiversity and threats to endangered species, as well as providing source data for developing relevant indicators (Pyek et al. 2012; van Kleunen et al. 2015; Latombe et al. 2017). Identifying invasive alien plant species that pose prospective or future threats while they are still in the early stages of invasion is a serious prediction challenge (Lambdon et al. 2008). The findings of this study will raise awareness of invasive alien plants, and the release of this list will encourage more data collection so that the effects of these species can be minimized.

CONCLUSION

The present paper provides information on the status of alien plant species in Hassan district. It is revealed that over 18% of Hassan district flora comprises of alien species, which is higher than the 8% for the Western Ghats region of Karnataka and 6.5% of alien species in Karnataka state. A majority of the species are of South

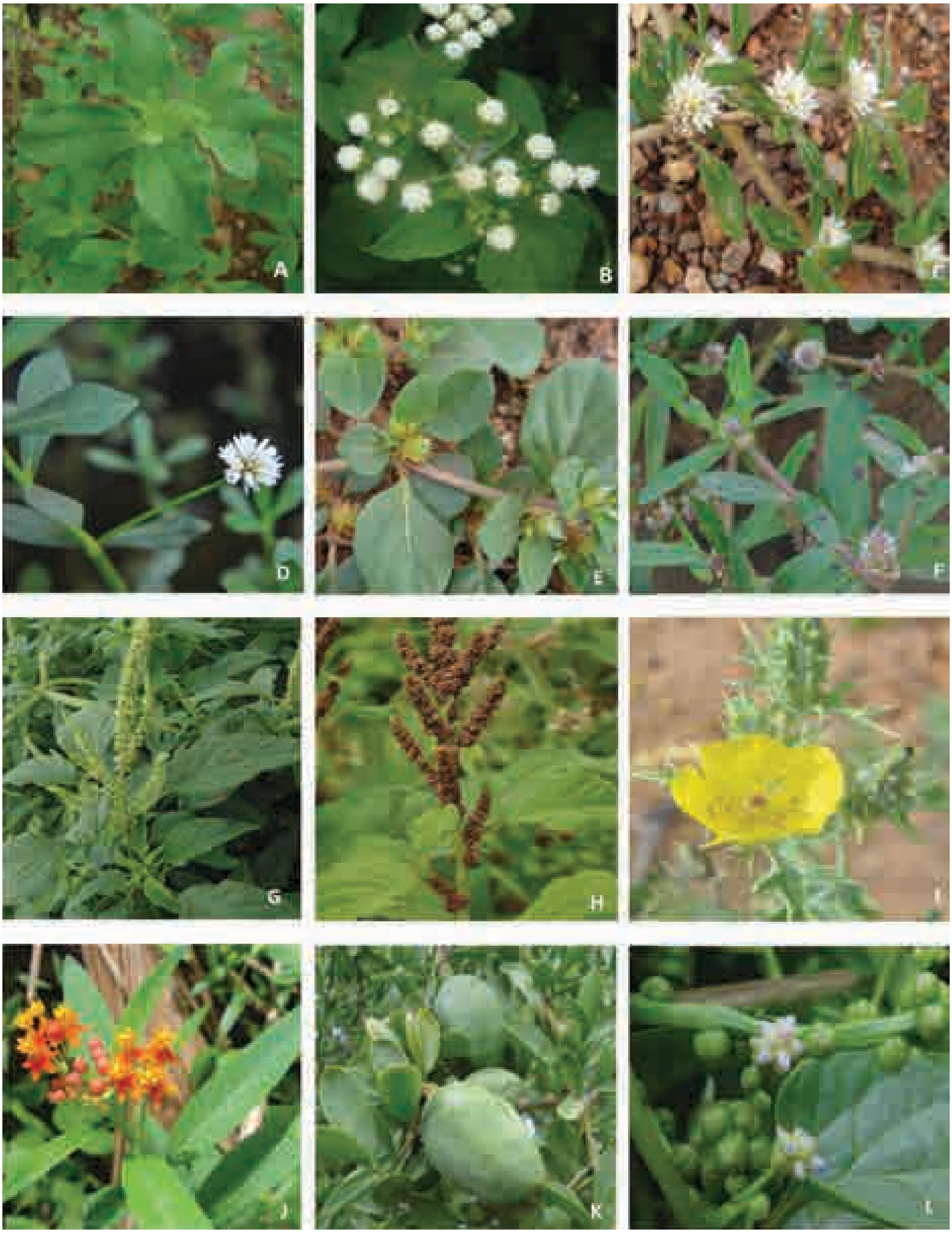

Image 1. A—*Acanthospermum hispidum* DC | B—*Ageratum houstonianum* Mill. | C—*Alternanthera paronychioides* A.St.-Hil. | D—*Alternanthera philoxeroides* (Mart.) Griseb. | E—*Alternanthera pungens* Kunth | F—*Alternanthera sessilis* (L.) R.Br. ex DC. | G—*Amaranthus spinosus* L. | H—*Amaranthus viridis* L | I—*Argemone mexicana* L. | J—*Asclepias curassavica* L. | K—*Balanites aegyptiaca* (L.) Delile. | L—*Basella alba* L. © G M Prashanth Kumar.

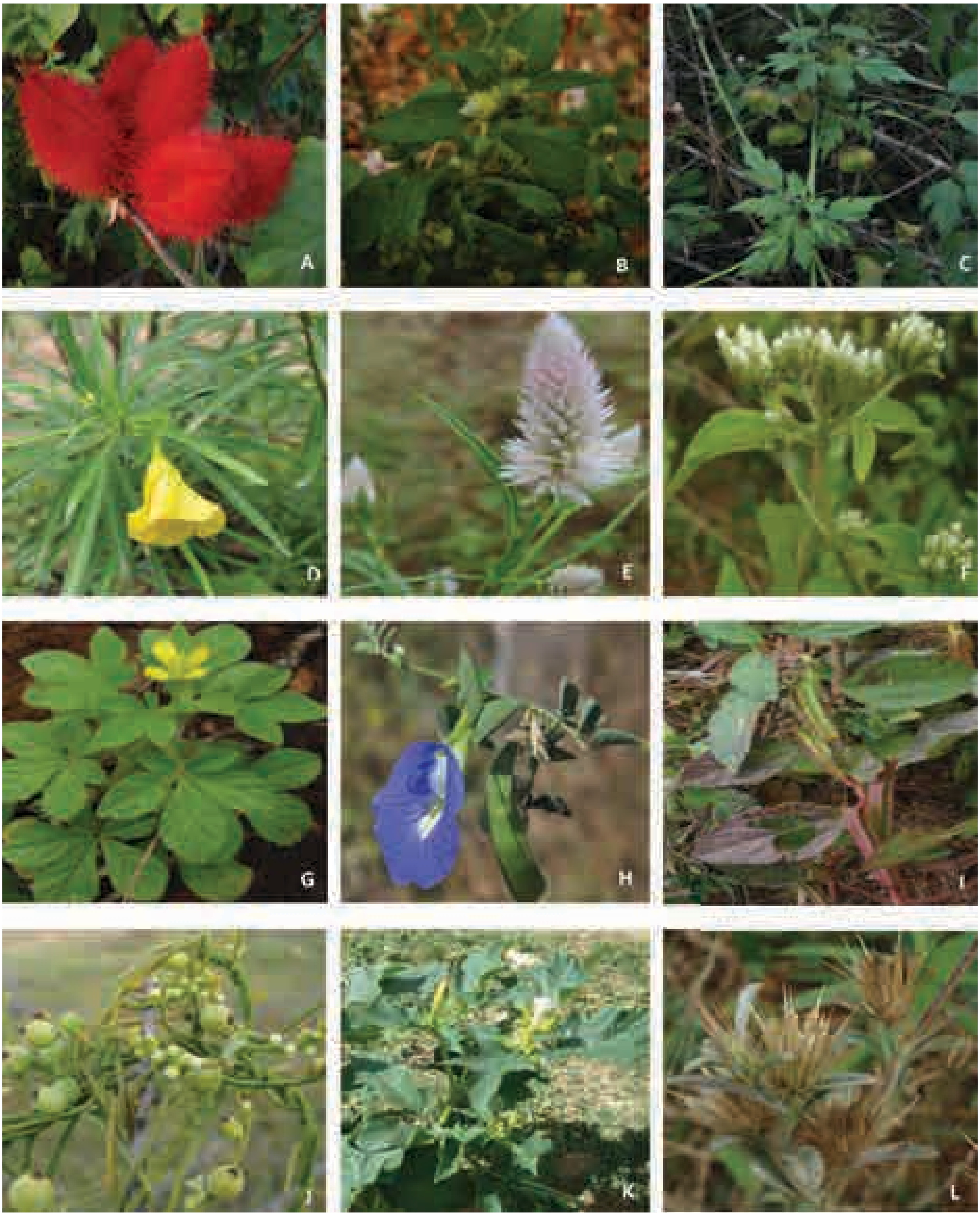

Image 2. A—*Bixa orellana* L. | B—*Blainvillea acmella* (L.) Philipson | C—*Cardiospermum halicacabum* L. | D—*Cascabela thevetia* (L.) Lippold. | E—*elosia argentea* L. | F—*Chromolaena odorata* (L.) RM.King& H.Rob. | G—*Cleome viscosa* L. | H—*Clitoria ternatea* L. | I—*Corchorus aestuans* L. | J—*Cuscuta reflexa* Roxb. | K—*Datura metel* L. | L—*Dicoma tomentosa* Cass. © G M Prashanth Kumar.

Image 3. A—*Echinops echinatus* Roxb. | B—*Eclipta prostrata* (L.) L. | C—*Euphorbia heterophylla* L. | D—*Euphorbia hirta* L. | E—*Glossocardia bosvallia* (L.f.) DC | F—*Gnaphalium polycaulon Pers.* | G—*Hyptis suaveolens* (L.)Poit. | H—*Impatiens balsamina* L. | I—*Ipomoea cairica* (L.) Sweet | J—*Ipomoea hederifolia* L. | K—*Jatropha curcas* L. | L—*Jatropha gossypifolia* L. © G M Prashanth Kumar.

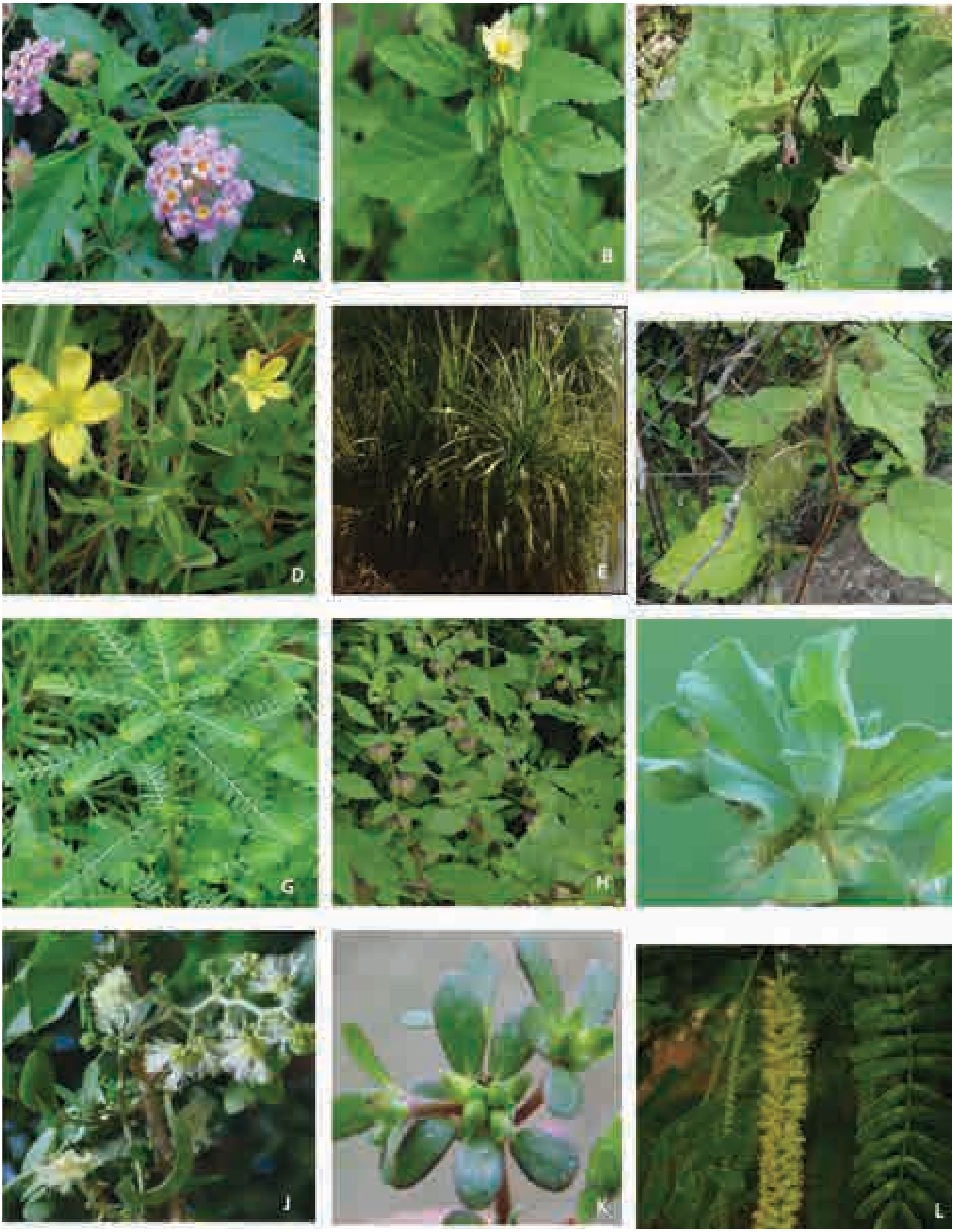

Image 4. A—*Lantana camara* L. | B—*Malvastrum coromandelianum* (L.) Garcke | C—*Martynia annua* L. | D—*Oxalis corniculata* L. | E—*Pandanus odorifer* (Forssk.) Kuntze | F—*Passiflora foetida* L. | G—*Phyllanthus amarus* Schumach. & Thonn. | H—*Physalis minima* L. | I—*Pistia stratiotes* L. | J—*Pithecellobium dulce* (Roxb.) Benth. | K—*Portulaca oleracea* L. | L—*Prosopis juliflora* (S.w.) DC. © G M Prashanth Kumar.

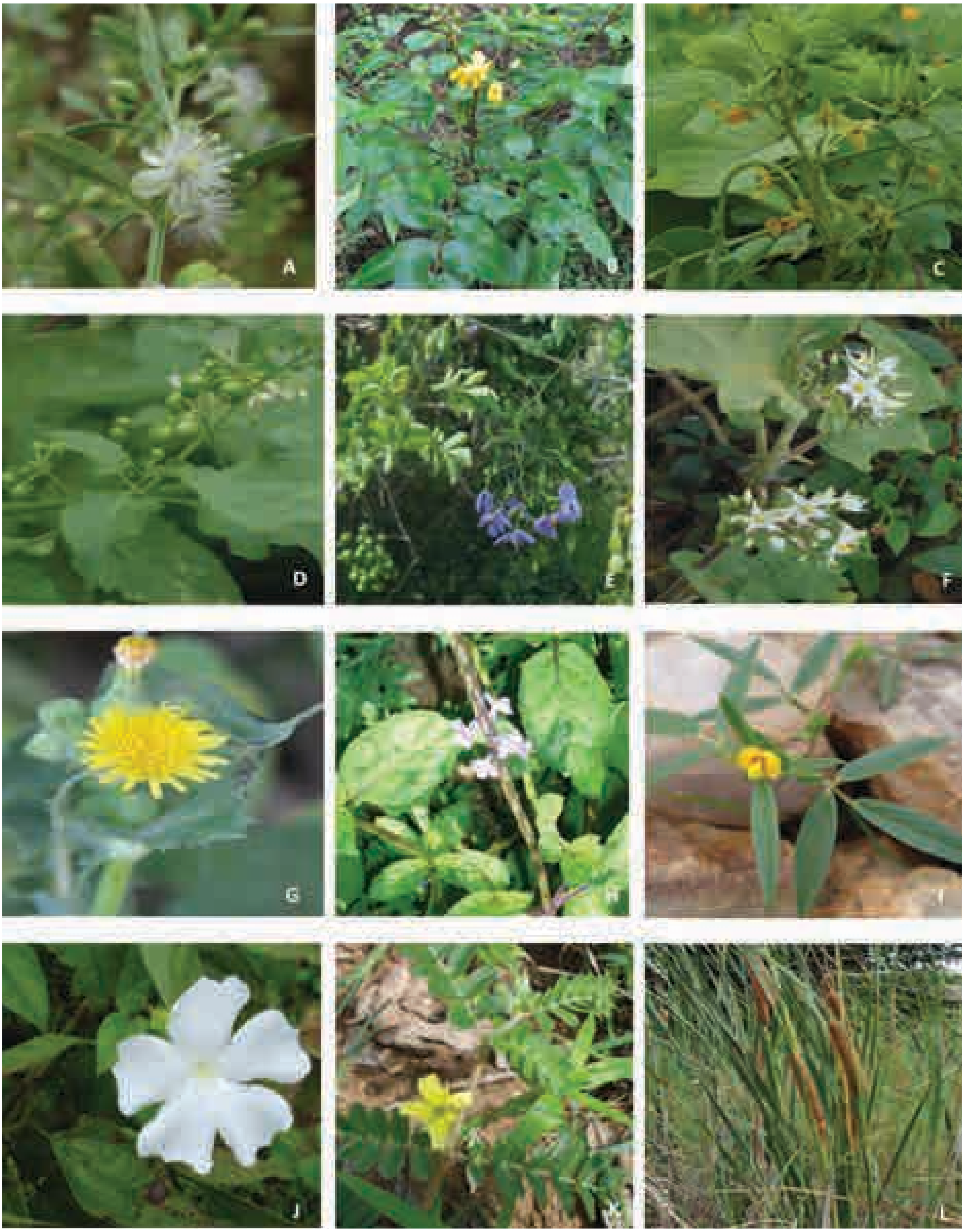

Image 5. A—*Scoparia dulcis* L. | B—*Senna occidentalis* (L.) Link | C—*Senna tora* (L.) Roxb. | D—*Solanum americanum* Mill. | E—*Solanum seaforthianum* Andrews | F—*Solanum torvum* Sw. | G—*Sonchus oleraceus* (L.) L. | H—*Stachytarpheta jamaicensis* (L.) Vahl | I—*Stylosanthes fruticosa* (Retz.) Alston. | J—*Thunbergia alata* Bojer ex | K—*Tribulus terrestris* L. | L—*Typha angustifolia* L. © G M Prashanth Kumar.

American origin and have been introduced for ornamental purposes. Our study indicated that the extent and present share of alien species and their naturalization cannot be considered safe for native and endemic flora. This is especially true of Hassan district, which is part of the Western Ghats 'hotspot' belt and is globally designated for priority of conservational activities. As most forests of the Western Ghats are already badly affected by the invasion of alien plant species, the need for effective control must be emphasized. This compiled work will fill a significant information gap regarding alien species, and will aid in the development of informed monitoring and management strategies, always preserving site biodiversity and peoples' cultural diversity in mind, rather than simply the scale of bio-invasion.

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NOTE

First photographic evidence of the Binturong *Arctictis binturong* (Raffles, 1821) from Nepal

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Binturong, also known as bearcat (Carnivora: Viverridae), is thought to be a close relative of the palm civet. It is the largest civet distributed in tropical and sub-tropical forests of southeastern Asia (Willcox et al. 2016). Binturong has a thick muscular prehensile tail, the only other carnivore which has a truly prehensile tail is the tropical American Kinkajou *Potos flavus*, a member of the Procyonidae, which closely resembles the Binturong in habits (Pocock 1939). The historical distribution and occurrence of Binturong in Nepal Himalaya are of doubtful accuracy (Blandford 1891). However, Pocock (1939) mentions that the species was distributed in the eastern Himalaya. According to Baral & Shah (2008) and Jnawali et al. (2011), the species is distributed in a small area in eastern Nepal, but the exact locality is not specified.

Nine subspecies of Binturong have been proposed (Pocock 1939; Cosson et al. 2007) and taxonomic clarification is needed where the population is restricted to small geographical ranges (Schreiber et al. 1989). The species is listed as Vulnerable in the IUCN Red List of Threatened Species (Willcox et al. 2016). In Nepal, the species is listed as Data Deficient (Jnawali et al. 2011). Globally, 30% of the population has declined over the last 18 years due to habitat loss as well as hunting and trapping for both local uses as food and wildlife trade (Willcox et al. 2016). In some countries, Binturongs are caught for the pet trade. In Indonesia, Binturongs are live trapped and kept in farms to produce Civet Coffee (Kopi Luwak), and the mortality rate is relatively high due to poor housing conditions (D'Cruze et al. 2014).

Binturong are primarily arboreal, and live in mature dense tropical forests (Pocock 1939; Corbet & Hill 1992). They are omnivorous, their natural diet consists of fruits, small animals such as insects, birds, and rodents (Blandford 1891; Willcox et al. 2016). Figs constitute the major proportion of their diet (Lambert 1990; Nakabayashi & Ahmad 2018). The species is known to occur in Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam (Willcox et al. 2016). Binturongs are mostly nocturnal and crepuscular (Lambert 1990; van Schaik & Griffiths 1996; Austin 2002; Grassman et al. 2005), but there are also records of their diurnal activities (Nettelbeck 1998; Datta 1999). Binturong was once thought

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Acknowledgements: We thank the people of Parshyang, Kaski district for showing the sighting area and sharing photographs of the species. We are very much thankful to Mr. Rhadhakrishna Rijal, who first spotted the animal and shared the picture with us. The second author immediately traveled to the site and assembled additional information about the captured animal. We are also thankful to the staff of Division Forest Office, Kaski for sharing the information. We are grateful to Prof. Miyabi Nakabayash and Dr. Sanjay Molur for helping us with species identification.

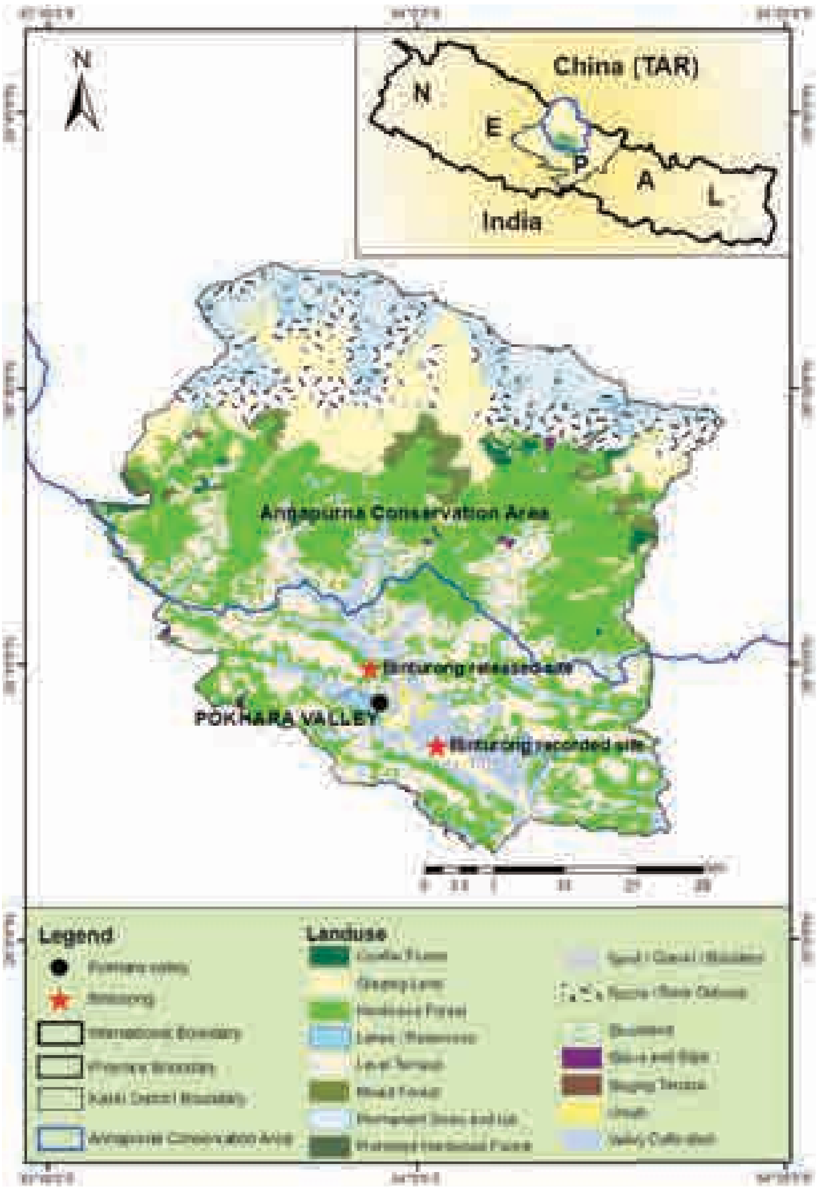

Figure 1. Map showing the recorded and released sites of Binturong in Pokhara Valley of western Nepal.

to be relatively common within its distribution range, but it is now approaching national extirpation in some range countries including Viet Nam and China (Willcox et al. 2016). Their wild population is still unknown.

On 20 July 2022 a young Binturong was observed at 0700 h struggling in a flooded house drainage, at Parshyang (28.175^{0}N, 84.019^{0}E; 916 m), Pokhara Valley, western Nepal (Figure 1). The drainage was overflowed due to the water coming from the traces of paddy fields and a small seasonal brook that were surrounded by mixed forest including Drooping Fig *Ficus semicordata*, Guava *Psidium guajava*, & Banana *Musa* spp. and ended at the Khode pokhari (a pond). The location of the area is <20 km south of Annapurna Conservation Area (ACA), the largest protected area of Nepal (7,629 km^2). The diverse topography and habitats in the ACA might serve as an important habitat for the species. The nearby forest patches of Thotnekhola Community Forest are also connected to the southern part of ACA. Mr. Radhakrishna Rijal, a local resident observed a small, shaggy creature lying in the drainage. The animal was struggling with the water current for an unknown period, and as a result it was exhausted. A few people from the neighboring area immediately gathered at the site and rescued the animal, which was taken to the house and provided rice mixed with milk as well as earthworms to eat. The Division Forest Office (DFO), Kaski district was notified requesting for a visit and to take further care of the rescued animal. The DFO personnel took the animal and kept it for one night and two days in their animal rescue centre. They provided first aid treatment, fed it with chayote squash and bananas, and constantly monitored its activities. Finally, the animal was released in the Thotnekhola community forest (28.245^{0}N, 83.958^{0}E; 1,293 m), Sharangkot, Kaski (Image 1, Figure 1).

According to Prater (1971) an adult Binturong head and body length is 61 to 96 cm, and tail length is 50 to 89 cm, almost equal to body length. An adult weighs 9–20 kg (Cosson et al. 2007). Therefore, judging by the body size from the photographs (Mr. Chhetra Bahadur Thapa pers. comm.) it is likely that the present animal was 2–3 months old.

Binturong have distinct white whiskers, long coarse black to brown fur with white, silver, or rust on the tips, the face has lighter fur, padded paws, flat-footed naked hind foot below, and prehensile tail (Raffles 1822; Blanford 1891; Pocock 1939). Present individual has a long shaggy black coat with light white frosting, tufted ears with a white edge, a thick muscular prehensile tail gradually tapering and slightly curling inwards at the tip. It has also long white whiskers forming a peculiar radiated circle round the face and five-toed feet with bare sole and large strong claws. These morphological features (Image 2a–d) closely match with the description provided by the above authors thus confirming its identification.

According to Blandford (1891) and Willcox et al. (2016), Binturong have not been previously recorded in Nepal. The occurrence of this species in Nepal without exact geographical references had been mentioned by Pocock (1939), Baral & Shah (2008), and Jnawali et al. (2011). The exact distribution in Nepal was unknown until the present information. This is the first photographic evidence record of the species from the country. For last 10–15 years camera traps have been widely used in wildlife research and monitoring in many areas of Nepal from lowland Tarai to high mountains (Chetri et al. 2014; Shrestha et al. 2014; Lama et al. 2019; DNPWC & DFSC 2022). A few species of mammal new to the country such as Steppe Polecat (Chetri et al. 2014), Pallas's Cat (Shrestha et al. 2014), Ruddy Mongoose (Subba et al. 2014), Rusty-spotted Cat (Lamichhane et al. 2016), and Marbled Cat (Lama et al. 2019) were recorded, but Binturong were not photographed. Research on the smaller mammalian taxa is highly limited. As a result, their occurrence, exact distribution, and conservation status are still poorly known. It is believed that the present finding will draw the attention of the researchers, students and concerned authorities for conducting a further study on the species in Nepal.

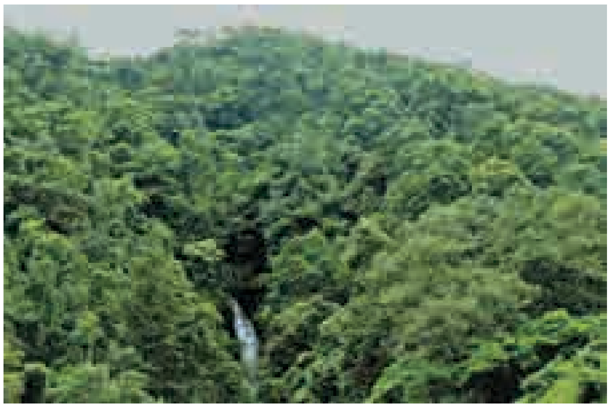

Image 1. A section of the forest patch where the young Binturong was released. © Purna Bahadur Ale.

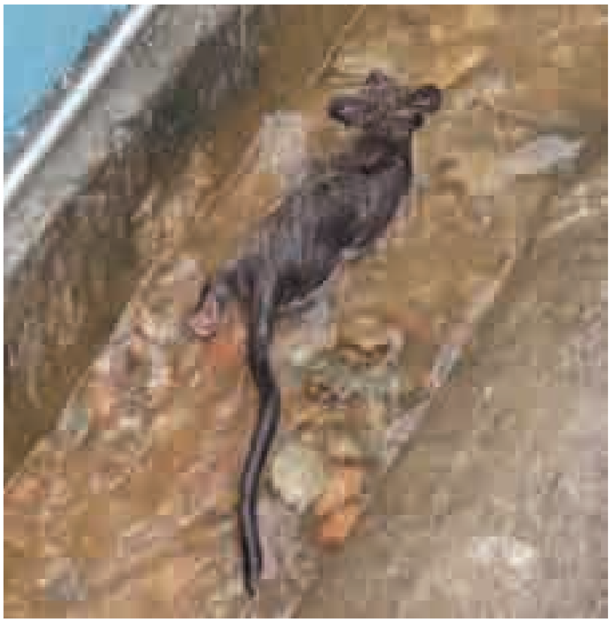

Image 2a. Young Binturong in a flooded drainage where the animal was first located showing bare sole a characteristic of the civets. © Samjhana Bhandari.

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Image 2b. Young Binturong with an almost as long tail as head and body together. © Smreeti Poudel.

Image 2c. Young Binturong (note the long shaggy black to brown coat, light white frosting on the body, tufted ears, long white whiskers forming a peculiar radiated circle round the face, five-toed feet with large strong claws). © Samjhana Bhandari.

Image 2d. Young Binturong's lateral view showing a long prehensile tail gradually tapering and slightly curling inwards at the tip. © Laxmi Sunar.

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NOTE

First record of *Chlorophorus jucundus* (Perroud, 1855) (Coleoptera: Cerambycidae: Cerambycinae) from Maharashtra, India

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In the checklist prepared by Kariyanna et al. (2017), there are 1,536 species of Cerambycidae, enumerated under 440 genera, 72 tribes, and seven subfamilies from India. The genus *Chlorophorus* is distributed in Afghanistan, India, Sri Lanka, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, Vietnam, Cambodia, Laos, Malaysia, Sunda Islands, Philippines, China, Hainan Island, Taiwan, Korea Japan, New Guinea, United States, and Brazil (Kariyanna et al. 2017). In India, *Chlorophorus* is represented by 28 species. Ghate (2012) enlisted 59 species of cerambycid beetles including two species of the genus *Chlorophorus.* The members of *Chlorophorus* were described first by Cheverolat in 1863 are round-necked longhorn beetles. The other genera of tribe Clytini taxonomically differ from the genus *Chlorophorus* due to the following characteristics—the antennae widely separate at the base (*Xylotrechus*), the first joint of hind tarsi is very little or no longer than second and third united *(Oligoenoplus*), antennae spined at apex of one or more of the joints from third to six (*Demonax*), and antennal third joint distinctly longer than first (*Rhaphuma*) (Gahan 1906). This species was described earlier as *Caloclytus jucundus* (see Gahan 1906).

While studying the cerambycid beetles of Kolhapur District, the authors came across a distinctly coloured beetle identified as *Chlorophorus jucundus* (Perroud, 1855) using the description given by Gahan (1906). This species was first described as *Clytus jucundus* by Perroud in 1855 and then redescribed as *Caloclytus jucundus* by Gahan in 1906. In India, *Caloclytus jucundus* is reported from Tamil Nadu: Chennai; Karnataka: Shimoga, Mysore; and Pondicherry (Kariyanna et al. 2017). Except for a few colour photographs of the habitus of the present species, there are no photographs detailing its various characters nor a re-description. Through the present communication, we aim to provide additional colour photographs (dorsal / ventral and lateral views) showing the colouration of *C. jucundus* collected from Shivaji University, Kolhapur, along with a very brief re-description. This will be the first record of *Chlorophorus jucundus* for Maharashtra.

Material examined: SUKZ Ceramb-111, 09.viii.2013, 1 ex. (Image 1A,B,C), Shivaji University, Kolhapur, Maharashtra, India, 16.678 °N, 74.255 °E, 595 m, coll. S.M. Gaikwad, preserved as dry at Department of Zoology, Shivaji University Kolhapur. The photography was done using Canon 550D camera with a 100 mm lens at various focal lengths and then stacked in Photoshop CC software. The map showing distributional records of *C. jucundus* in India was prepared in DIVA-GIS software

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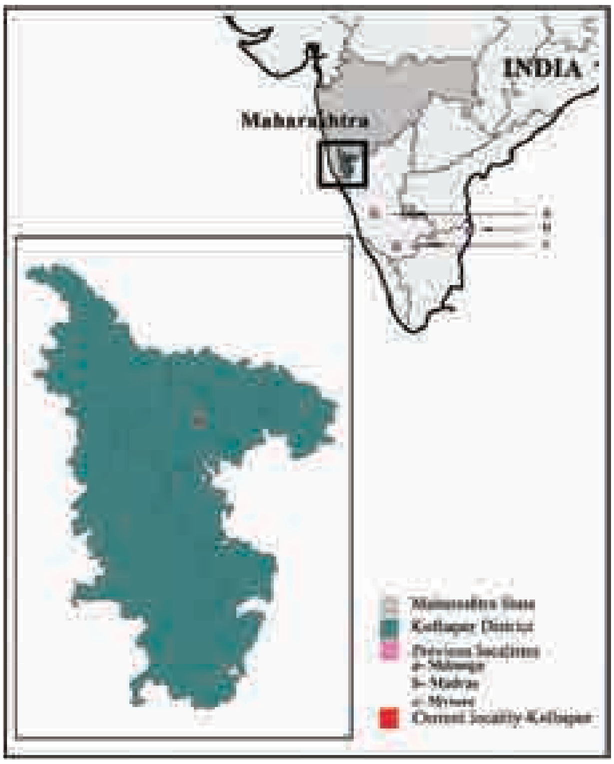

Figure 1. Map showing previous distributional localities and current locality (Kolhapur) of *Chlorophorus jucundus* (Perroud, 1855).

(Figure 1).

The collected specimen was studied under a Nikon stereo zoom (SMZ 800) microscope and identified as *C. jucundus* by using diagnostic characters and illustration given by Gahan (1906) and by comparing colour photographs available on the internet (https://www.cerambycoidea.com/forum/topic.asp?TOPIC_ID=18791 accessed on 20 April 2022).

Diagnostic characters: Body: The overall colouration was mentioned as 'yellow with black patterns' here: the body measured 12 mm in length (head to tip of elytra) and 3 mm in breadth (between humeral angles of elytra); the dorsum was densely covered with yellow pubescence with black markings (Image 1A). Ventrally, a broad longitudinal somewhat triangular black band was noted on the 1st to 4th ventrites, along with a large band on 5th ventrite with mixed pubescence of yellowish-grey colour (Image 1B). Head: small, sub-vertical with fine yellow pubescence; mandibles black and sharp at apex; eyes finely faceted with a large lower lobe, upper portion of lobe narrowed and curved towards the centre of the vertex; antennae (length 7.6 mm) eleven segmented, blackish with faint grey pubescence, antenniferous tubercles smooth, not widely separated at the base (Image 1D). Pronotum with three black spots, two near the dorsolateral and one at the middle forming two lobes posteriorly (Image 1A). Each elytron with a bare elytral margin without pubescence (and hence it looks brown) to which a black transverse median band joins laterally (Image 1C); median transverse band (black colour) curved and broadened posteriorly and narrowed anteriorly near suture to form a triangular shape; three angulated spots present near the base and one prominent black subapical spot; of these three angulated spots, one is on humerus and remaining two spots join each other with narrow connection near suture (Image 1A). Legs with pale greyish pubescence, femora strong and swollen, mid femora finely carinate on each side, the hind femora feebly carinate distally. Hind tibia provided with two ventral spines at apex. First joint of hind tarsi little longer than remaining two joints united, claws, brown curved and sharp (Image 1A,B,C).

Beeson (1941) stated that *Chlorophorus jucundus* was found on *Acacia* spp., *Scutia indica* and another unidentified climber. The present study area, Shivaji University Kolhapur has an area of 832 acres and has a lot of different *Acacia* trees—*A. catechu, A. mangium, A. nilotica*, and *A. auriculiformis.* Therefore, the occurrence *of C. jucundus* on the campus of Shivaji University was always likely.

While examining the characters of the specimen, it was observed that our specimen bears a resemblance to the species *Caloclytus jucundus* described by Gahan (1906) a synonym of *Chlorophorus jucundus* (Perroud, 1855). The closest relative of *C. jucundus* is *Chlorophorus agnathus* (Cheverolat, 1863) which differs from each other due to spots on the body. *C. agnathus* has a cordate spot on the prothorax and two short vittae at base on each elytron, a transverse band in the middle and a spot on the apex. However, the spots on the thorax and elytra of *C. jucundus* are completely different. Gahan (1906) mentioned that this species is found in Chennai, Shimoga and Mysore in southern India. Chevrolat (1863) described *C. cognatus*, a synonym of *C. jucundus* and mentioned its distribution from Sylhet (now in Bangladesh). Aurivillius (1912) listed this species as *Chlorophorus jucundus* and mentioned its distribution as southeastern India. According to Kariyanna et al. (2017), the distribution of this species is in India (Tamil Nadu: Madras; Karnataka: Shimoga, Mysore) and Bangladesh. Ghate (2012) recorded only two species, *Chlorophorus annularis* (Fabricius 1787) and *Chlorophorus quatuordecimmaculatus* (Chevrolat, 1863) in Maharashtra. None of the above studies and the localities for *C. jucundus* include Maharashtra. Hence, Kolhapur is a new locality for *C. jucundus* and

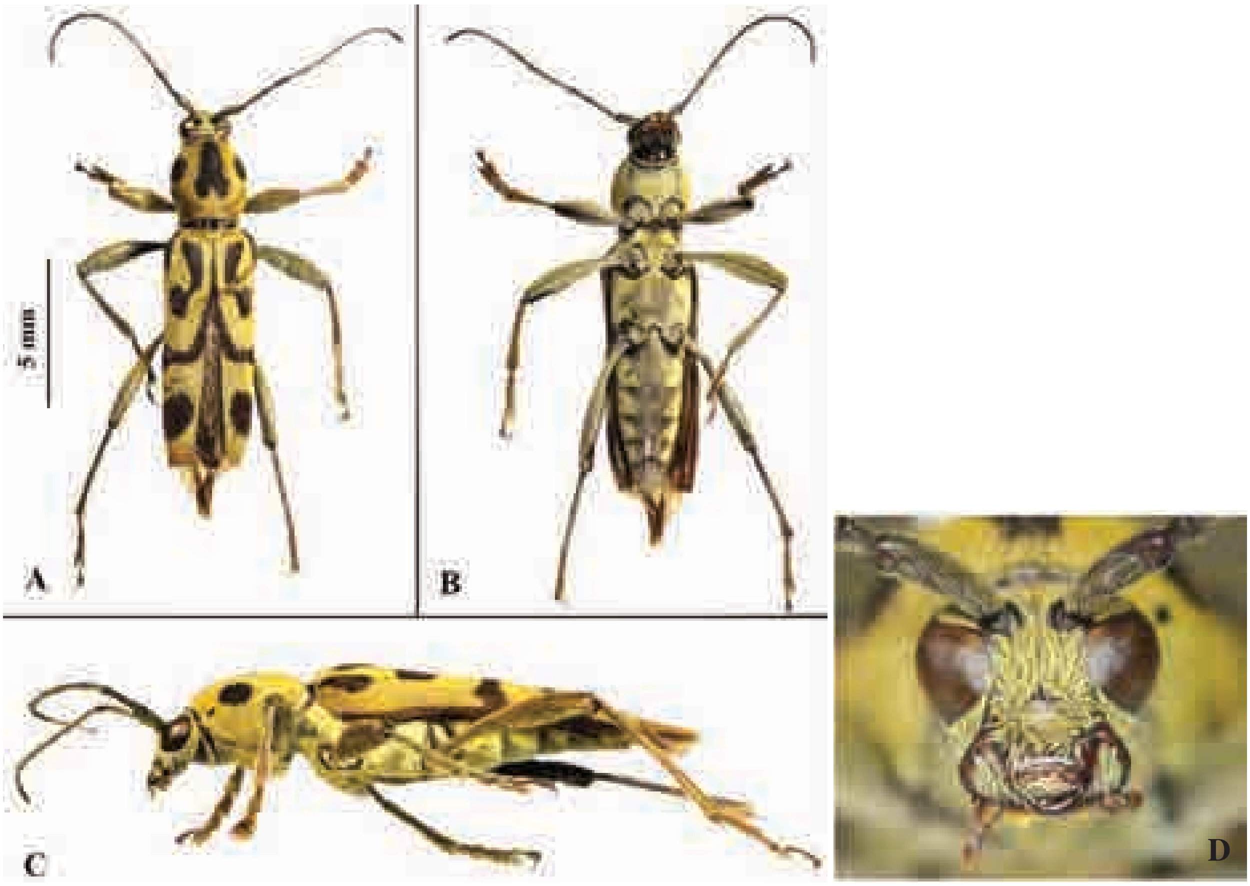

Image 1. *Chlorophorus jucundus* (Perroud, 1855) habitus. A—Dorsal view | B—Ventral view | C—Lateral view | D—Head (frontal view). © Yogesh Mane.

an addition to the cerambycid fauna of Maharashtra. The current record extends its known geographical range northwards from its previous locality, Mysore (Karnataka) by about 560 km.

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NOTE

First record of the swallowtail moth *Epiplema adamantina* Inoue, 1998 (Lepidoptera: Uraniidae: Epipleminae) from western Himalaya, India

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The genus *Epiplema* of Swallowtail moths was described by Herrich-Schäffer in 1855 and 22 species of this genus are so far known from southeastern and eastern Asia (India, Myanmar, China, Java, Sumatra, Sri Lanka, Borneo, and Japan) (Hampson 1895). Recently, *Epiplema adamantina* Inoue, 1998 was described from Nepal (Holotype: male; 08.v.1993; village Bagmati, Mt. Phulchowki; 2,732 m) and three paratypes (2 females; 25.vii.1992 & 19.v.1993; village Godavari and 1 female; 29. x.1986; village Janakpur) from eastern Nepal (Haruta 1998). The habitat around these sites comprises of 'moist temperate forest' mainly with tree species like *Quercus amellose, Q. lanata*, *Q. semecarpifolia*, and *Rhododendron arboreum*. After its description there is only one unconfirmed record of the species from Great Himalayan National Park from Himachal Pradesh state, India from a subtropical Himalayan Chir Pine forest(9/c1b) at 1,515 m (Chandra et al. 2019). However, specimen details, site and date of record are not given.

Identification and distinguishing features of *E. adamantina* with congeners: "Hind wing has slender tails at vein 4 and 7. The wings are red-brown above, forewing has dark brown ante and post median lines strongly angled at middle, a dark patch inside of the latter at hind margin, a sub-terminal dotted fascia between apex and the angle. Hind wings have a discal dash or dot, post median line strongly angled at vein 4, its inside shaped with dark brown and its outside margined with a slender yellowish line, there are one two small yellowish marks between the tails. Length of forewing varied from 12 mm (male) to 15 mm (female) (Image 1).

The species can be confused with *E. morataria* Leech, 1897 found in western China, as both are superficially similar, but upper side of *E. morataria* the wings are less dark, sub-terminal blackish mark from apex to angle is much slender and is spotted in cellules while the underside is much paler with stronger post-median lines and hindwings are yellowish (Haruta 1998). The species can also be confused with *Epiplema arcuata* Warren, 1896 that also occurs in Eastern Nepal [village Jiri (Janakpur); 1 female collected by T. Haruta on 24–27. vii.1993 (Haruta 1998); *E. arcuata* was also recorded by authors in Kedarnath Wildlife Sanctuary, Uttarakhand [village Mandal; 1,740 m; 30.466 N &79.262 E; 23.xi.2021; Temp. 10°C; RH 60%; 12/C1a Ban oak forest). In comparison to *E. adamantina*, this species has a significantly darker striae near the apex on the forewing; ante and post medial lines are less dark; discal area of hind wing is pale expanding up to the tails; and the discal dash or dot on the hindwing is absent (Image 2).

Present record: One individual *E. adamantina* (Image 1; female) was recorded on a moth screen being attracted at night by a CFL lamp at Bataghat near Mussoorie (2,113 m; Temp.: 19.9 °C & Relative humidity:

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Image 1. *Epiplema adamantina* Inoue, 1998 photographed on 15.ix.2020 at Bataghat (2,113m), Mussoorie Forest Division, Dehradun, Uttarakhand, India.

Image 2. *Epiplema arcuata* Warren, 1896 photographed on 23.xi.2021 at Mandal (1,740m), Chamoli Forest Division, Uttarakhand, India.

84%; 30.455 N &78.776 E, Mussoorie Forest Division) in Dehradun district of Uttarakhand, India during the late monsoon season (15.ix.2020). The forest type in the area is mainly '12/C1a Ban oak forest '(Champion & Seth 1968) being dominated by tree species like *Quercus leucotrichophora*, along with associates *Cedrus deodara*, *Pinus roxburghii*, *Rhododendron arboreum*, *Myrica esculenta* and *Cornus capitata*.

This record from Mussoorie is the first confirmed record of this species from the western Himalaya outside Nepal, which is ~800 km west from village Bagmati, Mt. Phoolchauki in eastern Nepal, the nearest known site record of this species. The species prefers to fly during the monsoon season in moist temperate oak forest zone of western and central Himalaya.

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NOTE

Visceral tetrathyridiosis *Mesocestoides* sp. (Cestoda: *Cyclophyllidea*) in a wild Barn Owl *Tyto alba* - a first report and new host record

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Mesocestoides sp. is most commonly recorded in all parts of the world (Soulsby 1982) except Australia (Bradley et al. 2018) and this is probably the first record from India. Incidence depends on the species and the region and the disease caused by *Mesocestoides sp.* tapeworms is called as mesocestoidosis or mesocestoidiasis. Predilection site of adult *Mesocestoides* sp. tapeworms is the small intestine.

Tapeworms of the genus *Mesocestoides* sp. require three hosts. The primary definitive host are carnivorous mammals or birds of prey and it does not affect cattle, sheep, goats, swine or horses (Padgett & Boyce 2004). Tetrathyridium is a second stage larvae affecting vertebrate (second intermediate host) and the first stage larvae (metacestode) of first intermediate host is unknown but believed to be an coprophagous arthropod (Brigitte 1991). *Mesocestoides* species can live in a wide range of hosts, but are particularly widespread in carnivores (Barker et al. 1993; Tenora 2004; David et al. 2011).

Tetrathyridium attached to internal organs were torn loose or cut free and fixed in histo-pathological examinations in 10% neutral-buffered formalin. During necropsy, the encapsulated tetrathyridium were searched throughout the body with a bright LED light source. Formalin fixed tissues were processed by routine paraffin embedding method and 4-µm-thick sections mounted and stained with hematoxylin and eosin (HE). The tissues samples were examined under light microscope. (Rifki et al. 2005; Karl et al. 2016).

Microscopic examination of the tissue samples taken from the liver and lung revealed chronic multiple pyogranuloma due to infestation by *Mesocestoides* sp. Individual larvae (around six number) were different in shape with convoluted borders. Thick eosinophilic cuticle lined larvae resemble a single layer of cells. The remaining body of the parasite was composed of a loose mesenchymal network with widely scattered parenchymal and muscle cells. Numerous clear vesicles/refractile bodies namely calcareous corpuscles, round to oval in shape, were observed within the stroma of the parasite. Mineralized areas were seen in some of the old lesions (Soulsby 1982; McAllister 2014; McAllister et al. 2018).

Tetrathyridia in the liver parenchyma were surrounded by a thick mantle of inflammatory cells and a scant, loose connective tissue. In some lesions, there were small lymphocytic nodules at the periphery. No

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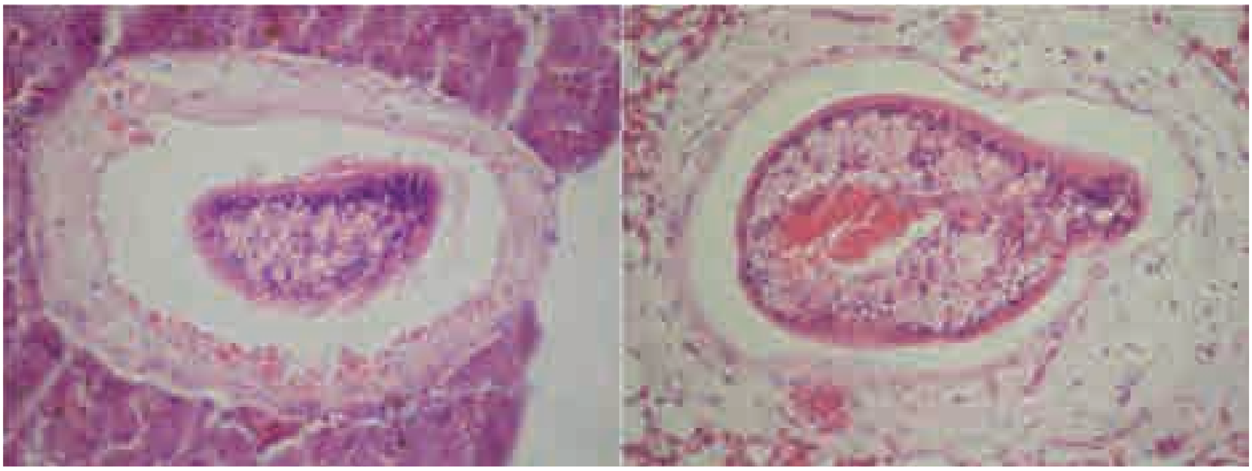

Image 1. Histological section of *Mesocestoides* sp. tetrathyridia from liver H&E. Bar: 50 µm

reactive changes were seen in the visceral peritoneum except in superficial lesions where the inflammation extended to the liver surface. Single tetrathyridia occurred in each nodule.

Tetrathyridium on the pleura surface of the lungs were surrounded by a thin layer of loose connective tissue that appeared to be continuous with the pleura. The inner lining of the capsule was partly lined by flattened epithelial-like cells. There was a mild inflammatory reaction to the tetrathyridia, with infiltration of a few macrophages, lymphocytes, and plasma cells. In all lesions examined, tetrathyridia were intact and showed no evidence of degeneration.

We conclude that, Tetrathyridium has been reported in various vertebrate hosts, including wild and domestic animals like birds, snakes, frogs, and rodents (Soulsby 1982; Frank 1991; McAllister et al. 2017) but this is the first record from Barn Owl. Prey species were more prone to risk due to hunting or scavenging on small vertebrates infected with tetrathyridia and detailed molecular discrimination (Skirnisson et al. 2016) within the species to be studied. There are no real effective preventative measures that prevent *Mesocestoides* tapeworm infection. Effective prevention and control can be achieved with numerous anthelmintic products in domestic animals but less possible in wildlife (Ivan et al. 2004; Ubelaker et al. 2014). Biological control of *Mesocestoides* is so far not feasible and there are no reports on resistance of *Mesocestoides* tapeworms to anthelmintics.

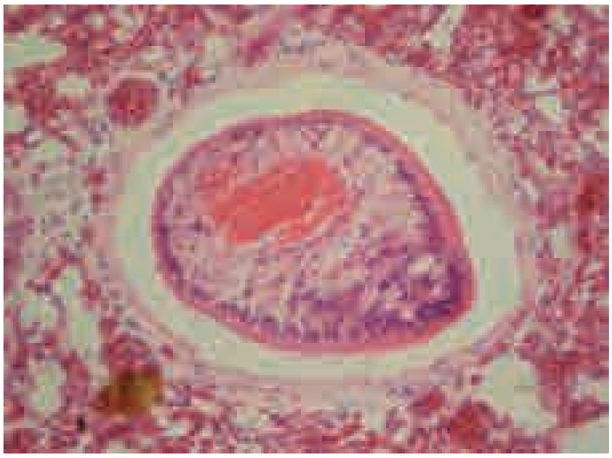

Image 2. Histological section of *Mesocestoides* sp. tetrathyridia from lung H&E. Bar: 50 µm

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