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continued on the back inside cover

Cover: A bag worm with its beautiful heap of junk. Acrylics on 300 GSM paper by Dupati Poojitha based on a picture by Sanjay Molur.

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ARTICLE

Dasymaschalon leilamericanum (Annonaceae), a new species with evidence of non-monophyly from Mount Lantoy Key Biodiversity Area, Philippines

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Abstract: A new Annonaceae species, *Dasymaschalon leilamericanum* is described from Mount Lantoy Key Biodiversity Area (KBA) in the Municipality of Argao, Cebu, Philippines. *D. leilamericanum* is distinguished from closely related species by morphological characters including laminar size, leaf areolation, and seed/fruit shape and size. Significant differences observed in a multivariate analysis of morphological data for *D. leilamericanum, D. clusiflorum*, *D. filipes*, *D. ellipticum*, and *D. blumei* indicate *D. leilamericanum* is a distinct species. A phylogenetic tree analysis performed using maturase K (*matK*) and ribulose 1,5-biphosphate carboxylase (*rbcL*) as molecular markers failed to match *D. leilamericanum* with other *Dasymaschalon* species. Taken together, the results of morphological and molecular analysis indicate a unique evolutionary pathway for *D. leilamericanum* with its genus.

Keywords: Conservation, Cebu Island, evolutionary, forest, limestone, multivariate, non-monophy, plant, paraphyletic, phylogenetic, sedimentary, shrub.

Cebuano: Espesye sa bag-ong Annonaceae ang *Dasymaschalon leilamericanum* nga gihulagway sa Mount Lantoy Key Biodiversity Area (KBA) sa Munisipyo sa Argao, Cebu, Pilipinas. Ang *D. leilamericanum* gipalahi gikan sa suod nga relasyon nga mga espisye pinaagi sa morphological nga mga karakter lakip ang laminar size, dahon areolation, ug liso/bunga porma ug gidak-on. Mahinungdanon nga mga kalainan nga nakita sa usa ka multivariate nga pagtuki sa morphological data alang sa *D. leilamericanum*, *D. clusiflorum*, *D. filipes*, *D. ellipticum*, ug *D. blumei* nagpakita nga ang *D. leilamericanum* usa ka lahi nga espisye. Usa ka phylogenetic tree analysis nga gihimo gamit ang maturase K (*matK*) ug ribulose 1,5-biphosphate carboxylase (*rbcL*) kay ang mga molecular marker napakyas sa pagpares sa *D. leilamericanum* sa ubang klase sa *Dasymaschalon*. Sa tingub, ang mga resulta sa morphological ug molecular analysis nagpakita sa usa ka talagsaon nga evolutionary pathway alang sa *D. leilamericanum* uban sa iyang genus.

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INTRODUCTION

The forest of Cebu island in the Philippines, is home to several endemic species of flora and fauna (Cadiz & Buot 2010; Rosales et al. 2020). Several of the endemic species growing in this area are threatened due to deforestation and continued human pressure (Lillo et al. 2019, 2020, 2021). The forest fragments of Mount Lantoy Key Biodiversity Area (KBA) in Argao, Cebu, listed two Critically Endangered, two Endangered, four Vulnerable, and 16 restricted-range species (CI/DENR-PAWB/Haribon 2006). The Tabunan forest of the Central Cebu Protected Landscape (CCPL) is the largest forest fragment with an area of 40 ha. The Tabunan forest is home to the endemic *Cinnamomum cebuense* Kosterm and among the threatened species in spite its distribution range is within the protected landscape (Quimio 2006).

The genus *Dasymaschalon* is classified under the order Magnoliales of the family Annonaceae. It was initially considered to be a part of section Unona auct. non L. (Hooker & Thompson 1855). *Dasymaschalon* was classified as a section of *Desmos* Loureiro's (1790:352) *Desmos* sect by Hooker & Thomson (1855:134) and Safford (1912:507) Saff, *Dasymaschalon* (1912:507) (e.g. Sinclair 1955; Maxwell 1989; Li 1993). Many taxonomists such as Finet & Gagnepain (1906), Merrill (1915), Hutchinson (1923), Fries (1959), Bân (1975), Klucking (1986), Van Heusden (1992), Kebler (1993), Koek-Noorman et al. (1997), Sun et al. (2002) disagreed with the taxonomic treatment of Safford and supported Dalla Torre & Harms' decision to raise *Dasymaschalon* to the generic rank in 1901.

The genus *Dasymaschalon* is primarily found in southeastern Asia (Craib 1912; Merrill 1915; Sinclair 1955; Ast 1938; Tsiang & Li 1979; Bân 2000; Nurmawati 2003; Wang et al. 2009, 2012) particularly in southern China, Philippines, Indonesia, Malaysia, Thailand, and Indochina. Dalla-Torre & Harms (1901) estimated that *Dasymaschalon* (Hook & Thomson 1885) may have up to 30 species (Wang et al. 2009, 2012), with three (http://www.philippineplants.org/Families/Annonaceae.html) found in the Philippines and one in India. According to Guo et al. (2018), the genus *Dasymaschalon* is closely related to *Friesodielsia* Steenis *s.str.* (1948:458) and is morphologically distinct with small trees and shrubs (rarely climbers), shallow conical torus, 2–3-cohering petals arranged in one whorl, echinate ornamentation and pollen with thin exine (Walker 1971; Le Thomas 1980, 1981; Van Heusden 1992; Kebler 1993**;** Doyle & Le Thomas 2012).

While undertaking a field survey of flora on Mount Lantoy KBA of the Municipality of Argao (Image 1), we came across an interesting species of *Dasymachalon* which did not match other known species. In this paper, we describe a new species of *Dasymaschalon* from Mount Lantoy Key Biodiversity Area, Cebu Island, Philippines.

MATERIALS AND METHODS

Sampling site

The novel *Dasymaschalon* was collected during a field survey of flora on Mount Lantoy KBA of the Municipality of Argao (Image 1). Mount Lantoy is one of the new sites classified as a key biodiversity area (KBA) among the 117 terrestrial areas in the Philippines based on irreplaceability and vulnerability criteria (Mallari et al. 2001). These sites are inhabited by 16 restricted-range, four Vulnerable, two Endangered, and two Critically Endangered species (CI/DENR-PAWB/Haribon 2006).

Plant morphological characterization

Photographic records were taken, and voucher specimens were collected and subsequently deposited in the DOST-NICER Biodiversity Museum and University of San Carlos (USC)-Terrestrial Species Museum. The description of morphological characters of the species is based on fruit and vegetative traits (LAWG 1999; Pi et al. 2009; Masungsong et al. 2019; Hernandez et al. 2020) (Ngoc-Daido et al. 2018). The vegetative traits were examined and measured from seedlings and press-dried specimens while field characteristics were noted on the spot. Fruit traits were noted in both fresh specimens and those preserved in 70% ethanol.

The third mature leaves, which are the ones that are fully exposed to sunlight, were chosen as the leaf samples for characterization (Pi et al. 2009). The specimen's ten mature leaf samples were employed in the investigation. With a hand lens with greater magnification, the leaf samples were inspected. Based on the Leaf Architectural Working Group Manual, the leaf architecture was described (LAWG 1999). Following Masungsong et al. (2019) and Hernandez et al. (2020), petiole length width and leaf blade were measured using a digital caliper, and venation angles, base and apex were determined using a protractor. Additionally, herbarium specimens were analyzed using online photos of the type specimens (www.philippineplants.org.). Except where noted, every photo was taken outdoors where the species were located. The morphological analysis of variance was used

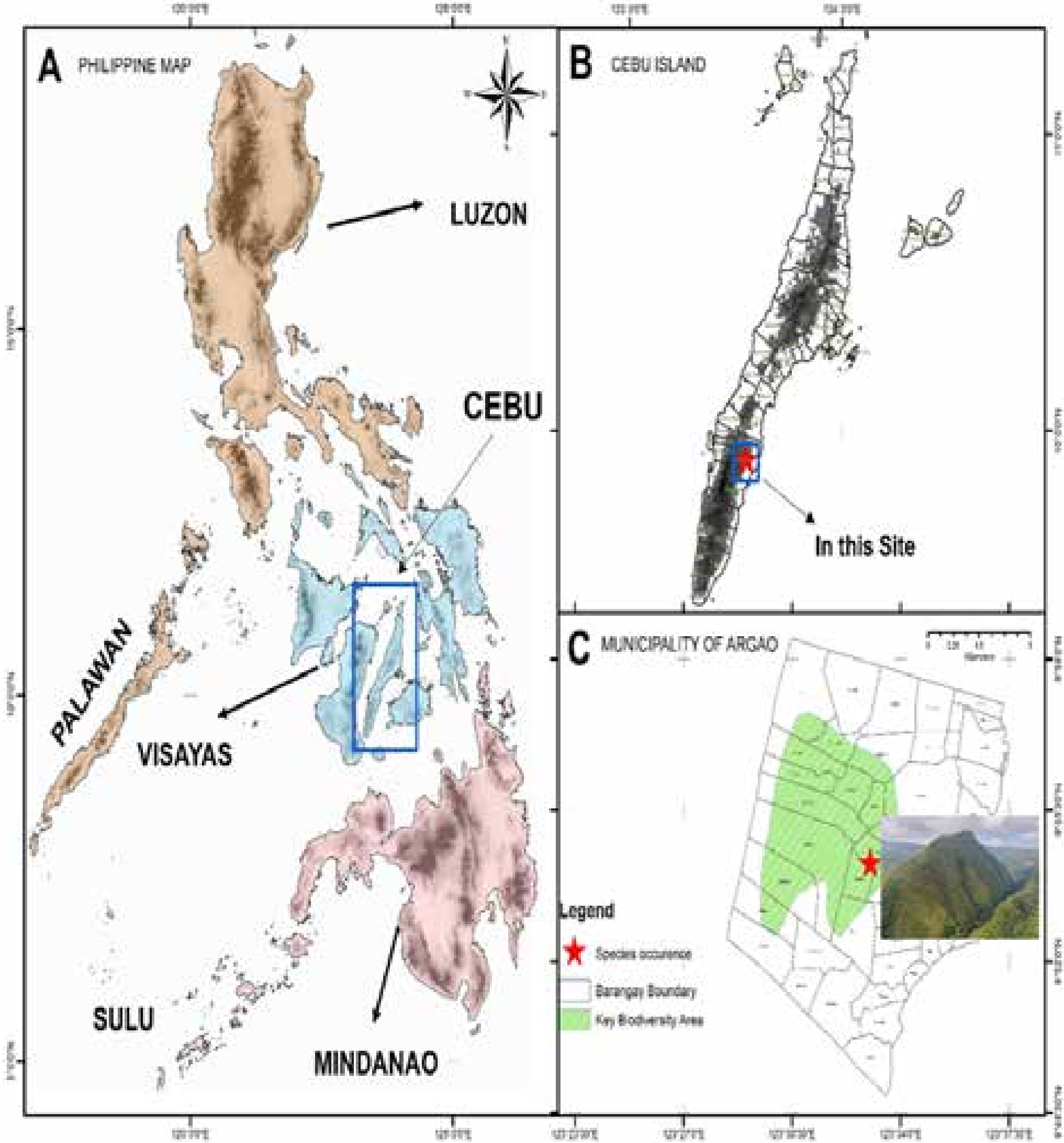

Image 1. Location of the new species in Mount Lantoy of the Municipality of Argao, Cebu at Philippine map (GIS generated map; Landsat 8; www.earthexplorer.usgs.ph; NAMRIA; Philippine GIS data). A—Philippine map and location of Cebu Island within the box | B—Cebu Island and location of the study site within the box | C—specimen collection site indicated by the star mark.

for the morphological traits of the *D. leilamericanum* and the related species (Meeran et al. 2023)

DNA Extraction, amplification, and sequencing

Chloroplast genomic DNA was extracted from dried leaves of the specimens collected from the study site using the QIAGEN DNeasy® Plant Mini Kit while sample cleanup was done using the QIAGEN DNeasy® PowerClean® Pro Cleanup Kit, following manufacturer's protocols, respectively. For amplification each 50 µl PCR contained 25 µl of MyTaq® HS Red Mix, 2x, 1 µl of each forward and reverse primer, 1 µl of DNA template, and 1 µl nuclease-free water (NFW). The respective thermal cycle conditions were 95^{0}C denaturation, 50^{0}C annealing, 70^{0}C, and 72^{0}C extension. A total of 12 samples were sent for sequencing at the facility of Macrogen, Inc., Seoul, South Korea.

For the molecular authentication of the new species, the most commonly preferred gene loci suggested by the Consortium for the Barcoding of Life (CBOL), maturase K (*matK*) and ribulose 1,5-biphosphate carboxylase (*rbcL*), were chosen as primers (Yu et al. 2011; Tran et al. 2021). These cpDNA were also used by Guo et al. (2018) in demonstrating the incongruence among different gene trees involving *Dasymaschalon* and other closely-related taxa. The forward and reverse primers used to amplify *matK* and *rbcL* genes were adopted from respective authors cited in de Vere et al. (2015). The primer sequence for the *matK*-forward (MatK-3FKIM-r) CGTACAGTACTTTTGTGTTTACGAG and *matK*-R (*matK*_1R_kim) ACCCAGTCCATCTGGAAATCTTGGTCC. The primer sequence for *rbcL*-forward (*rbcL*a-F) ATGTCACCACAAACAGAGACTAAAGC and *rbcL*-reverse (*rbcL*ajf634R) GAAACGGTCTCTCCAACGCAT.

Alignment and Phylogenetic Analyses

The complementary chromatogram reads from sequenced samples were checked and trimmed for quality control using Finch TV, then aligned to generate a consensus sequence using BioEdit software (CAP contig assembly). The consensus sequence was then reverse complemented followed by alignment with closelyrelated species in MEGA7 via MUSCLE (Edgar 2004). This is then followed by trimming of gaps between the sequences and deletion of sequences with common undefined base calls and sequences with relatively short alignment. There was also an addition of related plant species and/or replacement of different reference sequences in order to lengthen the generated alignment via MUSCLE. Using the same software, the Best Fit Model was determined via the Maximum Likelihood of the default setting (Model Selection ML – Automatic Neighbor-Joining Tree). The phylogenetic tree was then generated using the best model determined for the aligned sequences, and the test of phylogeny was set to bootstrap (1,000 replicates) and completion for gaps regardless of the method.

The sequences were submitted to nucleotide Basic Local Alignment Search Tools (BLAST) of the National Center for Biotechnology Information (NCBI) as well as to the Barcode of Life Database (BOLD) system for similarity checks and identification. Conversely, for further phylogenetic analyses and evolutionary tree construction, the *matK* and *rbcL* respective gene sequences of species belonging to all related genera in the family Annonaceae with *D. leilamericanum* were retrieved and accessed from GenBank® of the National Center for Biotechnology Information (NCBI) (Table 1). The *matK* and *rbcl* DNA sequences were submitted to NCBI for the application of accession numbers.

RESULTS AND DISCUSSION

The *D. leilamericanum* is described through morphological and molecular characterization. The morphological diagnostic characters used are plant habit, leaf pattern, apex of leaf, base, veins order and category, flower, petals, sepals, stamen, pedicels, fruits and monocarp, stalks, and seeds.

Morphological diagnostic characters

The analysis clearly showed that *D. leilamericanum* differs from other *Dasymaschalon* in having distinct morphological characteristics such as larger laminar size which belong to notophyll category (LAWG 1999) with leaf area ranging from 2,025–4500 mm^2, laminar length: width ratio of 4:1, vein orders; Leaf 10 vein category pinnately veined, 20 vein category festooned semicraspedodromous veined, agrophic veins simple, 20 vein spacing irregular, 20 vein angle smoothly decreasing toward the base, inter 20 veins weak inter-secondaries, 30 vein category alternate percurrent, 30 vein coarse sinuous, 30 vein angle to 10 obtuse, 30 vein angle variability inconsistent, 40 and 50 vein category regular polygonal reticulate, and the leaf areolation 5 or more sides. Fruit stalk (infructescence) 29 mm, axillary/terminal, Pedicels (per Monocarp) ranges 13–38 mm, Monocarps 50–60 pcs, ellipsoid 9–20 x 8–13 mm, pinkish to black color, 5–7 seeded/monocarp, embedded in pulpy tissue. Seed dimension 0.7–0.9 cm x 0.5–0.6 cm (Table 2; Images 2, 3, 4, & 5).

Taxonomy

***Dasymaschalon leilamericanum* Rosales & Lillo, sp. nov.**
(Images 2–6)

Type: Holotype: Lillo 00090 (CTU-DOST NICER Biodiversity Museum). Philippines, Cebu Island, Municipality of Argao, Mount Lantoy KBA (Lat. 9.904229, Long. 123.5513) at 99 m elevation (Image 1). The type specimen was located at the base of Mount Lantoy, along the river of Barangay Usmad, bearing multiple fruits, 2 March 2020.

Isotype: USCBM 2675 (University of San Carlos

Table 1. List of selected species used to reconstruct the phylogenetic tree for *Dasymaschalon leilamericanum* sp. nov. and their GenBank Accession information.

	Species	GenBank Accession	
		rbcL	*matK*
1	*Dasymaschalon leilamericanum* sp. nov.	**[PQ878320]**	**[PQ869009]**
2	*Dasymaschalon macrocalyx*	[AY841610.1]	[AB924891.1]
3	*Dasymaschalon clusiflorum*	[JQ768668.1]	[JQ768548.1]
4	*Dasymaschalon filipes*	[JQ768672.1]	[MH308078.1]
5	*Dasymaschalon ellipticum*	[JQ768670.1]	[JQ768550.1]
6	*Dasymaschalon oblongatum*	[JQ768679.1]	[JQ768559.1]
7	*Dasymaschalon megalanthum*	[JQ768678.1]	[JQ768558.1]
8	*Dasymaschalon longiflorum*	[JQ768675.1]	[MH308073.1]
9	*Dasymaschalon dasymaschalum*	[MT264015.1]	[MT264031.1]
10	*Dasymaschalon glaucum*	[JQ768673.1]	[JQ768553.1]
11	*Dasymaschalon acuminatum*	[MT264012.1]	[MT264028.1]
12	*Desmos dumosus*	[JQ768689.1]	[HG005013.1]
13	*Desmos chinensis*	[JQ762414.1]	[KP093298.1]
14	*Desmos polycarpus*	[KF496673.1]	[KX786589.1]
15	*Desmos elegans*	[HQ214067.1]	[JQ768571.1]
16	*Desmos cochinchinensis*	[JQ768688.1]	[OL604143.1]
17	*Friesodielsia desmoides*	[AY841618.1]	[JQ768577.1]
18	*Friesodielsia biglandulosa*	[MG896081.1]	[MG910438.1]
19	*Friesodielsia glauca*	[MG896051.1]	[MG910428.1]
20	*Schefferomitra subaequalis*	[KX786628.1]	[KX786606.1]
21	*Uvaria macrophylla*	[KP094324.1]	[KP093408.1]
22	*Uvaria concava*	[JN175197.1]	[JN175167.1]
23	*Uvaria cordata*	[JN175198.1]	[AB924906.1]
24	*Uvaria wrayi*	[FJ743821.1]	[AB924778.1]
25	*Uvaria siamensis*	[FJ743824.1]	[AB925067.1]
26	*Uvaria lucida*	[MN166687.1]	[MN166628.1]
27	*Melodorum fruticosum*	[AY319071.1]	[AB924724.1]
28	*Monanthotaxis micrantha*	[KX761331.1]	[KX761300.1]
29	*Monanthotaxis buchananii*	[JQ768700.1]	[JX517585.1]
30	*Monanthotaxis fornicata*	[JQ768702.1]	[JQ768583.1]
31	*Monanthotaxis montana*	[MF353789.1]	[MF353672.1]
32	*Monanthotaxis whytei*	[AY841635.1]	[EF179278.1]
33	*Cyathostema viridiflorum*	[AY841607.1]	[FJ743746.1]
34	*Cleistochlamys kirkii*	[JX572412.1]	[JX517486.1]
35	*Dielsiothamnus divaricatus*	[EU169759.1]	[KX146236.1]
36	*Meiocarpidium lepidotum*	[EU169754.1]	[EU169687.1]
37	*Mitrella kentii*	[AY841633.1]	[FJ743751.1]
38	*Monocyclanthus vignei*	[EU169765.1]	[EU169698.1]
39	*Ophrypetalum odoratum*	[EU169767.1]	[EU169702.1]
40	*Pyramidanthe prismatica*	[JN175193.1]	[JN175163.1]
41	*Toussaintia orientalis*	[EU169756.1]	[EU169689.1]

Image 2. Habitat and habit of *Dasymaschalon leilamericanum* sp. nov.: a—panoramic view of Mount Lantoy KBA | b— Argao river at the base of Mount Lantoy | c—Leaf arrangement | d–f—Habit of *Dasymaschalon leilamericanum* sp. nov. © John Lou Diaz.

Biological Museum).

Ecology: Near a height of 99 m, the species is found in creeks with thick vegetation at the foot of Mount Lantoy (Image 1). The Carcar formation dominates the Mount Lantoy KBA, which is defined as a forest over limestone habitat type. Its geological makeup is dominated by elevated sedimentary and metamorphic rocks, with limestone making up a sizeable portion of that composition (Audley-Charles et al. 1979).

The species was found 5 m from the river bed. The species associated with *Dasymaschalon leilamericanum* Rosales and Lillo at the type locality include, among many others, *Rapanea philippinensis* (A. DC.) Mez (Primulaceae), *Ficus benjamina* L. (Moraceae), *Bischofia javanica Blume* (Phyllanthaceae), *Guioa koelreuteria* (Blanco) Merr. (Sapindaceae), *Melicope triphylla* (Lam.) Merr. (Rutaceae), *Neonauclea calycina* (Bartl.) Merr. (Rubiacea), *Senna alata* (Fabaceae), *Schefflera obtusifolia* Merr. (Araliaceae), *Guioa acuminata* Radlk. (Sapindaceae), *Goniothalamus elmeri* Merr. (Annonaceae), *Semecarpus cuneiformis* Blanco (Anacardiaceae), *Vitex parviflora* Juss. (Lamiaceae), *Bridelia stipularis* Blume (Phyllanthaceae), and *Canarium asperum* Benth. (Burseraceae).

Distribution: Thus far, Mount Lantoy KBA in the Municipality of Argao, Cebu, is where this new species is known to exist (Image 1). *Dasymaschalon* species are widespread in forests and thickets at low and medium elevations, sometimes on limestone soil, according to Merrill (1923).

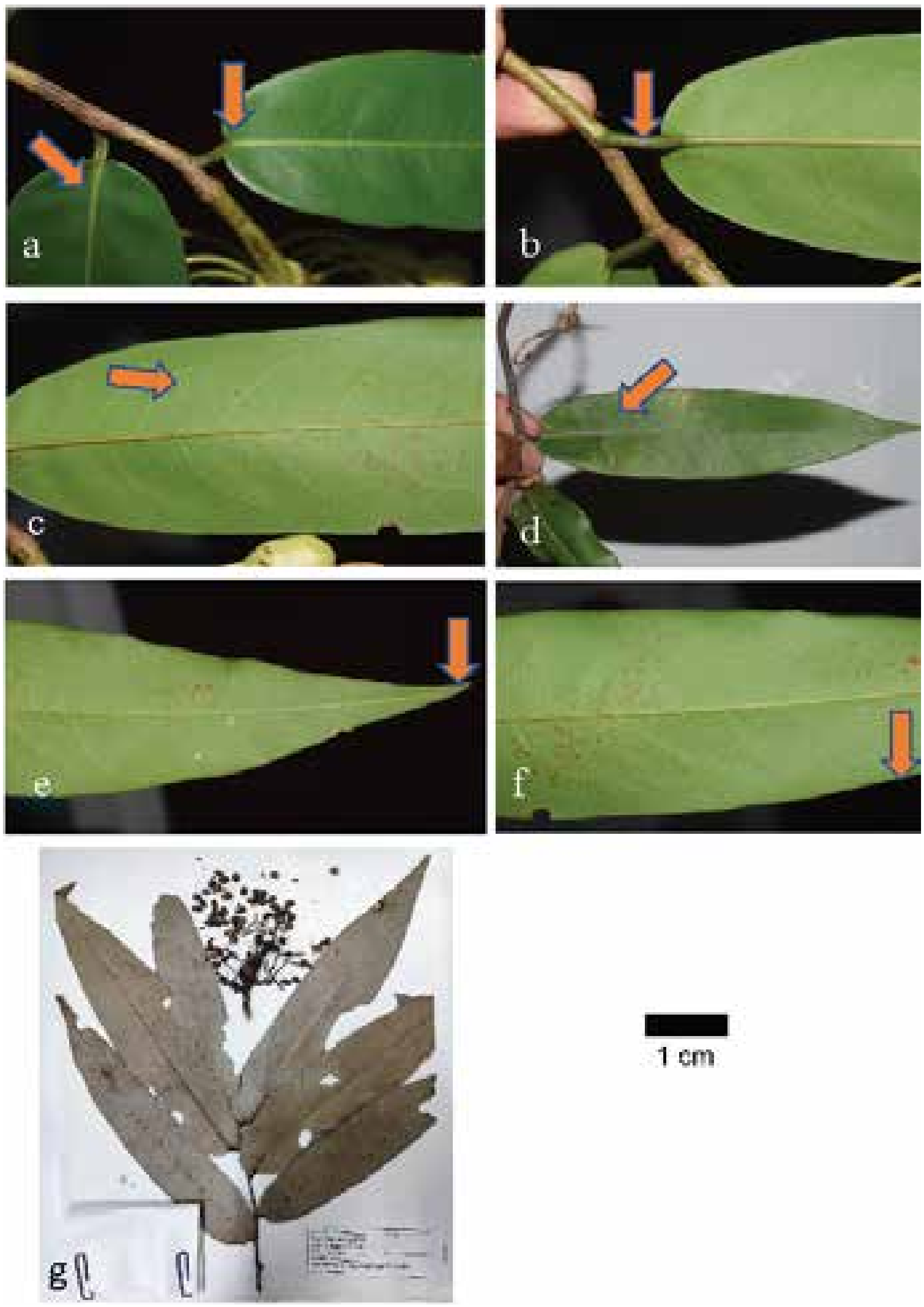

Image 3. Leaf morphology of *Dasymaschalon leilamericanum* sp. nov.: a—alternate leaf arrangement | b—swollen petiole | c—back surface (adaxial) | d—leaf surface (abaxial) | e&f—leaf apex (adaxial) | g—herbarium specimen. © John Lou Diaz.

Etymology: This new species is named in honor of Dr. Leila America who actively promoted biodiversity conservation in the Philippines. Dr. America was the former director of the Forestry and Environment Research Division (FERD), prior to her passing, of the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) under the Department of Science and Technology (DOST) of the Philippines.

This new species would add to the list of important species that serve as the basis for the protection and conservation of the mountain as a habitat for the endemic species of Cebu Island. Pelser & Barcelona (2017) recorded the 'Critically Endangered' *Cynometra cebuensis* species in Mount Lantoy KBA. Other endemic species include *Copsychus cebuensis* Steere, 1890 (Malaki et al. 2018) and *Anixa zebuensis* Broderip, 1841 (Rosales et al. 2020).

Image 4. Fruiting habit of ***Dasymaschalon leilamericanum*** sp. nov. © John Lou Diaz.

Image 5. Fruits and Seeds of ***Dasymaschalon leilamericanum*** sp. nov. © John Lou Diaz.

Table 2. Morphological comparison of *Dasymaschalon leilamericanum* sp. nov., *Dasymaschalon clusiflorum* (Merr.) Merr, *Dasymaschalon filipes* (Ridl.) Ban.*Dasymaschalon ellipticum* Nurmawati, and *Dasymaschalon blumei* (Finet & Gagnep 1906; Nurmawati 2003).

Plant Morphology (LAWG 1999)	*Dasymaschalon leilamericanum* sp. nov.	*Dasymaschalon clusiflorum* (Merr.) Merr.	*Dasymaschalon filipes* (Ridl.) Ban	*Dasymaschalon ellipticum* Nurmawati	*Dasymaschalon blumei* Finet & Gagnep
Habit	Small tree 5 m in height.	Small tree up to 10 m high.	Small trees, 5 m high. Branches glabrous	Small trees up to 5 m. Branches glabrous	Branches are either tomentose or glabrous and either a shrub or a small tree with a height of 6 m.
Leaf pattern	Simple and alternate in arrangement, petiolar attachment marginal and swollen appearance, glabrous, lamina chartaceous to sub coriaceous, laminar size notophyll with leaf area ranges from 2,025–4500 mm^2, laminar shape lanceolate, symmetrical, leaf margin entire and wavy	Petiole range is 1–2 x 7–15 mm, it is glabrous; ellipsoidal, lamina can be chartaceous and some are sub coriaceous, ellipsoidal in shape and narrow, some can be lanceolate or can be ellipsoidal while others can be broad, laminar size notophyll with leaf area ranges from 5.5–23.7 x 1.3–9 cm, pale on the lower surface; and glabrous in all sides including the midrib.	Petiole ranges from 9–17 x 2–3 mm; lamina is characterized with sub coriaceous or can be chartaceous, it is oblanceolate in shape or can be ellipsoidal, leaf area ranges from 16.5–35 x 5–9 cm. glaucous in the lower surface,	Petiole ranges from 10–17 x 3 mm, described as glabrous; sub-coriaceous for the lamina, oblong in shape, leaf area ranges from 17.5–33.6 x 4–9.6 cm, glaucous in the lower surface and glabrous in all sides in the midrib.	Petiole ranges from 2–3 x 3–5 mm, thickly tomentose or can be glabrous, covered mostly by a leaf base; lamina can be sub coriaceous or some can be chartaceous, leaf area ranges from 9–31 x 4–10 cm, oblanceolate
Apex of Leaf	Apex angle is acute; shape can be acuminate	Apex acute and can be shortly acuminate	Apex acute to acuminate	Apex acute or acuminate	Apex acute, shortly to abruptly acuminate
Base	Base angle obtuse, and base shape rounded	Base cuneate to subrounded	Base rounded	Base cuneate to sub rounded	Base cordate
Veins order					
1^0 vein category	Pinnately veined	Pinnately veined	Pinnately veined		Pinnately veined
2^0 vein category	2^0 vein category festooned semicraspedodromous, 12–14 pairs, agrophic veins simple, 2^0 vein spacing irregular, 2^0 vein angle smoothly decreasing toward the base, inter 2^0 veins weak inter-secondaries	Secondary veins slender raised above, curved, 6–12 pairs, including with the midrib an angle of about 35–55 degree, glabrous; lateral veins anastomosing inconspicuous	Secondary veins slender raised above, curved, including with the midrib an angle of about 55–60 degree, 14–17 pairs; lateral veins anastomosing inconspicuous.	Secondary veins slender raised above, glabrous, curved, 13–19 pairs, including with the midrib an angle of about 50–60 degree; lateral veins anastomosing.	Secondary veins faint, curved, 10–14 pairs, midrib an angle of about 35–55^0, glabrous or densely tomentose; lateral veins anastomosing inconspicuous
3^0 vein category	3^0 vein category alternate percurrent, 3^0 vein coarse sinuous, 3^0 vein angle to 1^0 obtuse, 3^0 vein angle variability inconsistent,	Tertiary veins reticulate.	Tertiary veins are scalariform.	Tertiary veins scalariform	Tertiary veins are scalariform.
4^0 and 5^0 vein category	4^0 and 5^0 vein category regular polygonal reticulate, and the leaf areolation 5 or more sides.				
Flower	Unknown	Axillary or terminal, single, seldom raceme two –six flowers.	Flowers unknown	Solitary, some can be raceme with three–five flowers	Axillary or terminal, solitary, seldom raceme with two–four flowers.
Petals	Unknown	Three coriaceous, ovate, triangular, lanceolate or rhomboid petals, with or without a distinct claw, 1.2–11 x 1–2.4 cm, thick 0.5–3 mm, a sharp or directly acuminate apex, valvate reduplicate, and puberulent.	Petals unknown	Petals 3, coriaceous, linear lanceolate, 3.3–7 cm x 0.8–1.2 mm, thick c. 1mm, apex described as sharp, with valvate reduplicate, not clearly defined claw, and velutinous.	Three–four petals, some are coriaceous others can be sub-coriaceous, it is lanceolate, size range is 3.5–7 x 1.5–2.4 cm, thickness is 0.5–1 mm, apex described as valvate reduplicate, and acuminate
Sepals	Unknown	Sepal is predominantly ovate, size ranges from 2–4 x 2–5 mm, apex can either be acuminate or acute, rarely pubescent.	Sepal is predominantly ovate, c. 3 x 4 mm, apex acuminate, sparsely pubescent	Sepal is predominantly ovate c. size range is 3–4 x c. 2 mm, apex can be rarely pubescent, and mucronate.	Triangular sepal with size ranges from c. 4 x 4–5 mm, apex van be densely pubescent, sparsely tomentose or acuminate

Plant Morphology (LAWG 1999)	*Dasymaschalon leilamericanum* sp. nov.	*Dasymaschalon clusiflorum* (Merr.) Merr.	*Dasymaschalon filipes* (Ridl.) Ban	*Dasymaschalon ellipticum* Nurmawati	*Dasymaschalon blumei* Finet & Gagnep
Stamen	Unknown	Stamens 2–4 mm x c. 0.5–1mm, apex discoid, glandular dots absent.	Stamens unknown	Stamens size ranges from 23 x c. 1 mm, described as convex apex with the presence of dotted glandular	Stamens 4 x 1 mm, apex convex, glandular dots absent
Pedicels	3–4 cm long	Pedicel 1.2–4.2 cm x 1–2 mm, glabrous.	Pedicel 19–33 cm x c. 1mm, glabrous (bearing carpidia).	Pedicel ranges from c. 1 mm x 1.5–2 cm and described as glabrous.	Pedicel rangers from 3.4–15 cm x 1.5–2 mm, predominantly tomentose or densely pubescent, and glabrous
Fruits	Axillary or terminal	Axillary or terminal	Axillary or terminal	Axillary or terminal	Axillary or terminal
Monocarps	30–50, ellipsoid 9–20 x 8–13 mm, pinkish to black color	Ranges from 20–50 and described as globose, with size ranges from 7–17 x 5–8 mm	Ranges from 20–35, ellipsoid, with size ranges from 10–14 x 7–9 mm.	Ranges from 20–30, described as ellipsoidal to sub globose, size ranges from 7.5–10 x 6–7.5 mm	Monocarps 7–30
Stalks	Stalks 13 x 38 mm glabrous	Size ranges 8–21 x 1–2 mm, described as rarely pubescent to glabrous	Size ranges from 8–22 x c. 0.5 mm, described as rarely pubescent.		Rarely pubescent, seldom glabrous, size ranges from 4–15 x 1–2 mm
Seeds	5–7 seeds, ellipsoid, embedded in pulpy tissue. Seed dimension 0.7–0.9 cm x 0.5–0.6 cm.	Granulate with 1 (-2) seeds, rarely pubescent to glabrous	Granulate with 1(–2) seeds, villous apiculum, and rarely pubescent.	1(–2) seeds, slightly smooth, glabrous.	Granulate with 2–7 seeds, described as ellipsoidal but seldom globose on each of its segment, size ranges from 7–9 x 5–8 mm.

Table 3. Maximum likelihood fits of 24 different nucleotide substitution models for the matK genes sequences aligned for *Dasymaschalon leilamericanum* sp. nov.

Model	#Parameter	BIC	AICc	lnL	Invariant
T92	77	4397.269592	3755.961766	-1800.758018	n/a
T92+G	78	4388.799433	3749.29861	-1796.420642	n/a
T92+I	78	4389.896853	3750.39603	-1796.969352	0.456754048
T92+G+I	79	4399.004029	3751.310358	-1796.420645	9.76544E-06
HKY	79	4406.668791	3758.97512	-1800.253025	n/a
HKY+G	80	4407.962061	3752.075691	-1795.797364	n/a
HKY+I	80	4409.135406	3753.249036	-1796.384037	0.454509194

Table 4. Maximum Likelihood fits of 24 different nucleotide substitution models for the rbcL genes sequences aligned for *Dasymaschalon leilamericanum* sp. nov.

Model	#Parameter	BIC	AICc	lnL	Invariant
K2	64	3048.949444	2546.264332	-1208.914456	n/a
T92	65	3050.818567	2540.285826	-1204.918388	n/a
K2+G	65	3052.503191	2541.97045	-1205.7607	n/a
K2+I	65	3053.728609	2543.195868	-1206.373409	0.45697074
T92+G	66	3054.534347	2536.154189	-1201.845649	n/a
T92+I	66	3055.717657	2537.3375	-1202.437304	0.45697074
K2+G+I	66	3062.2175	2543.837343	-1205.687226	9.24534E-06

Table 5. Multivariate analysis of morphological data *Dasymaschalon leilamericanum* sp. nov..

Plant morphology (LAWG 1999)	SS	df	MS	F	P-value	FCrit
Habit	94.49	4	23.62	45.2	0.00	2.87
Leaf pattern	17935657	4	4483914	4.52	0.00	2.87
2^0 vein category	189.2	4	47.3	13.75	0.00	2.87
Pedicels	2457.68	4	614.42	19.07	0.00	2.87
Monocarps	2290.24	4	572.56	6.23	0.00	2.87
Stalks	4109.44	4	1027.36	5.58	0.00	2.87
Seeds	96.56	4	24.14	23.21	0.00	2.87

Conservation Status: The new species *Dasymaschalon leilamericanum* is known only in limestone forest of Mount Lantoy along the river, at an elevation of 99 m. Merrill (1923) designated the three *Dasymaschalon* species found in the Philippines (www.philippineplants.org) as endemic to the country, just like this new species. The *Dasymaschalon clusiflorum* (Merr.), described as endemic in the Philippines, was designated as Least Concern (LC) based on the IUCN Redlist (2020–2) (https://www.iucnredlist.org/search?q%20uery=dasymaschalon&searchType=species).

The morphological comparison between *Dasymaschalon leilamericanum* (a newly described species) and closely related species—*Dasymaschalon clusiflorum* (Merr.) Merr., *Dasymaschalon filipes* (Ridl.) Ban., *Dasymaschalon ellipticum* Nurmawati, and *Dasymaschalon blumei* Finet & Gagnep—reveals significant differences across various plant characteristics (Meeran et al. 2023) (Table 5). The p-values for the traits Habit, Leaf pattern, 20 vein category, pedicels, monocarps, stalks, and seeds are all p-value is 0.00, indicating highly significant morphological divergence between *D. leilamericanum* and the other species. These differences suggest *D. leilamericanum* is a distinct species within the genus *Dasymaschalon*, with its own set of ecological adaptations and evolutionary characteristics. The morphological traits that set *D. leilamericanum* apart provide valuable insights into its functional ecology, reproductive success, and evolutionary history, helping to further refine its taxonomic status and improve our understanding of its role within its habitat.

Molecular Analyses

Model Selection for *matK* and *rbcL* genes

Models with the lowest BIC scores (Bayesian Information Criterion) were considered to describe the substitution pattern the best. For each model, the AICc value (Akaike Information Criterion, corrected), the maximum likelihood value (lnL), and the number of parameters (including branch lengths) are also presented (Nei & Kumar 2000). Non-uniformity of evolutionary rates among sites may be modeled by using a discrete Gamma distribution (+G) with five rate categories and by assuming that a certain fraction of sites are evolutionarily invariable (+I). Whenever applicable, estimates of gamma shape parameters and/or the estimated fraction of invariant sites were shown. Assumed or estimated values of transition/transversion bias (R) were shown for each model, as well. They were followed by nucleotide frequencies (f) and rates of base substitutions (r) for each nucleotide pair. Relative values of instantaneous r should be considered when evaluating them. For simplicity, the sum of r values is made equal to 1 for each model. For estimating ML values, a tree topology was automatically computed. The analysis involved 39 nucleotide sequences. Codon positions included were $1^{st}+2^{nd}+3^{rd}$+Noncoding. All positions containing gaps and missing data were eliminated. There was a total of 693 positions for *matK* genes and a total of 581 positions for *rbcL* genes in the final dataset (Tables 3 & 4). Evolutionary analyses were conducted in MEGA7 (Kumar et al 2016).

Phylogenetic relationships

The study represents the first molecular analysis of *Dasymaschalon* in Cebu Island, Philippines. As shown in reconstructed phylogenetic tree of the *matK* and *rbcL* gene sequences (Figures 1 & 2), *D. leilamericanum* sp. nov. is a new species molecularly related to *Uvaria* species as with other *Dasymaschalon* species. The position of *D. leilamericanum* sp. nov. in the phylogenetic tree is not unusual. Wang et al. (2012) and Guo et al. (2018) described this non-monophyletic characteristic of *Dasymaschalon*, particularly with regards to cpDNA genes. As also suggested by Guo et al. (2018), the incongruence of *Dasymaschalon* might be a result of hybridization with closely-related genera.

The evolutionary history using the *matK* and *rbcL*

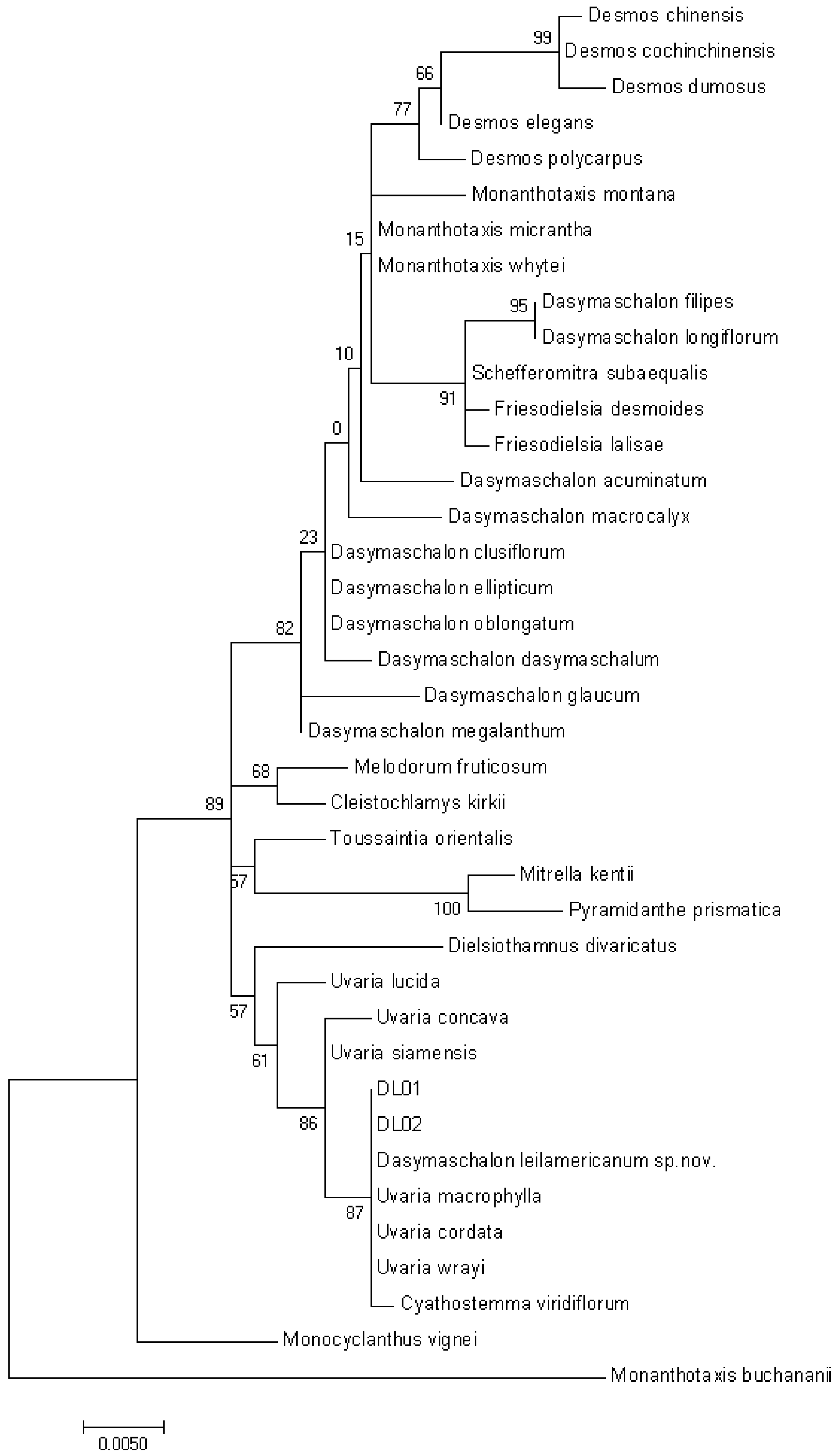

Figure 1. Molecular Phylogenetic analysis of the matK gene sequences aligned for *Dasymaschalon leilamericanum* sp. nov. by maximum likelihood method via Tamura 3-parameter model.

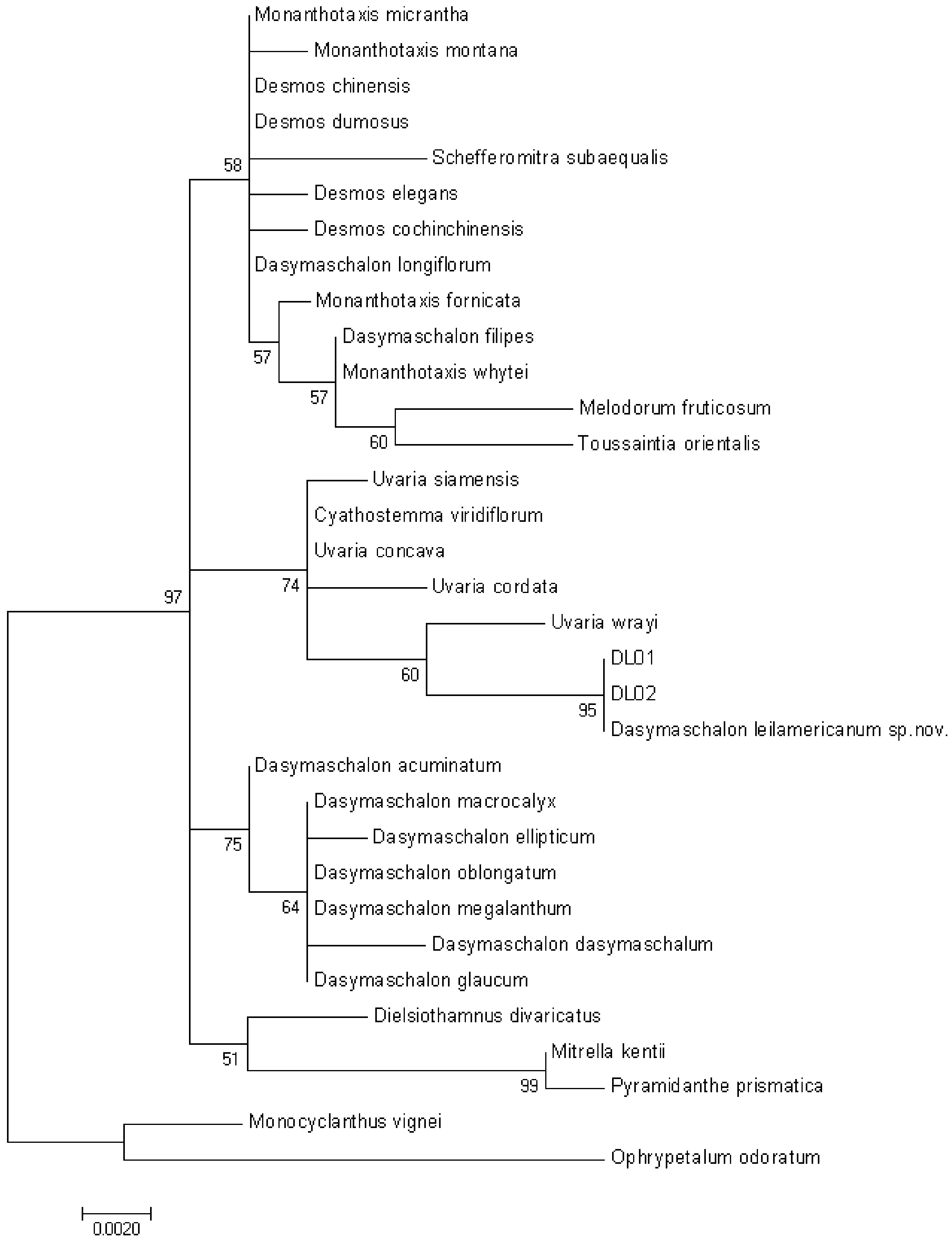

Figure 2. Molecular Phylogenetic analysis of the rbcL gene sequences aligned for *Dasymaschalon leilamericanum* sp. nov. by maximum likelihood method via Kimura 2-parameter model.

genes were inferred by using the Maximum Likelihood method based on the Tamura 3-parameter model (Tamura 1992) (Figures 1 & 2). The tree with the highest log likelihood (-1796.97) for *matK* gene and (-1208.91) for *rbcL* gene were shown (Table 3 & 4). The percentage of trees in which the associated taxa clustered together is shown next to the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pairwise distances estimated using the Maximum Composite Likelihood (MCL) approach and then selecting the topology with superior log likelihood value. The tree is drawn to scale, with branch lengths measured in the number of substitutions per site. Evolutionary analyses were conducted in MEGA7 (Kumar et al 2016).

The phylogenetic analyses of Couvreur et al. (2011) are in agreement with the inferred association of *Dasymaschalon* with another clade, containing species from the genera *Uvaria* and *Cyathostemma*, and the clade made up of species from the genera *Monanthotaxis*, *Melodorum*, and *Desmos*. The majority of *Dasymaschalon* species (*D. macrocalyx, D. clusiflorum*, and *D. ellipticum*) belong to a single, monophyletic group that is strongly supported. The *D. leilamericanum* demonstrated non-monophyly as it is more closely related to genus *Uvaria* than to the major clade of *Dasymaschalon* or with the clade of *Desmos* and *Monanthotaxis*.

According to Wang et al. (2012), certain Annonaceae species showed some degree of evolutionary flexibility in their morphological differences. A unique example of evolutionary adaptability may be seen in the pollination chamber of the flower in *Dasymaschalon*. Wang et al. (2012) also noted that some *Dasymaschalon* species (*D. tibetense, D. filipes*, and *D. longiforum*) belong to a distinct clade that is closely connected to Asian *Friesodielsia* species. This clade is distinct from the clade that contains the majority of *Dasymaschalon* species. The non-monophyly of the three species indicates a parallel evolution with another lineage where morphological convergence occurs (Zander 2008). The fundamental idea that all species are monophyletic restricts the ability of other species to evolve and their history to be complicated, which could lead to an underestimation of variability within and among closely related taxa (Alström et al. 2011).

CONCLUSION AND RECOMMENDATION

A new species of *Dasymaschalon* (Annonaceae), *Dasymaschalon leilamericanum,* is described and illustrated with diagnostic characters. Several notable morphological characters are the larger laminar size which belong to notophyll category with an area ranges from 2,025–4,500 mm^2, laminar length : width ratio of 4:1, 2^0 vein festooned semicraspedodromous, agrophic vein simple, 2^0 vein spacing irregular, 2^0 vein angle smoothly decreasing toward the base, inter 2^0 veins weak intersecondaries, 3^0 vein category alternate percurrent, 3^0 vein coarse sinuous, 3^0 vein angle to 1^0 obtuse, 3^0 vein angle variability inconsistent, 4^0 and 5^0 vein category regular polygonal reticulate, and leaf areolation five or more sides, Monocarps 50–60, ellipsoid 9–20 x 8–13 mm, pinkish to black color, longer fruit pedicel, and 5–7 ellipsoid seeds/monocarp. The significant differences observed in the plant morphology of *D. leilamericanum* compared to *D. clusiflorum, D. filipes, D. ellipticum*, and *D. blumei*—as indicated by the p-values of 0.000 across key morphological traits (Habit, leaf pattern, 2^0 vein category, pedicels, monocarps, stalks, and seeds) suggest that *D. leilamericanum* is a distinct species within the *Dasymaschalon* genus. These differences highlight the species' unique adaptations to specific ecological conditions, reproductive strategies, and evolutionary pathways. Phylogenetic trees of *matK* and *rbcL* genes showed that *D. leilamericanum* did not match to any species under *Dasymaschalon* but it is closer to genus *Uvaria*. Although the *D. leilamericanum* shares some morphological characteristics with other *Dasymaschalon* species, genetically it is closer to another genus thus the non-monophyletic characteristic exhibited in the phylogenetic tree is unexpected. The DNA barcode established in this study can help enrich the literature on molecular data of Philippine flora. The Mt. Lantoy KBA in Argao, Cebu, Philippines, is becoming a hotspot for biodiversity conservation with the addition of new species. It is recommended that future studies on phylogenetic analyses be conducted on other *Dasymaschalon* species found in the Philippines to understand its intergeneric relationships, endemicity, and evolutionary history.

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ARTICLE

Association analysis of *Castanopsis tungurrut* and the neighboring vegetation community in Cibodas Biosphere Reserve, Indonesia

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Abstract: *Castanopsis tungurrut* (Blume) A.DC. (Fagaceae) is an endangered species, specifically found in the tropical forests of Java and Sumatra. There is currently a lack of specific information regarding its interactions with other species across different life stages and natural habitats, particularly in relation to altitudine gradients. This study is aimed at investigating the relationship between *Castanopsis tungurrut* and the adjacent vegetation during different stages of its life cycle. The study also analyses the impact of this association on vegetation dynamics and propose effective strategies for *C. tungurrut* conservation strategy. The study established 41 plots across four distinct sites within the Cibodas Biosphere Reserve located in Gede Pangrango National Park. Identification of trees, poles, saplings, and wildings was carried out using the nested sampling method. A comprehensive list of 153 tree, 104 pole, 135 sapling, and 111 wilding species was documented and paired with *C. tungurrut* for association test, and a positive association was observed with the tree species *Casearia coriacea* and the wilding species *Symplocos costata* (Jaccard indices for these pairings were 0.34 and 0.33, respectively). In addition, a negative association was found for trees of *C. tungurrut* with *Castanopsis javanica* and *Macropanax dispermus*; Jaccard indices for pairings were 0.17 and 0.18, respectively. It was noted that *C. tungurrut* exhibited lower competitive ability and selectivity in less favorable habitats, and its facilitative effect on the surrounding vegetation was limited. The prevalence of negative association with neighbouring vegetation within the natural forest of Cibodas Biosphere Reserve indicates that *C. tungurrut* is isolated and facing threats such as environmental stress and competition. This condition contributes to the forest's overall diversity and promotes the sustainability of the reserve by enhancing ecosystem stability.

Keywords: Altitudine gradients, endangered species, Fagaceae, Gede Pangrango National Park, life stages, nested sampling method, natural habitats, plant community, tropical forests.

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Author contributions: DRN—proposed the objectives, methods and conducted fieldwork. He analysed data sets, wrote the paper and oversee the final drafting and publication. IEBJr—commented on the proposed objectives and methods. He actively participated in the analysis of data sets and contributed to the discussion of results, ensuring that the paper is acceptable for publication

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INTRODUCTION

Castanopsis tungurrut tends to grow independently and shows selectivity in its habitat preferences. A previous study on the association of *Castanopsis* species in remnant forests found a positive association between *C. tungurrut* and *C. javanica* in the sapling stage, while wildings and mature trees were absent (Nurdiana & Buot 2021). The association and interactions among plants are primarily driven by environmental conditions (Anthony & Germino 2023; Senthilnathan & D'Andrea 2023). In extreme conditions, plant interactions are facilitated, while in milder conditions, competition arises (Díaz-Borrego et al. 2024).

Understanding the interspecific relationships between dominant species can provide insights into the structure, function, development, maintenance, and succession of natural forests. Interspecific associations reveal habitat preferences and the mutual attraction or repulsion of co-occurring species in specific environments (Song Jin et al. 2015). Limited research has been conducted on the interspecific relationships between native species in the Cibodas Biosphere Reserve forest, and there is no clear evidence of how these associations influence dynamic processes in forests. Baokun et al. (2019) indicated that a higher diameter class of a given species pair leads to a lower positive-to-negative association ratio, suggesting that these relationships occur during the successional stage of a forest rather than in its mature state.

The ecological role of the native species *C. tungurrut* in the Cibodas Biosphere Reserve forest remains poorly understood and subject to debate. Therefore, gaining a better understanding of its function can contribute to the knowledge of the forest vegetation's condition and the impact of interspecific relationships involving *C. tungurrut* on the forest's structure. This study aims to examine the interspecific relationships of *C. tungurrut*, specifically its interactions with neighboring plants and its contributions to the dynamics of the forest community. Specifically, the study investigates the following: 1) interspecific association between *C. tungurrut* and neighbouring vegetation at tree, pole, sapling, and wilding stages; 2) type of association between *C. tungurrut* with neighbouring vegetation in various life stages; 3) preferred forest type for *C. tungurrut*; 4) importance of association of *C. tungurrut* in species conservation strategies. These outcomes are expected to advance the understanding of vegetation dynamics and support the design of sustainable management strategies for *C. tungurrut* in Cibodas Biosphere Reserve.

MATERIALS AND METHODS

A total of 41 plots, covering an area of 16,400 m^2 or 1.64 ha, were assessed in this study, which was conducted within the core zone in four locations: Cibodas, Bodogol, Cisarua, and Selabintana (Image 1).

Species sampling

A nested plot technique involving different plot sizes for different vegetation categories was employed for the study. The main plots had dimensions of 20 × 20 m and were used to measure trees. Within each main plot, smaller plots of 10 × 10 m were established for poles, 5 × 5 m for saplings, and 2 × 2 m for wildings. These plots were set up along an altitude gradient ranging 750–1,800 m, and their coordinates were recorded using a GPS Garmin e-trex 10. The number of plots established varied based on the location, elevation, and topography of the area. Specifically, there were 10 plots for Bodogol, 14 plots for Cibodas, eight plots for Cisarua (Image 2), and nine plots for Selabintana forest In each plot, the name and number of species present across different vegetation categories, including wildings, saplings, poles, and trees were recorded. Trees were defined as woody plants taller than 2 m with a stem diameter of at least 5 cm. Poles were categorized as stands with a diameter greater than 2.5 cm but less than 5 cm (Newton 1988; Fathia et al. 2019). Saplings were stands with a diameter at breast height (DBH) less than 2.5 cm and a height of at least 130 cm, while wildings referred to individuals with a height below 130 cm (Vargas-Rodriguez et al. 2005).

Interspecific association measurement

To examine the association between species, the presence and absence of each species were recorded, following the approach used by Song jin et al. (2015). The association coefficient (AC) was then calculated using a 2 × 2 contingency table to quantify the interspecific association for each pair of species. Statistical tests, including chi-square (x^2) and Jaccard's association index, were performed on the data (Pielou 1972; Dogra et al. 2009). This association analysis was conducted for all recorded species across all locations.

Data analysis

The vegetation at the research site was analyzed using the Shannon-Wiener Diversity index and evenness indices. In the analysis, a 2 × 2 contingency table, chi-square test, and Jaccard index were utilized to determine the condition of the natural forest where the *Castanopsis* species occurred.

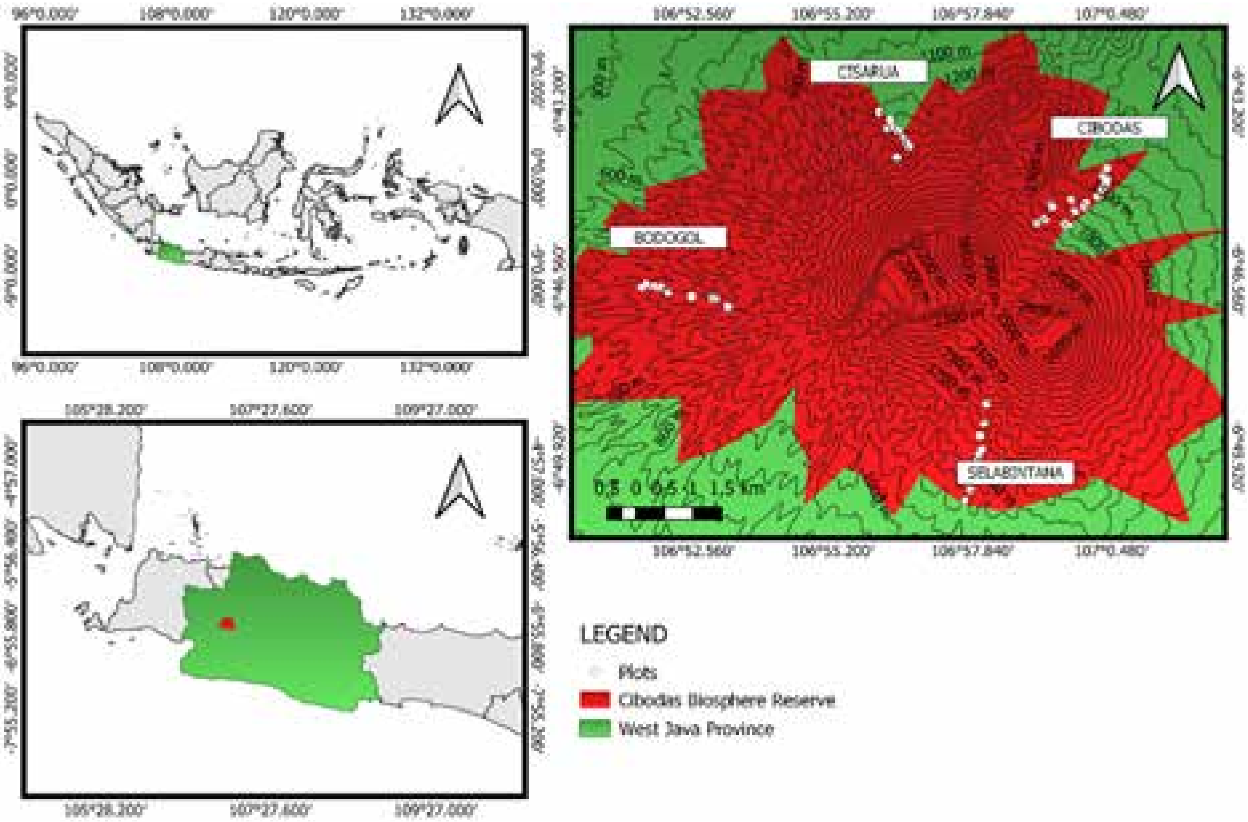

Image 1. Map of established plot in Cibodas Biosphere Reserve (https://earth.google.com/web, https://www.gedepangrango.org). The maps were generated by QGIS version 3.16.

Association coefficient using 2 x 2 contingency table

		Species Y: Present	Species Y: Absent	
Species X	Present	a	b	$a+b$
	Absent	c	d	$c+d$
		$a+c$	$b+d$	

To test the null hypothesis of independence of the 2 × 2 table, the chi-square test statistic was used.

The formula for chi-square (x^2) test

$$x^2 = \frac{[a - E(a)]^2}{E(a)} + \frac{[b - E(b)]^2}{E(b)} + \frac{[c - E(c)]^2}{E(c)} + \frac{[d - E(d)]^2}{E(d)}$$

$$E(a) = \frac{(a+b)(a+c)}{n} \quad E(b) = \frac{(a+b)(b+d)}{n}$$

$$E(c) = \frac{(a+c)(c+d)}{n} \quad E(d) = \frac{(b+d)(c+d)}{n}$$

a >E (a) refers to positive association type,a <E (a) to negative association type, x^2 test >x table to associated and x^2 test <x table not associated, and x table 3.84.

Jaccard index computation

$$Sj = \frac{a}{a+b+c}$$

a refers to the number of species in both sites; *b* refers to the number of species in the second site; *c* refers to the number of species in the first site. The data obtained were then analysed using chi-square analysis.

RESULTS

The diversity and occurrence of *C. tungurrut*

The nested sampling method was employed for vegetation analysis, in order to collect data on density, diversity index, evenness index, and occurrence of *C. tungurrut* across different life phases in 41 sampling plots (Table 1).

Data presented in Table 1 showed that *C. tungurrut* occurs at 750–1,500 m elevation at all four locations selected in the study. But, the occurrence of this tree species varies in its life stages at each location. Its wildings are present only at Bodogol and Selabintana locations while its mature individuals occur in all four locations indicating that each location has a dynamic

Table 1. Diversity of vegetation and the occurrence data of *Castanopsis tungurrut* in all life stages at Cibodas Biosphere Reserve. BDL = Bodogol, CBS—Cibodas, SBL—Selabintana and CSR—Cisarua, 1—present, 0—absent.

		Tree	Pole	Sapling	Wilding
Number of species		153	104	135	111
Diversity index		4.3	4.2	4.3	3.9
Evenness index		0.48	0.65	0.5	0.5
Locations					
Sampling plot	Altitude (m)				
BDL10	750	1	0	0	0
BDL3	823	1	0	0	0
BDL2	857	1	1	0	0
BDL1	931	1	0	0	0
BDL9	950	1	0	1	0
BDL8	1000	1	0	0	1
BDL7	1039	1	0	0	0
BDL6	1050	1	0	0	0
BDL5	1080	0	0	0	1
BDL4	1104	1	0	0	1
CSR8	1157	1	0	0	0
SBL9	1163	0	1	1	0
SBL8	1205	0	1	0	0
CSR7	1219	1	0	0	0
CSR6	1264	1	0	0	0
SBL7	1300	0	0	1	1
CSR1	1306	1	0	1	0
CBS14	1346	1	0	0	0
CSR2	1350	0	0	1	0
CBS13	1373	1	0	0	0
SBL1	1387	1	0	0	0
CBS12	1403	1	0	1	0
CSR3	1413	1	1	0	0
SBL2	1459	1	0	0	1
CSR4	1461	1	0	0	0
CBS11	1465	1	0	0	0
CBS10	1479	0	1	0	0
CSR5	1500	1	0	1	0
SBL6	1500	0	0	0	0
CBS9	1550	0	0	0	0
CBS8	1600	0	0	0	0
SBL5	1600	0	0	0	0
CBS7	1700	0	0	0	0
SBL4	1717	0	0	0	0
CBS5	1720	0	0	0	0
CBS6	1739	0	0	0	0
CBS3	1793	0	0	0	0
CBS1	1806	0	0	0	0
CBS2	1807	0	0	0	0
SBL3	1829	0	0	0	0
CBS4	1830	0	0	0	0

role in the regeneration of this tree species.

Interspecific association

The chi-square analysis compared *C. tungurrut* with 153 tree species, resulting in the identification of the top ten species pairs based on the highest chi-square values (Table 2). The findings revealed that out of all the pairs examined, only three pairs involving different tree life stages showed associations: *C. tungurrut* × *C. javanica*, *C. tungurrut* × *Macropanax dispermus*, and *C. tungurrut* × *Casearia coriacea*. The remaining pairs did not show any significant associations. Among these three associations, only the pair of *C. tungurrut* × *C. coriacea* displayed a positive association.

The chi-square analysis in the pole stage yielded data on 104 pole species pairs (Table 2). Surprisingly, the results indicated that *C. tungurrut* showed no associations with any species, even those belonging to the same genus. This lack of association may be attributed to intense competition for limited resources such as water, light, and nutrients within the habitat, as well as the slope factor. To cope with these challenging conditions, plants undergo morphological and physiological adjustments in response to location conditions. These adaptations enable plants to optimize their competitiveness in both above-ground and below-ground components (Xue et al. 2012).

Additionally, upon analyzing the sapling stage, the chi-square analysis of 135 sapling species pairs yielded similar results to the pole stage. Once again, *C. tungurrut* did not show any associations with other species. The prevalence of these non-associations suggests that *C. tungurrut* is a robust competitor and a key species capable of inhibiting the growth of other species due to resource limitations, similar to the effect observed in *Dactylis* at successional forest of William L. Hutcheson Memorial Forest Centre, USA as described by Myster & Pickett (1992). The behavior of *Dactylis* is very similar to that of *C. tungurrut.*

During the assessment of the wilding stage, a total of 111 wilding species pairs were examined. Interestingly, only *Symplocos costata* exhibited positive associations with *C. tungurrut*. This suggests that facilitation only occurred in specific pairs, while intense competition was observed among most tree wildings. Furthermore, the asymmetric competition resulting from canopy shading by adult trees could also have influenced the observed associations (Paine 2008).

Co-occurence of dominant vegetation with *C. tungurrut*

Table 4 presents the preferences of *C. tungurrut* for

Table 2. Results of association test on tree, pole, sapling and wilding life stage between *Castanopsis tungurrut* and 10 dominant co-occurrence species.

Co-occurring plant species	Associated/not associated (based on chi-square test)	Types of association (positive/negative)	Degree of association (Jaccard index)
Tree stage			
Castanopsis javanica (Blume) A.DC.	Associated (8.8)*	Negative	0.17
Macropanax dispermus (Blume) Kuntze	Associated (5.3)*	Negative	0.18
Casearia coriacea Thwaites	Associated (5.2)*	Positive	0.35
Ostodes paniculata Blume	Not Associated	-	0.26
Villebrunea scabra (Blume) Wedd.	Not Associated	-	0.44
Ficus fistulosa Reinw. Ex Blume	Not Associated	-	0.26
Syzygium pycnanthum Merr. & L.M.Perry	Not Associated	-	0.23
Schima wallichii (DC.) Korth.	Not Associated	-	0.32
Altingia excelsa Noronha	Not Associated	-	0.22
Ficus ribes Reinw. Ex Blume	Not Associated	-	0.27
Pole stage			
Villebrunea scabra (Blume) Wedd.	Not Associated	-	0.20
Bridelia insulana Hance	Not Associated	-	0.20
Alangium rotundifolium (Hassk.)Bloemb.	Not Associated	-	0.20
Brugmansia suaveolens (Humb.& Bonpl. Ex Willd.) Sweet	Not Associated	-	0.20
Dysoxylum alliaceum (G.Forst.) Seem.	Not Associated	-	0.20
Euonymus indicus B.Heyne ex Wall.	Not Associated	-	0.20
Laportea Stimulans (L.f.)Miq.	Not Associated	-	0.20
Schefflera J.R.Forst. & G.Forst.	Not Associated	-	0.20
Trevesia sundaica Miq.	Not Associated	-	0.20
Cestrum aurantiacum Lind.	Not Associated	-	0.17
Sapling stage			
Cinchona pubescens Vahl	Not Associated	-	0.25
Didymocheton alliaceus (G.Forst.) Mabb.	Not Associated	-	0.25
Polyalthia subcordata (Blume) Blume	Not Associated	-	0.23
Lasianthus rigidus Miq.	Not Associated	-	0.14
Dinochloa scandens (Blume ex Nees) Kuntze	Not Associated	-	0.14
Bridelia sp.	Not Associated	-	0.14
Ficus heterophylla L.f.	Not Associated	-	0.14
Angiopteris evecta (G.Forst.) Hoffm.	Not Associated	-	0.14
Austroeupatorium inulifolium (Kunth) R.M.King & H.Rob.	Not Associated	-	0.14
Bridelia insulana Hance	Not Associated	-	0.14
Wilding stage			
Symplocos costata (Blume) Choisy ex Zoll.	Associated (4.8)	Positive	0.33
Smilax javensis A.DC.	Not Associated	-	0.29
Calamus reinwardtii Mart.	Not Associated	-	0.29
Piper baccatum Blume.	Not Associated	-	0.25
Magnolia liliifera (L.)Baill.	Not Associated	-	0.25
Lasianthus laevigatus Blume	Not Associated	-	0.22
Ficus repens Rottler	Not Associated	-	0.20
Gonostegia hirta (Blume) Miq.	Not Associated	-	0.20
Raphidophora Hassk.	Not Associated	-	0.20
Clerodendrum eriosiphon Schauer	Not Associated	-	0.20

*x^2 test >x table is associated; x^2 test <x table is not associated; x table.3.84 (df = 1; α = 0.05). Type of association is positive if a >E (a) and negative if a< E (a). Value of the Jaccard index (strength of association) is equal to 0 at "no association" and to 1 at "complete/maximum association".

Image 2. The study site at Cisarua.

specific forest associations highlighting its tendency towards forests dominated by the Lauraceae family, where it exhibits high density and size. These findings further support the results obtained from the interspecific association test mentioned earlier.

DISCUSSION

Association of *C. tungurrut* with neighbouring vegetation

Based on Table 1, the presence of *C. tungurrut* tree phases in each location is generally observed up to 1,500 m. This shows that altitude is one of the limiting factors for the distribution of *C. tungurrut* in the Cibodas Biosphere Reserve. This is common in Javamountain forests, where the restricted diversity of adaptive species may be due to the stress that higher elevations put on environmental factors including temperature, humidity, wind, and nutrient availability as reported by Simbolon (2001) that tree species diversity decreased by 62% from 1,000 m to 1,800 m. Similar condition is depicted on pole, sapling and wilding stages. *C. tungurrut* is absent above 1,500 m and has variation in occurrence at each site. Different factors contribute to the rarity of pole, sapling and wilding in the sampling sites. This includes the restriction of altitude affect to the competition between individuals within same species and competition between different species in terms of light, groundwater, oxygen, nutrient, carbon dioxide, and space (Fathia et al. 2019), dispersal failure, high pollen limitation, and also predation on seed and wildings (Janzen 1970; Wotton & Kelly 2011; Etten et al. 2015). Furthermore, forest gap and climate change also contribute to the rarity of the pole, sapling and wilding as described by (Beckage et al. 2008; Davis et al. 2019). The forest with gaps provides more chance for the tree regeneration than the dense understorey, while the climate change may show abrupt shifts in vegetation communities.

Table 3. The total number of association species (associated & not associated) and type of association of *C. tungurrut* in various life stages based on chi-square value.

Life stage	Associated pairs	Not associated pairs	Negative association type	Positive association type
Tree	3	150	64	89
Pole	0	104	78	26
Sapling	0	135	101	34
Wildings	1	110	81	30

Association of *C. tungurrut* with neighbouring vegetation

Plant-plant associations often exhibit repetition, with approximately 70% of the data from long-term observations in old-field and glasshouse settings showing similar associations within the same species (Myster & Pickett 1992). In the case of *C. tungurrut*, this pattern remains consistent across different tree life stages. Negative associations were observed between *C. javanica* and *C. argentea* pairs.

Delving deeper into the analysis of above-ground vegetation associations between *C. tungurrut* and other species, it was found that most pairs did not exhibit any associations. Out of a total of 154 tree pairs, 105 pole pairs, 135 sapling pairs, and 111 wilding pairs, only the tree and wilding stages revealed positive and negative associations. These findings agree with the hypotheses pertaining to niche differences, the Janzen-Connel effect and negative density dependence reported by Wright (2002). *C. tungurrut* may possess niche distinctions or inhabit separate microhabitats, reducing direct competition with neighboring species and enabling coexistence without being overpowered by stronger competitors. Furthermore, the presence of a herbivore that primarily feeds on seeds may result in reduced recruitment near reproductive adults compared to competitors. Competition among conspecifics may also occur. The coexistence of other species under similar conditions can be attributed to evolutionary factors, such as speciation and adaptive traits.

Comparing with other *Castanopsis* species, various studies have indicated that *Castanopsis* species, including *C. kawakamii*, *C. eyrei*, and *C. chinensis*,

Table 4. *Castanopsis tungurrut* vegetation associations at four locations within Cibodas Biosphere Reserve.

Locality	Vegetation association	Plots characteristics
Bodogol (Humid forest with slope and long ridge)	Lauraceae is dominant – 10 species (*Cinnamomum rhynchophyllum, Cryptocarya ferrea, C. laevigata, Endiandra rubescens, Lindera polyantha, Litsea* sp. *L. garciae, Neolitsea javanica, Persea excelsa* and *Phoebe excelsa*).	Uneven canopy, reaching to a height of 28 m, dominated by several species based on IVI, *Schima wallichii, Castanopsis tungurrut, Syzygium rostratum, Lithocarpus pseudomoluccus, Maesopsis eminii, Casearia coriacea* and *Prunus arborea.*
Cibodas (Humid forest with less slope and some open area)	Lauraceae is dominant – 8 species (*Cryptocarya ferrea, Litsea resinosa, Neolitsea cassiifolia, N. javanica, N. triplinervia, Persea rimosa, Phoebe excelsa* and *P. grandis*).	Even canopy, reaching to a height of 20–30 m, dominated by several species based on IVI, *Schima wallichii, Macropanax concinnus,Dacrycarpus imbricatus,Castanopsis javanica,Villebrunea scabra, Macropanax dispermus.*
Cisarua (Near to *Cinchona* plantation; relatively humid forest with slope and small portion of opened forest)	Fagaceae is dominant – 6 species (*Castanopsis argentea, C. javanica, C. tungurrut, C. acuminatissima, Lithocarpus indutus, L. pseudomoluccus*).	Uneven canopy, the upper canopy reaching to a height of 38 m, dominated by several species based on IVI, *Castanopsis tungurrut,C. javanica, Villebrunea scabra, Cinchona pubescens, Schima wallichii, Casearia coriacea.*
Selabintana (Humid forest with steepy slope)	Rubiaceae is dominant – 5 species (*Cinchona pubescens, Coffea* sp., *Lasianthus stercorarius, Neonauclea lanceolata, Wenlandia* sp.).	Relatively even canopy, reaching to a height of 10–30 m. The dominant species based on IVI include *Schima wallichii*, *Macropanax dispermus,Villebrunea scabra*, *Neolitsea javanica*, *Acronychia pedunculata*, *Macropanax concinnus.*

exhibit diverse levels of inter-specific associations. *C. kawakamii* shows a weak association with dominant *Castanopsis* forests (Jinfu et al. 2001), while *C. eyrei* demonstrates a decrease in positive associations between species pairs with increasing diameter classes, leading to heightened inter-specific competition within the plot (Etten et al. 2015; Baokun et al. 2019). Also, the intensity of association in *C. chinensis* decreases as life stages progress (Li et al. 2008). Additionally, *C. argentea* showed a positive association with *Pinus merkusii* which is known as the producer of allelopathic substances (Hendrayana et al. 2022).

Moreover, it is worth noting that *C. tungurrut* only exhibits positive associations with *Casearia coriacea* and *Symplocos costata* in the tree and wilding stages, while negative or no associations were observed with other species. These intriguing findings suggest that *C. tungurrut* is a selective species and offers less facilitation to other species within the same habitat. It appears that competition outweighs facilitation when it comes to neighboring species.

It is probable that *C. tungurrut* and *Casearia coriacea* have complementary biological characteristics and nutrition requirements. *C. coriacea* provides protection from insects, while *C. tungurrut* provides nutrients and protection for *C. coriacea.* Therefore *C. tungurrut* and *C coriacea* can be successfully mixed with each other as they have complementary requirements. Similarly, *Symplocos costata* and *Castanopsis tungurrut* have a positive association because there is complementary interaction between them. Wihermanto (2004) reported that *Symplocos costata* has scattered clumped distribution at 1,000–1,421 m elevation and is positively associated with *Castanopsis javanica*. Further, this species lacks allelopathy substances that promote the development of *Rhizobium* and mycorrhiza in the roots of other plants. Therefore, in the wilding phase, *C. tungurrut* is facilitated by *S. costata* and vice-versa, especially in terms of providing nutrients to each other.

Types of association

a. Positive association between *C. tungurrut* and other species

The positive association observed between *C. tungurrut* and *Casearia coriacea* likely indicates a facilitation mechanism or mutualism between these species. Several factors may contribute to positive associations between neighboring plants, including mutual protection from harsh environmental conditions. One organism creates a more favorable local environment for another through direct means such as shading and wind reduction, or indirect means such as removing competitors and deterring predators. Ecologically, positive associations play a crucial role in shaping community structure and dynamics by reducing physical and biotic stress in habitats and creating new habitats for dependent species (Callaway 1995; Hacker & Bertness 1996; Stachowicz 2001). Different authors (Wihermanto 2004; Li et al. 2008, 2010; Song Jin et al. 2015; Hendrayana et al. 2022) reported that *Castanopsis* has positive association with several species such as *Pinus merkusi*i, *P. taiwanensis, Nauclea* sp., *Schima superba, Saurauia bracteosa*, *S. cauliflora*, *Symplocos costata*, *Altingia chinensis* and *Engelharditia roxburghiana*). It is noteworthy that *Castanopsis* species are mostly associated positively with dominant species

Image 3. Plant forms of *Castanopsis tungurrut*: a—wilding | b—sapling | c—pole | d—tree. © Authors.

in particular forest because *Castanopsis* species occupy a specific ecological niche within their habitat and flourish in the understory or with other dominant plants as forests mature since they are frequently early- to mid-successional species (Yang et al. 2003; Wang et al. 2012).

Casearia coriacea is a species that can survive under changing environmental conditions and adapt to extreme conditions. It produces various bioactive compounds, including clerodane-type diterpenoids that serve as insect antifeedants (Ledoux et al. 2023). On the other hand, *C. tungurrut* prefers to grow on slopes and exhibits buttress morphological characteristics, which can provide nutrients to surrounding plants and reduce the impact of wind exposure (Tang et al. 2010). These factors may explain the positive association between *C. tungurrut* and *Casearia coriacea*. The facilitative relationships are also similar to other *Castanopsis* species, just like *Castanopsis chinensis* and *Schima superba* providing shelter to small trees (Li et al. 2008).

Positive association occurs between *C. tungurrut* and *Symplocos costata* in the wilding phase but the associations between these species are different during the tree phase. Differences in associations during different life phases are common and influenced by dynamic conditions, including variations in life history and seasons (Osawa et al. 2014). *S. costata* exhibits random dispersion patterns, acts as a pioneer plant, and produces numerous seeds, making it easily found in the mountainous regions of West Java (Wihermanto 2004; Zuhri et al. 2020). In contrast, *C. tungurrut* shows habitat selection and faces significant threats from seed predation. Similar condition with *Castanopsis chinensis* that are eaten either by rodent and people contribute to the poor regeneration. The positive association observed in the wilding phase may be attributed to similar habitat requirements for the germination phase of both plants, facilitating wilding establishment.

It is noteworthy that the dynamic association within the life stages is correlated with the environmental heterogeneity or patchiness, where positive association in early stages is different from mature stage as depicted of different association type of *C. tungurrut* with *S. costata* in wilding and mature stages. The presence of positive associations between these two species can significantly impact vegetation structure and dynamics. The associations observed between them are dynamic and may change during a plant's life. From an ecosystem perspective, maintaining positive associations with other species can help preserve endangered species diversity such as *C. tungurrut* by providing favorable conditions. In addition, the different numbers of positive and negative association of *Castanopsis* will reflect the successional stage of the species. Yang et al. (2003) revealed that high number of insignificant association reflected a stable late successional stage of species community. More positive association with dominant species will reflect an unstable succession. The negative associations between later life stages and early life stages usually indicate the suppression of early stages by later stages. Helmanto et al. (2020) reported that negative association Indicates a tendency for exclusion or different responses in the same environment.

The study shows that the small number of positive associations of *C. tungurrut* is correlated with the facilitation relationship among the neighbouring vegetation and regeneration capacity of species. The mature tree cannot produce the wilding due to predation and hunting of seed, while the wilding cannot grow to the later stages due to suppression of dominant species in habitat. In the end, *C. tungurrut* is aggregated and had been less facilitative to neighbouring vegetation during tree and pole phase.

b. *Negative associations between C. tungurrut and other species*

Negative associations are commonly observed in perennial plants, including *C. tungurrut*. The negative association of *C. tungurrut* were observed only with *Castanopsis javanica* and *Macropanax dispermus* on the tree stage. There is no observed negative association between pole, sapling, and wilding. The negative association within the same genus was also described by Helmanto et al. (2020) where *Saurauia microphylla* was paired with *S. pendula* indicating that they have a tendency to exclude one another or respond differently to a similar environment. The negative association is not observed in the pole, sapling, and wilding stages. This dynamic condition suggests that *C. tungurrut* is a species that tends to compete within its habitat with minimal interaction between surrounding plant species. Intraspecific associations within the genus *Castanopsis* reveal that the patterns exhibited by *C. tungurrut* vary depending on the species' life phase. Similar observations have been found by Rejmánek & Leps (1996), Yang et al. (2003), and Cheng et al. (2014) in *Arctostaphylos patula* and *Cirsium vulgare* as well as *Quercus liaotungensi* and *Castanopsis chinensis*. The early stages association changed in the later stages due to competition for resources (light, nutrients, and water) and facilitation among the species. Competition for limited resources like water, nutrients, and light significantly impacts plant growth, community composition, and ecosystem function. Plants compete for these resources, with those capturing more light, such as those growing above others, gaining an advantage. This competition shapes plant evolution, favoring traits that enhance survival in the early stages, even if detrimental later. Additionally, environmental factors like slope influence species interactions, with negative associations decreasing in drier environments, suggesting adaptations to specific microclimates and resource utilization.

The negative associations of *C. tungurrut* with surrounding plants have significant impacts on the distribution and abundance of other species, especially those with high morphological plasticity and adaptability, which struggle to grow and develop. The present study found the prevalence of negative associations between *C. tungurrut* and other species. In interspecific competition, the availability of nutrients and light plays a primary role. Plant competition shapes community structure, influences nutrient cycling, and even affects the evolution of plant species (Goldberg & Barton 1992; Fréville & Silvertown 2005). The negative association among *Fagus lucida*, *Quercus variabilis, Castanopsis lamontii,* and *Litsea cubeba* is brought about by the differences of environmental requirements due to long-term adaptation of micro-environment, resources spaces and niche separation (Song jin et al. 2015). *C. tungurrut* tends to grow in isolation and restricts its associations with neighboring vegetation, hence, there were not many associated species. The association was driven mainly by environmental factors such as light availability, water, nutrient, and temperature. The association could be positive or negative depend on the resource utilization patters, level of competition, and habitat preferences (Maihaiti & Zhang 2014).

Forest Association Preference

C. tungurrut is commonly found and thrives in forests dominated by the Lauraceae family. Yamada (1975) reported similar situation in Mount Pangrango montane forest. In this forest, Lauraceae, Fagaceae and Theaceae have been found to be dominant families. But, *C. tungurrut* tends to have a negative association with the members of all these three families. This species is negatively associated with Theaceae member, *Schima wallichii* suggesting that *C. tungurrut* does not facilitate the growth of other trees, which is most likely due to intense competition among them for resources. Soepadmo & van Steenis (1972) described that when Fagaceae litter decomposes, it releases compounds (allelopathic) that, combined with specific fungi, may hinder or limit the growth of other forest trees. This phenomenon could contribute to *C. tungurrut*'s less facilitative nature. Matsuoka et al. (2019) and Wang (2011) reported that the association of ectomycorrhizal (ECM) fungi is closely related to the dispersal and distribution pattern of *Castanopsis*. Latitude and longitude also play a significant role in influencing the diversity and community structure of ECM fungi. Moreover, these biogeographic shifts in the ECM community are strongly linked with *Castanopsis* as the host tree. Hendrayana et al. (2022) revealed the positive association of *C. argentea* with dominant species *Pinus merkusii* and *Nauclea* sp. in Mount Ciremai National Park while Li et al. (2008) revealed the dynamic association in different life stages of species pair, *Castanopsis eyrei* and *Schima superba*. Nurdiana & Buot (2021) found a positive association of *C. tungurrut* and *C. javanica* in a remnant forest of the Cibodas Botanical Garden.

In general, *C. tungurrut* is capable of growing alongside major dominant families in the montane forest. It prefers to grow independently. Its density decreases when the dominant vegetation does not belong to the dominant families of Fagaceae, and Lauraceae, as observed in the case of the Selabintana forest, where Rubiaceae is dominant The lower density of *C. tungurrut* can possibly be attributed to its limited morphological adaptability and reduced competition with neighboring species. Further, favorable conditions, as commonly found in Fagaceae according to Soepadmo & van Steenis (1972), are necessary for the growth of *C. tungurrut*.

Importance of association of *C. tungurrut* and its conservation strategy

C. tungurrut plays a vital role as a keystone species in supporting the existence of other species within their habitats, thereby contributing to conservation efforts and promoting sustainability. This indicates that unfavorable interactions within the same species can create opportunities for the regeneration of different species, thus preserving biodiversity and preventing the dominance of monocultures. Different authors (Dolezal et al. 2020; Loreau & de Mazancourt 2013; Rozdilsky & Stone 2001) reported that intense interspecific competition, species asynchrony to environmental fluctuation, connectance, the strength of competition, speed of species in responding the perturbation and diverse plant communities are significant factors in shaping the ecosystem stability. The present study highlights how these effects differ depending on the age of the wildings: younger wildings are more affected by interactions with their conspecific neighbors, whereas older wildings are influenced to a greater extent by neighboring trees of the same species. These findings can provide valuable insights for conservation initiatives aimed at sustaining biodiversity in forests and similar environments where similar processes occur. It is important to note that even though intraspecific interactions weaken as the wildings age, they still impact overall survival rates in later stages of development (Zhao et al. 2021). It is worth mentioning that the study was limited to observations of above-ground vegetation and did not investigate subterranean associations, such as the involvement of microorganisms in the growth of *C. tungurrut*. To mitigate biases in observations and assess interactions in underground associations, it is recommended to conduct repeated observations using consistent patterns.

CONCLUSION

The association of *C. tungurrut* with other species in the community is dynamic and influenced by competition, facilitation, and succession. Overall, *C. tungurrut* is not associated with neighbouring species indicating that the co-occurrence of *C. tungurrut* and the paired species is independent. It is a selective species that does not rely on the presence of other species for its growth. Instead, it tends to grow independently up to 1500 m in Lauraceae and Fagaceae forests, reducing its density in unfavorable habitats. Furthermore, *C. tungurrut* prefers not to be associated with the dominant species in its habitat. This behavior provides important insights for reserve management, specifically in the development of sustainable management frameworks for the Cibodas Biosphere Reserve. Factors such as favorable location, including soil conditions, environmental parameters, and vegetation types, should be considered while crafting these management strategies. *C. tungurrut* can be planted with *Casearia coriacea* and *Symplocos costata* since both exhibit complementary ecological characteristics and facilitation mechanisms.

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ARTICLE

Riparian flora of Haveri District, Karnataka, India

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Abstract: The Haveri District is located in the central part of Karnataka, acting as a transitional zone between the Western Ghats and Maidan region. The riparian zones are the most diverse, dynamic, and complex habitats on land. The present study on the riparian vegetation along the four rivers of Haveri District identified a total of 307 species belonging to 233 genera of 73 families. Out of that 231 species are indigenous belonging to 160 genera and 68 families. The remaining 76 non-native species belong to 63 genera and 27 families. The highest number of species were recorded from the Tungabhadra River (232 species), followed by the rivers Kumadwathi (181), Dharma (156), and Varada (149). Herbs are the most common among the recorded plants, with 186 species representing approximately 61% of the total flora. With 36 species, Fabaceae is the most represented family accounting for 12% of the flora. The riparian vegetation in the study area faces several threats, including habitat loss due to encroachment for agriculture, overgrazing, dumping of plastic waste, sand mining, invasive species, and tourism activities. Effective conservation measures are needed to protect the riparian zones and their plant wealth.

Keywords: Angiosperms, aquatic plants, conservation, Dharma, diversity, Kumadwathi, nativity, rivers, Tungabhadra, Varada.

Kannada: ಹಾವೇರಿ ಜಿಲ್ಲೆಯು ಕರ್ನಾಟಕದ ಮಧ್ಯ ಭಾಗದಲ್ಲಿದ್ದು, ಉತ್ತರ ಕರ್ನಾಟಕದ ಹೆಬ್ಬಾಗಿಲು ಎಂದೆ ಪ್ರಸಿದ್ಧವಾಗಿದೆ. ಇದು ಪಶ್ಚಿಮ ಘಟ್ಟ ಮತ್ತು ಮೈದಾನ ಪ್ರದೇಶಗಳ ನಡುವೆ ಪರಿವರ್ತನೆಯ ವಲಯವಾಗಿ ಕಾರ್ಯನಿರ್ವಹಿಸುತ್ತದೆ. ನದಿತೀರದ ಪ್ರದೇಶಗಳು ಭೂಮಿಯ ಮೇಲಿನ ಅತ್ಯಂತ ವೈವಿಧ್ಯಮಯ, ಕ್ರಿಯಾತ್ಮಕ ಮತ್ತು ಸಂಕೀರ್ಣ ಆವಾಸಸ್ಥಾನಗಳಾಗಿವೆ. ನದಿಪಾತ್ರದ ಸಸ್ಯಸಂಪತ್ತಿನ ಕುರಿತ ಪ್ರಸ್ತುತ ಅಧ್ಯಯನ ಹಾವೇರಿ ಜಿಲ್ಲೆಯಲ್ಲಿರುವ ನಾಲ್ಕು ನದಿಗಳ ಉದ್ದಕ್ಕೂ ವ್ಯಾಪಿಸಿಕೊಂಡಿರುವ 73 ಕುಟುಂಬಗಳ 233 ತಳಿಗಳಿಗೆ ಸೇರಿದ ಒಟ್ಟು 307 ಪ್ರಭೇದಗಳನ್ನು ದಾಖಲಿಸಲಾಗಿದೆ. ಅದರಲ್ಲಿ ಸ್ಥಳೀಯವಾದ 231 ಪ್ರಭೇದಗಳು 160 ಜಾತಿಗಳು ಮತ್ತು 68 ಕುಟುಂಬಗಳಿಗೆ ಸೇರಿದರೆ. ಉಳಿದ 76 ಸ್ಥಳೀಯವಲ್ಲದ ಪ್ರಭೇದಗಳು 63 ತಳಿಗಳು ಮತ್ತು 27 ಕುಟುಂಬಗಳಿಗೆ ಸೇರಿವೆ. ತುಂಗಭದ್ರಾ ನದಿತೀರದ ಪ್ರದೇಶದಿಂದ (232) ಅತಿ ಹೆಚ್ಚು ಪ್ರಭೇದಗಳು ದಾಖಲಾದರೆ, ಕುಮದ್ವತಿ ನದಿ (181), ಧರ್ಮಾನದಿ (156) ಮತ್ತು ವರದಾ ನದಿ (149). ಒಟ್ಟು ದಾಖಲಾದ ಸಸ್ಯಗಳಲ್ಲಿ ಗಿಡಗಳು (186 ಪ್ರಭೇದಗಳು) ಹೆಚ್ಚಿನ ಸಂಖ್ಯೆಯಲ್ಲಿದ್ದು ಸರಿಸುಮಾರು 61% ಅನ್ನು ಪ್ರತಿನಿಧಿಸುತ್ತವೆ. 36 ಪ್ರಭೇದಗಳೊಂದಿಗೆ ಫ್ಯಾಬೇಸಿಯೇ ಹೆಚ್ಚು ಪ್ರತಿನಿಧಿಸುವ ಕುಟುಂಬವಾಗಿದ್ದು, ಸಸ್ಯವರ್ಗದ 12% ರಷ್ಟಿದೆ. ಈ ಅಧ್ಯಯನದಲ್ಲಿ ನದಿಯತೀರದ ಪ್ರದೇಶವು ಕೃಷಿಕಾರ್ಯಕ್ಕಾಗಿ ಅತಿಕ್ರಮಣ, ಪ್ಲಾಸ್ಟಿಕ್ ತ್ಯಾಜ್ಯಗಳ ಸುರಿಯುವಿಕೆ, ಮರಳು ಗಣಿಗಾರಿಕೆ, ಆಕ್ರಮಣಕಾರಿ ಜಾತಿಯ ಸಸ್ಯಗಳು ಮತ್ತು ಪ್ರವಾಸೋದ್ಯಮ ಚಟುವಟಿಕೆಗಳು ಸೇರಿದಂತೆ ಹಲವಾರು ಕಾರಣಗಳಿಂದ ಅಳವಿನಂಚಿನಲ್ಲವೆ. ನದಿತೀರದ ವಲಯಗಳನ್ನು ಮತ್ತು ಅವುಗಳ ಸಸ್ಯ ಸಂಪತ್ತನ್ನು ರಕ್ಷಿಸಲು ಪರಿಣಾಮಕಾರಿ ಸಂರಕ್ಷಣಾ ಕ್ರಮಗಳ ಅಗತ್ಯವಿದೆ.

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Author contributions: NSM—fieldwork, data collection, species identification and preparation of the draft; KK—designed the research and edited the manuscript. Both authors read and approved the final manuscript.

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INTRODUCTION

The term riparian is derived from the Latin word 'riparius', referring to the banks of rivers, ponds or lakes, along with their surrounding landscapes. Riparian zones serve as the transitional areas between the aquatic and the terrestrial environment (Zaimes et al. 2010; Betz et al. 2018). They consist of the riverbed, banks, vegetation, adjacent land and floodplains, and are crucial for maintaining the water quality in aquatic ecosystems (Maraseni & Mitchel 2016; Singh et al. 2021). Riparian zones encompass the space between flowing water at low levels and the highest watermark where vegetation is influenced by floods, elevated water tables, and soil type (González et al. 2017). The riparian vegetation has been recognized as a 'keystone ecosystem', since it harbors unique habitats which are highly influenced by water (Sunil et al. 2016).

In Karnataka, Kotresha & Taranath (2010) recorded 275 angiosperm species in the Varahi River basin in Udupi District. Rao et al. (2014) studied the threatened tree species of swamps and riparian habitats along different streams of Uttara Kannada and Shimoga districts. Previous reports reveal that there was no proper documentation of floristic resources in the riparian vegetation of Haveri district and hence it was attempted in the present study. We explored the riparian flora along four rivers, namely, Dharma, Kumadwathi, Tungabhadra, and Varada, and enumerated the angiosperm species.

MATERIAL AND METHODS

Study area

Situated in the central part of Karnataka, the Haveri District serves as a gateway to the northern districts of the state. It is located at 14.661 N, 75.434 E (Figure 1). It comprises of eight talukas, namely: Byadagi, Haveri, Hanagal, Hirekerur, Ranebennur, Rattihalli, Savanur, and Shiggaon.

Dharma River: The river Dharma is a tributary of river Varada which flows a distance of about 32 km in northern Canara and Shimoga districts and further down it enters Haveri District near Mantagi Village in Hanagal Taluka. It drains about 625 km^2 of area and traverses for about 56 km before joining the Varada River Kudala near Naregal. The canals flow in the middle of Hanagal and serve as a major water source for the surrounding agricultural lands.

Varada River: The Varada River originates near Varadamoola in Sagara Taluka of Shimoga District in Karnataka. It is one of the tributaries of the Tungabhadra River. It enters the Haveri District near Honkana Village in Hanagal Taluka. This river flows in a north-easterly direction in Hanagal Taluk and becomes a border between Haveri and Savanur. The river confluences with the Tungabhadra River at Galaganath. In its total length of 185 km, the Varada River traverses a distance of 101 km with several tributaries and drains an area of about 3,120 km^2 in the Haveri District.

Kumadwathi River: This river, also known as Joradi, originates in Agastyaparvata near Humcha of Shikaripur Taluk in Shimoga District. The river flows through northern Kumsi and Shikaripur and then enters Hirekerur Taluka. It serves as the lifeline for the Madaga tank in Masur (Madagada Kenchavvana Kere). The total length of the river is about 96 km. It flows through Ranibennur and Hirekerur taluks in Haveri District for about 32 km, before joining the Tungabhadra River at Mudenur.

Tungabhadra River: The rivers Tunga and Bhadra originate in the Western Ghats flowing north-east and merging near Kudli (16 km away from Shimoga) from there the river is called Tungabhadra. It serves as a lifeline for several districts in northern Karnataka and traverses a distance of about 403 km in the geographical limits of Karnataka State. It enters the district at 14.315 N, 75.633 E near Hallur Village of Hirekerur Taluka. Confluence of River Kumadwathi at 14.494 N, 75.697 E near Mudenur village in Ranebennur Taluka and the river Varada joins at 14.929 N, 75.682 E near Galaganath. Havanur, Galaganath, and Chaudayyadanapur are important pilgrim centers in the district located on the banks of Tungabhadra.

Data collection and analysis

The floristic diversity along riparian zones was documented along all four rivers of the Haveri District: the Dharma, Kumadwathi, Tungabhadra, and Varada Rivers. These rivers are the major sources of water in the district (Figure 1). Random and criss-cross surveys were conducted across each study site and plant specimens were collected during different seasons, from November 2020 to August 2023. Observations made during the field visits were noted in the field notebook. The collected plant specimens were pressed and prepared herbarium vouchers following the standard methods (Jain & Rao 1977). The collected specimens were treated with a diluted solution (0.1%) of mercuric chloride ($HgCl_2$) to prevent fungal infections. The processed herbarium specimens were deposited in the Herbarium of the Botany Department, Karnatak Science College, Dharwad (HKSCD). All the collected specimens were taxonomically

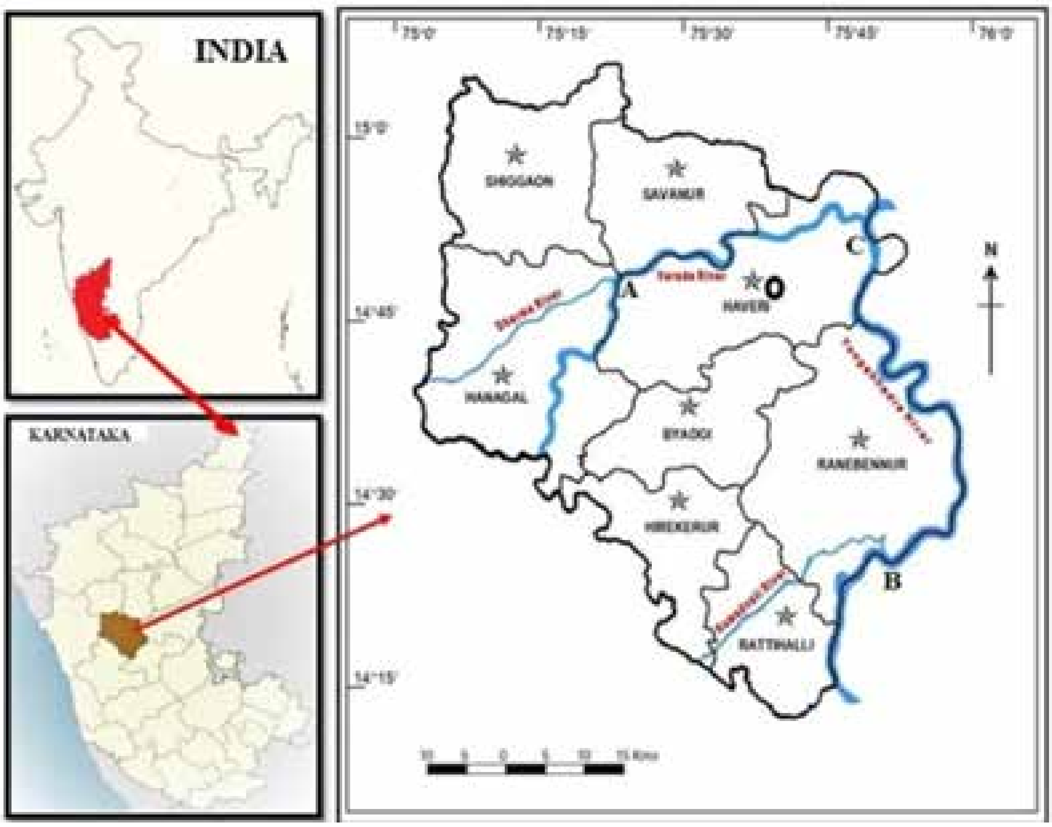

Figure 1. Map of Haveri District showing the major rivers: A—Confluence of Dharma River with Varada | B—Confluence of river Kumadwathi with Tungabhadra | C—Confluence of Varada River with Tungabhadra. Source: Survey of India.

identified and confirmed using relevant literature and floras, including Cooke (1958), Saldanha & Nicolson (1976), Blatter & McCann (1984), Saldanha (1984, 1996), Singh (1988), Prasad & Singh (2002), Gamble (2008), and Bhat (2014). The identified specimens were labeled with their accepted names and families as per the APG IV classification (Chase et al. 2016).

RESULTS

The present study documented a total of 307 species belonging to 233 genera from 73 families. Out of that 231 species belonging to 160 genera and 68 families are native to the Indian subcontinent, and remaining 76 species belonging to 63 genera and 26 families from the riparian vegetation of four rivers in the Haveri District of Karnataka, India (Table 1; Images 1–5). Of these, 249 species are dicots (181 native and 68 non-native) belonging to 63 families and 58 are monocots (49 native and 9 non-native) belonging to 10 families. The highest number of species were recorded from the riparian vegetation of the Tungabhadra River with 232 species belonging to 182 genera and 61 families. It includes 167 native species belonging to 146 genera & 59 families and 65 non-native species belonging to 56 genera & 22 families. This is followed by the river Kumadwathi with 181 species, 148 genera, & 52 families comprising of 134 native species, 115 genera, & 43 families and 48 non-native species belonging to 43 genera & 20 families. River Dharma has a diversity of 156 species belonging to 130 genera & 48 families represented by 120 native species belonging to 109 genera & 33 families and 36 non-natives belonging to 33 genera & 17 familes. River Varada has a floral diversity of 149 species belonging to 125 genera & four families, which comprises of 116 native species belonging to 102 genera & 43 families and 33 non-native species belonging to 26 genera & 17 families (Figure 2).

Life form study of the collected indigenous plants shows that herbaceous flora is dominant, with 186 species (141 native and 45 non-native) contributing to about 61% of the total flora, followed by 41 shrubs (13%; 30 native and 11 non-native), 52 trees (17%; 38 native and 14 non-native), and 28 climbers (10%; 21 native and 7 non-native). (Figure 3).

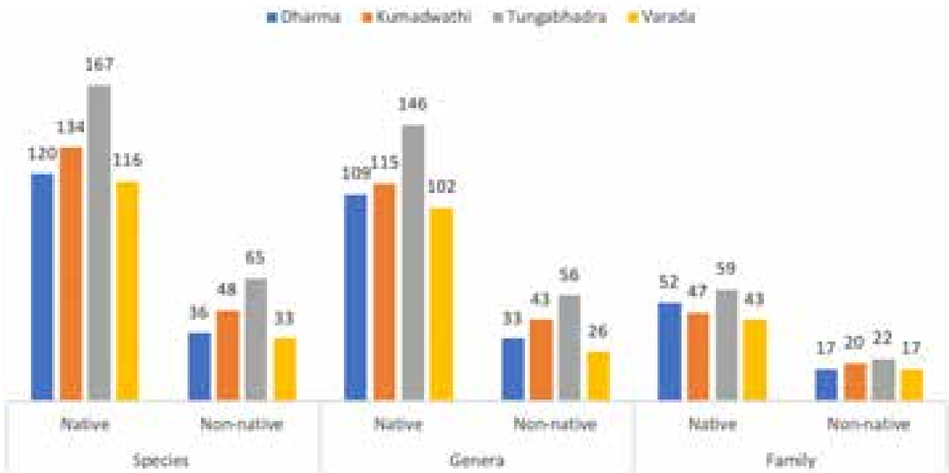

Figure 2. Comparison of riparian flora among the four rivers of Haveri District.

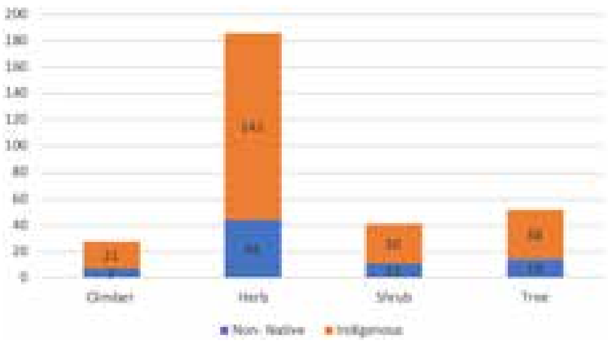

Figure 3. Habit-wise distribution of riparian plants.

With 25 native species, Fabaceae is the most represented family, accounting for 11% of the flora of the study area. Poaceae is the second largest family with 24 species (10%), followed by Asteraceae 16 species (7%), Euphorbiaceae, Acanthaceae, & Cyperaceae with 11 species each (5%), Lamiaceae with nine species (4%), Convolvulaceae eight species, and Moraceae & Apocyancaeae families with seven species each (Figure 4).

Limnocharis flava (L.) Buchenau (Alismataceae) collected at Makanur and Somalapura villages from the riparian vegetation of the Tungabhadra River, formed a new generic report to the flora of Karnataka state (Makanur & Kotresha 2022). As for the IUCN Red List status of the collected species, *Aegle marmelos* (L.) Correa is classified as 'Near Threatened'. Four endemic species were recorded during the present study: *Dicliptera cuneata* Nees (endemic to the Western Ghats), *Acilepis dendigulensis* (DC.) H.Rob. (Peninsular India), *Homonoia retusa* (Graham ex Wight) Müll.Arg. (Western Ghats of Karnataka), and *Phyllanthus lawii* J.Graham (Andhra Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Tamil Nadu, and West Bengal). *Alternanthera philoxeroides* (Mart.) Griseb, *Mikania micrantha* Kunth, and *Pontederia crassipes* Mart. are invasive alien aquatic species recorded. *Crinum viviparum* (Lam.) R.Ansari & V.J.Nair, *Cryptocoryne spiralis* (Retz.) Fisch. ex Wydler, *Homonoia retusa* (Graham ex Wight) Müll. Arg., *Homonoia riparia* Lour., *Hydrilla verticillata* (L.f.) Royle, *Hygrophila auriculata* (Schumach.) Heine, *Ottelia alismoides* (L.) Pers., *Pistia stratiotes* L., *Pontederia vaginalis* Burm.f., *Rotula aquatica* Lour., *Tamarix ericoides* Rottler, and *Vallisneria spiralis* L., are the aquatic plants documented during the study.

CONCLUSION

The riparian zones are the most diverse, dynamic, and complex habitats on Earth. The present study documented a total of 231 indigenous species belonging to 160 genera & 69 families and 76 non-native species belonging to 27 families of flowering plants along the riparian vegetation of four rivers in Haveri District, Karnataka. The highest number of species were recorded from the Tungabhadra River, with 232 species belonging to 61 families, followed by the river Kumadwathi with 181 species. The rivers Dharma and Varada showed a diversity of 156 and 149 species, respectively. Herbaceous flora is dominant in the study area, with 186 species accounting for about 61% of the total flora. Fabaceae was the predominant family, with 36 species representing 11.8% of the total flora.

The riparian vegetation in the study area is facing numerous threats. Key factors contributing to habitat

Table 1. Checklist of riparian plants along four rivers in Haveri District, Karnataka.

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Abutilon indicum (L.) Sweet	Malvaceae	S	+	+	+	+	I
Acacia auriculiformis A.Cunn. ex Benth.	Fabaceae	T	+	+			I
Acalypha indica L.	Euphorbiaceae	H			+	+	I
Acanthospermum hispidum DC.	Asteraceae	H	+	+	+		I
Achyranthes aspera L.	Amaranthaceae	H	+		+		I
Acilepis dendigulensis (DC.) H.Rob.	Asteraceae	H	+		+		I
Acmella radicans (Jacq.) R.K.Jansen	Asteraceae	H					I
Aegle marmelos (L.) Correa	Rutaceae	T	+		+	+	I
Aeschynomene indica L.	Fabaceae	H	+				I
Afrohybanthus enneaspermus (L.) Flicker	Violaceae	H			+		I
Ageratum conyzoides L.	Asteraceae	H			+		I
Ageratum houstonianum Mill.	Asteraceae	H	+		+	+	I
Alangium salviifolium (L.f.) Wangerin	Cornaceae	T			+		I
Albizia amara (Roxb.) Boivin	Fabaceae	T	+	+			I
Albizia lebbeck (L.) Benth.	Fabaceae	T				+	I
Alternanthera philoxeroides (Mart.) Griseb	Amaranthaceae	H			+		Ar
Alternanthera pungens Kunth	Amaranthaceae	H	+	+	+		Am
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	+	+	+	+	I
Alysicarpus vaginalis (L.) DC.	Fabaceae	H			+		I
Amaranthus spinosus L.	Amaranthaceae	H		+	+		Tam
Ammannia baccifera L.	Lythraceae	H	+		+		I
Andrographis paniculata (Burm.f.) Wall.	Acanthaceae	H		+		+	I
Anisomeles indica (L.) Kuntze	Lamiaceae	H	+	+	+	+	I
Anisomeles malabarica (L.) R.Br. ex Sims	Lamiaceae	H	+	+	+	+	I
Apluda mutica L.	Poaceae	H	+				Wp
Argemone mexicana L.	Papaveraceae	H			+	+	I
Argyreia cymosa (Roxb.) Sweet	Convolvulaceae	C			+		I
Aristida setacea Retz.	Poaceae	H	+	+	+		I
Artocarpus heterophyllus Lam.	Moraceae	T	+		+		I
Arundo donax L.	Poaceae	H			+	+	I
Asparagus racemosus Willd.	Asparagaceae	S				+	I
Aspidopterys cordata (Wall.) A.Juss.	Malpighiaceae	C	+				I
Azima tetracantha Lam.	Salvadoraceae	S	+	+	+		I
Bacopa monnieri (L.) Wettstein	Plantaginaceae	H		+	+	+	I
Bambusa bambos (L.) Voss	Poaceae	T	+	+	+	+	I
Barringtonia acutangula (L.) Gaertn.	Lecythidaceae	T	+	+		+	I
Basilicum polystachyon (L.) Moench	Lamiaceae	H		+	+		I
Bergia ammannioides Roxb.	Elatinaceae	H	+		+		I
Bidens biternata (Lour.) Merr. & Sherff ex Sherff	Asteraceae	H	+	+		+	I
Blumea axillaris (Lam.) DC.	Asteraceae	H			+	+	I
Boerhavia diffusa L.	Nyctanginaceae	H		+	+		I
Boerhavia erecta L.	Nyctanginaceae	H			+		Tam
Bolboschoenus maritimus (L.) Palla	Cyperaceae	H			+	+	I

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Bonnaya antipoda (L.) Druce	Linderniaceae	H	+		+		I
Breynia retusa (Dennst.) Alston	Phyllanthaceae	H		+	+		I
Butea monosperma (Lam.) Taubert	Fabaceae	T	+		+		I
Cadaba fruticosa (L.) Druce	Capparaceae	S		+		+	I
Caesalpinia bonduc (L.) Roxb.	Fabaceae	S		+	+	+	I
Calotropis gigantea (L.) R.Br.	Apocynaceae	S	+	+	+	+	I
Calotropis procera W.T.Aiton	Apocynaceae	S	+		+		I
Calyptocarpus vialis Less.	Asteraceae	H		+	+		I
Cansjera rheedei Gmelin	Opiliaceae	S		+			I
Canthium coromandelicum (Burm.f.) Alston	Rubiaceae	S	+	+		+	I
Capparis sepiaria L.	Capparaceae	S	+	+	+	+	I
Cardiospermum halicacabum L.	Sapindaceae	C	+		+		I
Careya arborea Roxb.	Lecythidaceae	T		+		+	Afg–M
Caryota urens L.	Arecaceae	T	+	+			I
Cascabela thevetia (L.) Lippold	Apocynaceae	S			+		Tam
Cassia fistula L.	Fabaceae	T	+		+		I
Catharanthus pusillus (Murray) G.Don	Apocynaceae	H	+			+	I
Causonis trifolia (L.) Mabb. & J.Wen	Vitaceae	C	+		+		I
Cenchrus pedicellatus (Trin.) Morrone	Poaceae	H	+				I
Centella asiatica (L.) Urb.	Apiaceae	H	+				I
Centrosema pubescens Benth.	Fabaceae	C		+			I
Chloris barbata Sw.	Poaceae	H	+	+	+	+	I
Chloris quinquesetica Bhide	Poaceae	H	+	+			I
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	S		+	+		Am
Chrozophora plicata (Vahl) A.Juss. ex Spreng.	Euphorbiaceae	H	+			+	I
Chrozophora rottleri (Geiseler) A.Juss. ex Spreng.	Euphorbiaceae	S		+	+	+	I
Cleome gynandra L.	Cleomaceae	H	+	+	+		I
Cleome viscosa L.	Cleomaceae	H	+	+	+		Taf
Clerodendrum phlomidis L.f.	Lamiaceae	T			+	+	I
Clitoria terneata L.	Fabaceae	C	+	+	+		I
Coccinia grandis (L.) Voigt	Cucurbitaceae	C		+	+	+	I
Coldenia procumbens L.	Boraginaceae	H	+	+	+	+	I
Colocasia esculenta (L.) Schott	Araceae	H			+	+	I
Combretum albidum G.Don	Convolvulaceae	C			+	+	I
Commelina benghalensis L.	Commelinaceae	H			+		I
Conyza japonica (Thunb.) Less.	Asteraceae	H		+	+		Afg
Corchorus fascicularis Lam.	Malvaceae	H	+	+	+		I
Crateva magna (Lour.) DC.	Capparaceae	T		+	+		I
Crinum viviparum (Lam.) R.Ansari & V.J.Nair	Amaryllidaceae	H	+	+	+	+	I
Crotalaria hebecarpa (DC.) Rudd	Fabaceae	H	+		+		I
Crotalaria pallida Aiton	Fabaceae	S		+	+		I
Croton bonplandianus Baill.	Euphorbiaceae	H			+	+	I
Cryptocoryne spiralis (Retz.) Fisch. ex Wydler	Araceae	H	+	+	+		I
Cryptolepis buchananii Roemer & Schultes	Apocynaceae	C		+	+		I
Cryptostegia grandiflora R.Br.	Apocynaceae	S		+	+		Mad

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Cucumis melo L.	Cucurbitaceae	C		+	+		I
Cucumis sativus L.	Cucurbitaceae	C	+	+		+	I
Cuscuta campestris Yunck.	Convolvulaceae	C			+		I
Cyathocline purpurea (D.Don) Kuntze	Asteraceae	H	+	+	+	+	I
Cynodon dactylon (L.) Pers.	Poaceae	H	+	+	+		I
Cyperus difformis L.	Cyperaceae	H			+		I
Cyperus flavidus Retz.	Cyperaceae	H				+	Eu–Au
Cyperus haspan L.	Cyperaceae	H		+	+	+	I
Cyperus iria L.	Cyperaceae	H		+		+	I
Cyperus pumilus L.	Cyperaceae	H	+		+		I
Dactyloctenium aegyptium (L.) P.Beauv.	Poaceae	H	+	+	+		Sam
Dalbergia sissoo Roxb.	Fabaceae	T		+	+	+	I
Datura discolor Bernh.	Solanaceae	H		+	+		I
Datura ferox L.	Solanaceae	H		+	+	+	Te–Me
Datura stramonium L.	Solanaceae	S		+	+		Nam
Delonix regia (Hook.) Raf.	Fabaceae	T			+	+	Mad
Dentella repens (L.) J.R.Forst. & G.Forst.	Rubiaceae	H	+		+		I
Dichanthium annulatum (Forssk.) Stapf	Poaceae	H		+	+	+	I
Dicliptera cuneata Nees	Acanthaceae	H				+	I
Dicliptera paniculata (Forssk.) I.Darbysh.	Acanthaceae	H			+		I
Digera muricata (L.) Mart.	Amaranthaceae	H		+	+		I
Digitaria ciliaris (Retz.) Koeler	Poaceae	H	+	+		+	I
Dinebra retroflexa (Vahl) Panz.	Poaceae	H			+	+	I
Dipteracanthus patulus (Jacq.) Nees	Acanthaceae	H			+		I
Dyschoriste erecta (Burm.f.) Kuntze	Acanthaceae	H	+			+	I
Ecbolium ligustrinum (Vahl) Vollesen	Acanthaceae	H				+	I
Echinochloa colona (L.) Link	Poaceae	H		+	+	+	I
Echinochloa crus-galli (L.) P.Beauv.	Poaceae	H	+		+	+	Pal
Eclipta prostrata (L.) L.	Asteraceae	H			+	+	Sta
Eleocharis geniculata (L.) Roem. & Schult.	Cyperaceae	H	+	+	+		I
Eleusine indica (L.) Gaertn.	Poaceae	H	+		+		I
Emilia sonchifolia (L.) DC.	Asteraceae	H	+	+		+	I
Enicostema axillare (Poir. ex Lam.) A.Raynal	Gentianaceae	H	+	+	+		I
Enteropogon dolichostachyus (Lag.) Keng	Poaceae	H		+			I
Eragrostis aspera (Jacq.) Nees	Poaceae	H	+				I
Eragrostis ciliaris (L.) R.Br.	Poaceae	H	+		+		I
Eragrostis japonica (Thunb.) Trin.	Poaceae	H	+		+		I
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	Poaceae	H	+	+		+	I
Erigeron sumatrensis Retz.	Asteraceae	H	+		+		I
Eucalyptus globulus Labill.	Myrtaceae	T	+	+	+	+	Au
Euphorbia heterophylla L.	Euphorbiaceae	H		+	+	+	Cam
Euphorbia heyneana Sprengel	Euphorbiaceae	H	+	+	+	+	I
Euphorbia hirta L.	Euphorbiaceae	H	+	+	+	+	Tam
Euphorbia hypericifolia L.	Euphorbiaceae	H					Sta

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Evolvulus nummularius (L.) L.	Convolvulaceae	H	+	+	+		Tam
Ficus benghalensis L.	Moraceae	T	+	+	+		I
Ficus heterophylla L.f.	Moraceae	T		+	+	+	I
Ficus hispida L.f.	Moraceae	T			+	+	I
Ficus mollis Vahl	Moraceae	T		+			I
Ficus racemosa L.	Moraceae	T	+	+	+	+	Pa
Ficus religiosa L.	Moraceae	T	+	+	+		I
Fimbristylis ovata (Burm.f.) J.Kern	Cyperaceae	H					I
Fimbristylis quinquangularis (Vahl) Kunth	Cyperaceae	H		+	+		I
Flueggea leucopyrus Willd.	Phyllanthaceae	S					Ch
Fuirena umbellata Rottboell	Cyperaceae	H			+	+	I
Glinus lotoides L.	Molluginaceae	H	+		+	+	I
Glinus oppositifolius (L.) Aug.DC.	Molluginaceae	H		+	+		I
Gmelina arborea Roxb.	Lamiaceae	T				+	I
Gnaphalium polycaulon Pers.	Asteraceae	H		+	+	+	I
Gomphrena celosioides Mart.	Amaranthaceae	H		+		+	Sam
Grangea maderaspatana (L.) Poir.	Asteraceae	H	+	+	+		Af
Grona triflora (L.) H.Ohashi & K.Ohashi	Fabaceae	H			+		I
Heliotropium indicum L.	Boraginaceae	H			+		Ar
Heliotropium marifolium J.Koenig ex Retz.	Boraginaceae	H	+	+	+	+	I
Heliotropium ovalifolium Forrsk.	Boraginaceae	H	+	+		+	I
Hemigraphis latebrosa (Roth) Nees	Acanthaceae	H	+	+			I
Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.	Poaceae	H	+		+		I
Holarrhena pubescens (Buch.-Ham.) Wall. ex G.Don	Apocynaceae	S	+				I
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	T	+	+	+	+	I
Homonoia retusa (Graham ex Wight) Müll. Arg.	Euphorbiaceae	S	+	+	+	+	I
Homonoia riparia Lour.	Euphorbiaceae	S		+		+	I
Hydrilla verticillata (L.f.) Royle	Hydrocharitaceae	H	+	+	+	+	I
Hygrophila auriculata (Schumach.) Heine	Acanthaceae	H	+	+	+	+	I
Indigofera astragalina DC.	Fabaceae	H		+	+		I
Indigofera linifolia (L.f.) Retz.	Fabaceae	H	+	+	+	+	I
Indigofera linnaei Ali	Fabaceae	H			+		I
Ipomoea alba L.	Convolvulaceae	C					Tam
Ipomoea aquatica Forsk.	Convolvulaceae	C				+	I
Ipomoea cairica (L.) Sweet	Convolvulaceae	C		+			Med
Ipomoea carnea (L.) Sweet	Convolvulaceae	S	+		+		Sam
Ipomoea obscura (L.) Ker Gawl.	Convolvulaceae	C	+		+		I
Ipomoea staphylina Roem. & Schult.	Convolvulaceae	C	+		+	+	I
Ipomoea triloba L.	Convolvulaceae	C	+	+	+		Tam
Jatropha curcas L.	Euphorbiaceae	S			+	+	I
Jatropha gossypiifolia L.	Euphorbiaceae	H		+	+		Me
Kalanchoe lanceolata (Forssk.) Pers.	Crassulaceae	H	+				I
Lagascea mollis Cav.	Asteraceae	H	+	+	+		Tam
Lantana camara L.	Verbenaceae	S	+	+	+	+	Cam

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Lemna minor L.	Araceae	H			+		I
Leptochloa chinensis (L.) Nees	Poaceae	H		+	+		I
Leucaena leucocephala (Lam.) de Wit	Fabaceae	T		+	+		Tam
Leucas aspera (Willd.) Link	Lamiaceae	H		+	+	+	I
Leucas urticifolia R.Br.	Lamiaceae	H	+		+		I
Limnocharis flava (L.) Buchenau	Alismataceae	H		+	+		Me–Tam
Limonia acidissima L.	Rutaceae	T		+			I
Lindernia hyssopioides (L.) Haines	Linderniaceae	H		+	+	+	I
Lindernia parviflora (Roxb.) Haines	Linderniaceae	H		+	+	+	I
Lindernia rotundifolia (L.) Alston	Linderniaceae	H	+	+	+		I
Ludwigia adscendens (L.) Hara	Onagraceae	H		+	+		I
Ludwigia hyssopifolia (G.Don) Exell	Onagraceae	H	+			+	Tam
Macroptilium lathyroides (L.) Urb.	Fabaceae	H			+		Tam
Mallotus nudiflorus (L.) Kulju & Welzen	Euphorbiaceae	T	+	+	+		I
Malvastrum coromandelianum (L.) Garcke	Malvaceae	H	+	+	+		I
Mecardonia procumbens (Mill.) Small	Plantaginaceae	H		+	+		Tam
Melinis repens (Willd.) Zizka	Poaceae	H	+	+	+		Af
Merremia emarginata (Burm.f.) Hallier.f.	Convolvulaceae	C		+	+	+	Sea
Merremia hederacea Hall.f.	Convolvulaceae	C	+	+		+	I
Merremia tridentata (L.) Hallier.f.	Convolvulaceae	C		+			I
Mesosphaerum suaveolens (L.) Kuntze	Lamiaceae	H	+	+	+	+	Cam
Microcos paniculata L.	Malvaceae	S				+	I
Mikania micrantha Kunth	Asteraceae	C	+	+	+	+	Sta
Mimosa pudica L.	Fabaceae	H	+		+	+	I
Mitragyna parvifolia (Roxb.) Korth.	Rubiaceae	T		+	+		I
Momordica charantia L.	Cucurbitaceae	C		+	+	+	I
Morinda coreia Buch.-Ham.	Rubiaceae	T	+	+			I
Muntingia calabura L.	Muntingiaceae	T			+		Tam
Nicoteba betonica (L.) Lindau	Acanthaceae	H	+	+	+		I
Nicotiana plumbaginifolia Viv.	Solanaceae	H		+	+	+	Tam
Nymphoides hydrophylla (Lour.) Kuntze	Menyanthaceae	H	+		+		I
Ocimum americanum L.	Lamiaceae	H	+		+		Pal
Oldenlandia corymbosa L.	Rubiaceae	H		+	+		I
Ottelia alismoides (L.) Pers.	Hydrocharitaceae	H		+	+		I
Ouret lanata (L.) Kuntze	Amaranthaceae	H			+		I
Oxalis corniculata L.	Oxalidiaceae	H	+	+	+		I
Oxystelma esculentum (L.f.) R.Br.ex Schult.	Apocynaceae	C		+	+	+	Au
Parthenium hysterophorus L.	Asteraceae	H			+		Am
Paspalum distichum L.	Poaceae	H	+		+	+	Vt
Paspalum vaginatum Sw.	Poaceae	H		+	+		Sta
Passiflora foetida L.	Passifloraceae	C		+	+	+	Tam
Pergularia daemia (Forssk.) Chiov.	Apocynaceae	C	+		+		I
Persicaria glabra (Willd.)	Polygonaceae	H			+	+	I
Phaulopsis dorsiflora (Retz.) Sant.	Acanthaceae	H		+			I
Phyla nodiflora (L.) Greene	Verbenaceae	H	+	+	+	+	I

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Phyllanthus acidus (L.) Skeels	Phyllanthaceae	T		+	+	+	Br
Phyllanthus amarus Schumacher & Thonn.	Phyllanthaceae	H	+		+	+	Am
Phyllanthus lawii J.Graham	Phyllanthaceae	S	+	+	+	+	I
Phyllanthus maderaspatensis L.	Phyllanthaceae	H			+	+	I
Phyllanthus reticulatus Poir.	Phyllanthaceae	S		+	+	+	I
Phyllanthus urinaria L.	Phyllanthaceae	H	+	+			Tea
Physalis angulata L.	Solanaceae	H	+	+	+	+	Tam
Pistia stratiotes L.	Araceae	H		+	+	+	I
Pithecellobium dulce (Roxb.) Benth.	Fabaceae	T			+		Tam
Pluchea tomentosa DC.	Asteraceae	H		+	+		I
Plumbago zeylanica L.	Plumbaginaceae	H			+	+	I
Polygonum plebeium R.Br.	Polygonaceae	H	+	+	+		I
Pongamia pinnata (L.) Pierre	Fabaceae	T	+	+	+	+	I
Pontederia crassipes Mart.	Pontederiaceae	H			+	+	Sam
Pontederia vaginalis Burm.f.	Pontederiaceae	H		+	+	+	I
Portulaca oleracea L.	Portulacaceae	H	+	+		+	Pa
Prosopis cineraria (L.) Druce	Fabaceae	T		+	+	+	I
Prosopis juliflora (Sw.) DC	Fabaceae	T	+	+	+	+	Tam
Rhynchospora corymbosa (L.) Britton	Cyperaceae	H		+			I
Ricinus communis L.	Euphorbiaceae	S		+			I
Rotula aquatica Lour.	Boraginaceae	S	+		+		I
Rungia pectinata (L.) Nees	Acanthaceae	H	+			+	I
Saccharum spontaneum L.	Poaceae	H	+	+	+	+	I
Salix tetrasperma Roxb.	Salicaceae	T	+	+	+	+	I
Samanea saman (Jacq.) Merr.	Fabaceae	T		+	+	+	Sam
Santalum album L.	Santalaceae	T	+	+		+	I
Schoenoplectiella articulata (L.) Lye	Cyperaceae	H			+		I
Scoparia dulcis L.	Plantaginaceae	H	+	+	+	+	Tam
Senegalia catechu (L.f.) P.J.H.Hurter & Mabb.	Fabaceae	T	+	+		+	I
Senna auriculata	Fabaceae	S		+		+	I
Senna occidentalis (L.) Link	Fabaceae	H	+		+		Tam
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae	T	+				Sea
Senna sophera (L.) Roxb.	Fabaceae	S		+	+	+	Tam
Senna tora (L.) Roxb.	Fabaceae	H		+	+	+	I
Sesamum indicum L.	Pedaliaceae	H			+		I
Sesbania sesban (L.) Merr.	Fabaceae	S	+			+	I
Setaria geminata (Forssk.) Veldkamp	Poaceae	H	+	+		+	I
Setaria intermedia Roem. & Schult.	Poaceae	H	+	+	+		I
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	H		+		+	I
Sida cordata (Burm.f.) Borssum	Malvaceae	H		+	+	+	I
Solanum nigrum L.	Solanaceae	H	+	+	+	+	I
Solanum torvum Sw.	Solanaceae	S	+		+		Pan
Solanum virginianum L.	Solanaceae	H	+		+		I
Sonchus asper Hill	Asteraceae	H	+	+	+	+	I
Spermacoce verticillata L.	Rubiaceae	H	+	+	+		Tam

Botanical name	Family	Habit	Dharma	Kumadwathi	Tunga Bhadra	Varada	Nativity
Sphaeranthus indicus L.	Asteraceae	H	+		+		Tam
Spilanthes paniculata Wall. ex DC.	Asteraceae	H	+	+	+	+	Ch
Spilanthes radicans Jacq.	Asteraceae	H					I
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	S			+		Tam
Stachytarpheta jamaicensis (L.) Vahl	Verbenaceae	H	+	+	+	+	Tam
Stemodia viscosa Roxb.	Plantaginaceae	H	+	+	+	+	I
Streblus asper Lour.	Moraceae	T		+	+	+	I
Striga asiatica (L.) Kuntze	Orobanchaceae	H	+		+		I
Striga densiflora (Benth.) Benth.	Orobanchaceae	H					I
Synadenium grantii Hook.f.	Euphorbiaceae	S		+		+	I
Syzygium cumini (L.) Skeels	Myrtaceae	T		+	+		I
Tamarindus indica L.	Fabaceae	T	+	+	+	+	Taf
Tamarix ericoides Rottler	Tamaricaceae	S			+	+	I
Tecoma stans (L.) Kunth	Bignoniaceae	S	+			+	I
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T			+	+	I
Terminalia catappa L.	Combretaceae	T	+	+	+	+	I
Terminalia elliptica Willd.	Combretaceae	T		+		+	I
Themeda triandra Forssk.	Poaceae	H	+				I
Tinospora cordifolia (Willd.) Hook.f. & Thomson	Menispermaceae	C		+	+		I
Tithonia diversifolia (Hemsl.) A.Gray	Asteraceae	S		+	+		I
Tonningia axillaris (L.) Kuntze	Commelinaceae	H	+		+		I
Trianthema portulacastrum L.	Aizoaceae	H	+	+	+	+	I
Tribulus terrestris L.	Zygophyllaceae	H		+	+	+	I
Trichodesma indicum (L.) Lehmann	Boraginaceae	H	+		+	+	I
Tridax procumbens L.	Asteraceae	H	+	+	+		Cam
Turnera ulmifolia L.	Turneraceae	H		+	+		I
Typha domingensis Pers.	Typhaceae	H	+	+	+	+	I
Vachellia farnesiana (L.) Wight & Arn.	Fabaceae	T	+		+	+	Tam
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	Fabaceae	T	+	+	+	+	I
Vahlia dichotoma (Murray) Kuntze	Vahliaceae	H			+		I
Vallisneria spiralis L.	Hydrocharitaceae	H		+	+	+	I
Ventilago maderaspatana Gaertner	Rhamnaceae	S	+				I
Verbascum coromandelianum (Vahl) Hub.-Mor.	Scrophulariaceae	H	+		+	+	I
Vincetoxicum indicum (Burm.f.) Mabb.	Apocynaceae	C		+	+	+	I
Vitex leucoxylon L.f.	Lamiaceae	T	+	+		+	I
Vitex negundo L.	Lamiaceae	T		+	+		Ja
Volkameria inermis L.	Lamiaceae	S	+		+		I
Wendlandia thyrsoidea (Roem. & Schult.) Steud.	Rubiaceae	S	+	+		+	I
Xanthium strumarium L.	Asteraceae	S			+		Sam
Zaleya decandra (L.) Burm.f.	Aizoaceae	H	+	+	+	+	I
Ziziphus nummularia (Burm.f.) Wight & Arn.	Rhamnaceae	T			+	+	I

C—Climber | H—Herb | S—Shrub | T—Tree | +—Present | Af—Africa | Afg—Afganistan | Am—America | Ar—Argentina | Au—Australia | Br—Brazil | Cam—Central America | Ch—China | Eu—Europe | I—Indigenous | Ja—Japan | M—Malyasia | Mad—Madgaskar | Me—Mexico | Med—Mediterranean | Nam—North America | Pa—Pakistan | Pal—Paleotropics | Pan—Pantropical | Sam—South America | Sta—Subtropical America | Sea—Southeast Asia | Taf—Tropical Africa | Tam—Tropical America | Te—Texas | Tea—Tropical East Asia | Vt—Vietnam | W—West Pacific.

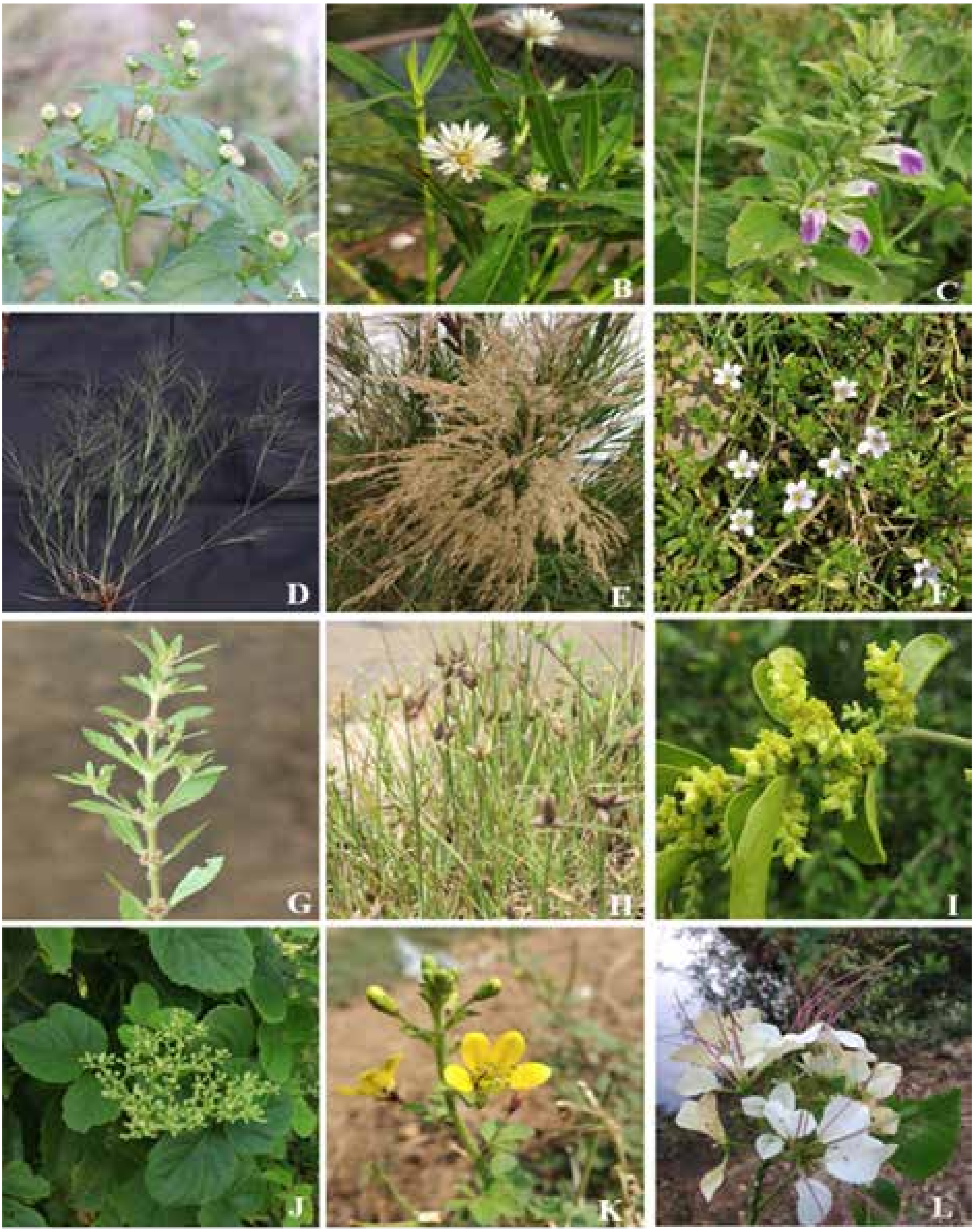

Image 1. A—*Acmella radicans* (Jacq.) R.K.Jansen (Native) | B—*Alternanthera philoxeroides* (Mart.) Griseb (Non-native) | C—*Anisomeles indica* (L.) Kuntze (Native) | D—*Aristida setacea* Retz. (Native) | E—*Arundo donax* L. (Native) | F— *Bacopa monnieri* (L.) Wettstein (Native) | G—*Bergia ammannioides* Roxb. (Native) | H—*Bolboschoenus maritimus* (L.) Palla (Native) | I—*Cansjera rheedei* Gmelin (Native) | J—*Causonis trifolia* (L.) Mabb. & J.Wen. (Native) | K—*Cleome viscosa* L. (Non-native) | L—*Crateva magna* (Lour.) DC. (Native). © Ningaraj S. Makanur.

Image 2. A—*Crinum viviparum* (Lam.) R.Ansari & V.J. Nair (Native) | B—*Croton bonplandianus* Baill. (Native) | C—*Cryptolepis buchananii* Roemer & Schultes (Non-native) | D—*Cryptostegia grandiflora* R.Br. (Non-native) | E—*Cuscuta campestris* Yunck. (Non-native) | F—*Datura discolor* Bernh. (Non-native) | G—*Dentella repens* (L.) J.R.Forst. & G.Forst. (Native) | H—*Dicliptera cuneata* Nees (Native) | I—*Dinebra retroflexa* (Vahl) Panz. (Native) | J—*Ficus heterophylla* L.f. (Native) | K—*Fuirena umbellata* Rottboell (Native) | L—*Glinus oppositifolius* (L.) Aug. DC. (Native). © Ningaraj S. Makanur.

Image 3. A—*Gnaphalium polycaulon* Pers. (Native) | B—*Grangea maderaspatana* (L.) Poir. (Non-native) | C—*Heliotropium marifolium* J.Koenig ex Retz. (Native) | D—*Hemigraphis latebrosa* (Roth) Nees (Native) | E—*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult. (Native) | F—*Homonoia retusa* (Graham ex Wight) Müll. Arg. (Native) | G—*Homonoia riparia* Lour. (Native) | H—*Hygrophila auriculata* (Schumach.) Heine (Native) | I—*Ipomoea aquatica* Forsk. (Native) | J—*Ipomoea carnea* (L.) Sweet (Non-native) | K—*Limnocharis flava* (L.) Buchenau (Non-native) | L—*Lindernia hyssopioides* (L.) Haines. (Native). © Ningaraj S. Makanur.

Image 4. A—*Ludwigia adscendens* (L.) Hara (Native) | B—*Mallotus nudiflorus* (L.) Kulju & Welzen (Native) | C—*Merremia tridentata* (L.) Hallier f. (Native) | D—*Mikania micrantha* Kunth (Non-native) | E—*Nymphoides hydrophylla* (Lour.) Kuntze (Native) | F—*Ottelia alismoides* (L.) Pers. (Native) | G—*Phyllanthus lawii* J. Graham (Native) | H—*Pistia stratiotes* L. (Native) | I—*Pontederia crassipes* Mart. (Non-native) | J—*Pontederia vaginalis* Burm.f. (Native) | K—*Rotula aquatica* Lour. (Native) | L—*Saccharum spontaneum* L. (Native). © Ningaraj S. Makanur.

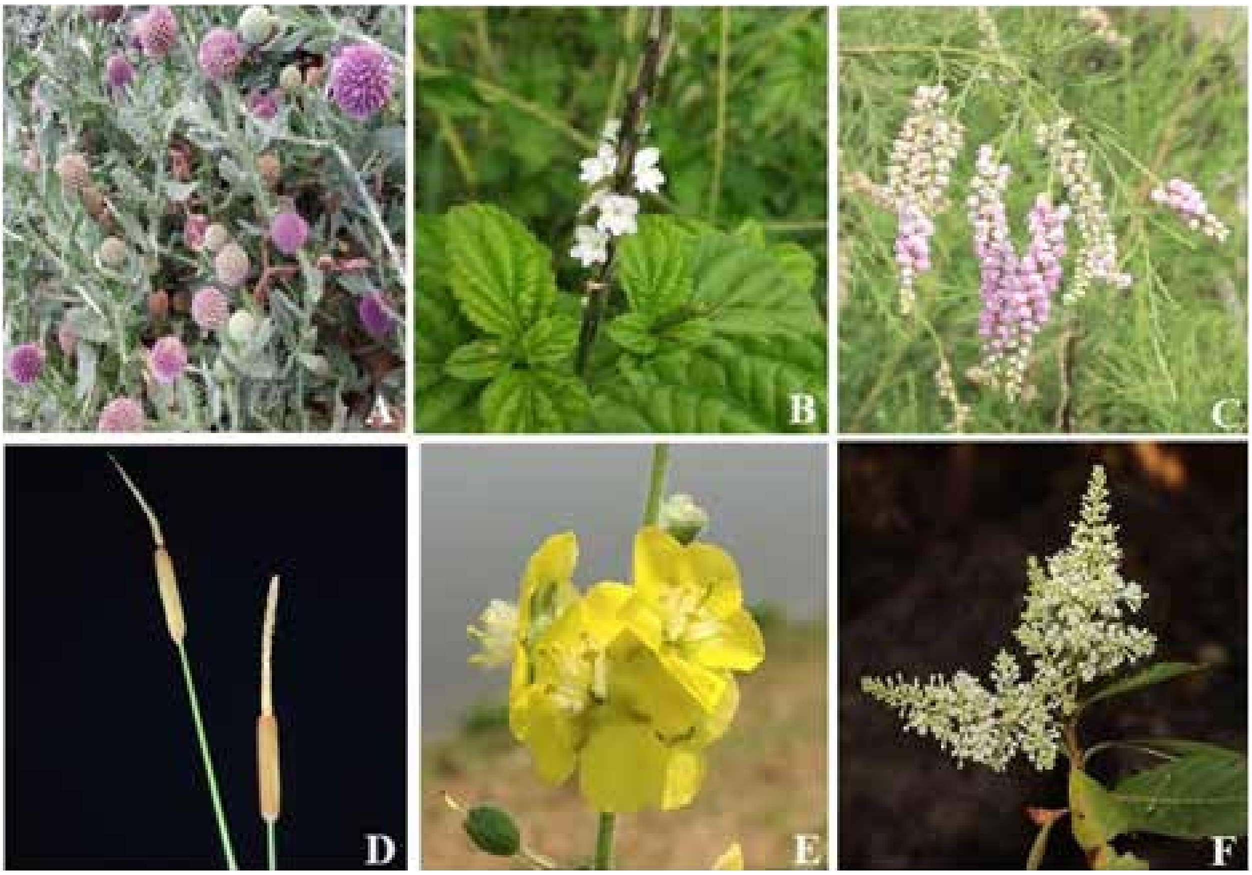

Image 5. A—*Sphaeranthus indicus* L. (Non-native) | B—*Stachytarpheta cayennensis* (Rich.) Vahl (Non-native) | C—*Tamarix ericoides* Rottler (Native) | D—*Typha domingensis* Pers. (Native) | E—*Verbascum coromandelianum* (Vahl) Hub.-Mor. (Native) | F—*Wendlandia thyrsoidea* (Roem. & Schult.) Steud. (Native). © Ningaraj S. Makanur.

Image 6. Threats to the riparian vegetation in the study area: A—Dumping of plastic waste | B—Sand mining | C—Construction of dams and check dams | D—Discharging of industrial effluents | E—Invasive alien species. © Ningaraj S. Makanur

loss and vegetation degradation include agricultural encroachment, overgrazing, the construction of dams and check dams, sand mining, dumping of plastic and chemical waste, invasive species, and tourism activities. Therefore, it is crucial to implement effective conservation programs to protect these vital riparian ecosystems.

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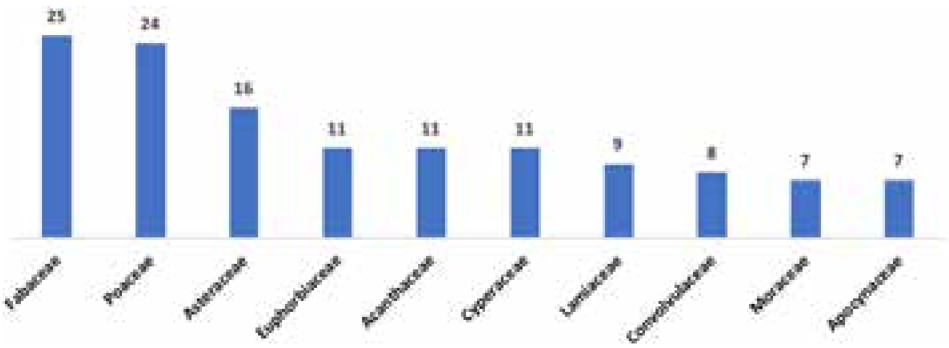

Figure 4. Ten native dominant families in the study area.

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ARTICLE

Conservation strategies for *Vatica lanceifolia* (Roxb.) Blume: habitat distribution modelling and reintroduction in northeastern India

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Abstract: *Vatica lanceifolia* (Roxb.) Blume is a Critically Endangered species and native to the northeastern India, faces significant conservation challenges. Habitat distribution modelling approach was adopted to determine the potential region and suitable habitat for reintroduction of this species in order to improve its conservation status. The model incorporated six key variables: normalized difference vegetation index (NDVI), elevation, slope, stress index, soil type, and soil moisture based on weighted overlay modelling approach. The study identified prospective locations for species reintroduction in the lower altitudes (175–470 m) and moderate slope of 10–30 degrees with excessively drained loamy soils within its present home range. NDVI exhibited a crucial role with intermediate magnitudes of 0.2–0.43 along with soil moisture of moderate range of 30–60 % respectively. The physiological impact in the study site was assessed in terms of stress index, which exhibited values of 0.2–0.31. These values indicate a moderate magnitude of stress, highlighting the fragile state of the ecosystem supporting the species. The model delineated the study area into three habitat zones, highly suitable (51%), moderately suitable (46%), and least suitable (3%) for reintroducing *V. lanceifolia*. This study provides comprehensive scientific evidence to enhance biodiversity conservation initiatives and optimize management strategies.

Keywords: East Karbi Anglong, habitat fragmentation, in-situ conservation, management strategy, native species, protected area, species diversity, species preference area, species reintroduction, weighted overlay modelling.

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Author contributions: PM, RMK, AB, and PKM conceived the ideas. PM, AB, and RMK designed methodology. PM, BD and RMK collected the data. PM, RMK, and AB analysed the data; PM and RMK led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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INTRODUCTION

Ecosystem destruction by altering structural and functional integrity have been driven by rapid changes in climatic conditions, habitat fragmentation, anthropogenic intervention, pollution, coupling invasion of unwanted species, and pathogens. A healthy ecosystem with proper functioning depends on the status of biodiversity and anthropogenic factors to a great extent. Some species act as keystone species and serve as flagships to drive larger conservation programmes (Rivers et al. 2015). An increase in the number of threatened species and their gradual extinction at global level indicates that biodiversity is under serious threat (Pimm et al. 1995; Balmford et al. 2003; Jenkins et al. 2003). Therefore, it is inevitable to conserve individual species to sustain the existing biodiversity.

Alterations of ecosystems have been accounted for the decline of about one fifth of the economically important plant species (Brummitt et al. 2008). The knowledge of distribution of threatened species is important for their conservation, restoration, and rehabilitation. Potentially, habitat modelling can support the ecosystem by identifying the region for the mass propagation of the species along with its conservation (Barik & Adhikari 2011; Zurell et al. 2020).

Vatica lanceifolia (Roxb.) Blume belonging to the family Dipterocarpaceae is an evergreen species distributed throughout the moist tropical forests of India (Assam), Bangladesh, eastern Himalaya, Myanmar, and Tibet. The plant is listed in the IUCN Red List of Threatened Species as 'Critically Endangered' (IUCN 2024) under criteria A1cd, C2a. It is an important source of non-timber forest product (NTFP). Its bark is useful as incense and in charcoal production in eastern Asian countries. Besides having immense potential as an economically important species, the population of *V. lanceifolia* is found to be declining at an alarming rate. The human activities such as over-exploitation, habitat destruction, and fragmentation of forest areas have substantially altered the natural landscapes, affecting the *V. lanceifolia* population in its native habitats and preventing its sufficient propagation in its natural state (Borah & Devi 2014). The distribution of a species is a crucial spatial trait that is impacted by the environment and human activity. The occurrence of new species, changes in a species' range, species extinction, loss of biodiversity, loss of ecosystem resilience and disturbance regimes have all been linked to climate change (Piirainen et al. 2023). Due to mass extraction, the native species of the region are mostly confined to the protected areas like national parks, biosphere reserves, wildlife sanctuaries, and reserve forest with few populations' counts. The number of species with constrained ranges of suitable habitat is rapidly rising globally, and it also applies to well-known taxa. By connecting a species' occurrence to the predictor variables, distribution modelling seeks to comprehend and display a species' spatial distribution in hypothetical climate scenarios from the past, present or future. Due to its diversity and the presence of numerous endemic species, the sustainable management of the flora and fauna of the Indian subcontinent is a matter of global importance. Habitat distribution modelling identifies optimal environmental conditions for a species and maps their actual and potential geographic distribution. They increase our understanding of the ecological niche of the species by demonstrating the relationship between environmental variables and the logistic probability of presence also known as habitat appropriateness (Chandra et al. 2021). The geographical range of a species is frequently estimated using habitat distribution modelling based on the occurrence data and environmental factors that are thought to affect their dispersion (Tsegmed et al. 2023).

The noticeable presence of *V. lanceifolia* have been reported from Gibbon Wildlife Sanctuary, Nambor Wildlife Sanctuary, Jeypore Reserve Forest, Tinkupani Reserve Forest, Abhaypur Reserve Forest, Kukuramora Reserve Forest in the region (Sankar & Devi 2014; Giri et al. 2019). Mass multiplication of species through seeds, awareness and active participation of locals, community-based organizations, non-government organizations, and the forest department are essential for both in situ and ex situ conservation. For predicting the geographic distribution of plant species, a variety of species distribution models, including the generalised additive model, the domain environmental envelope, the genetic algorithm for rule-set construction, maximum entropy model (Maxent) and weighted overlay model are often utilised. Among them, the weighted overlay model has been demonstrated to be one of the reliable and consistent ones to estimate and predict current and future suitable habitats for various threatened and important medicinal plants with minimal input and ease of analysis of parameters for fruitful application (Paudel et al. 2012; Nath et al. 2021). The study depicts population size and habitat distribution of *V. lanceifolia* in the study area. The destruction of ecosystems caused by climate change, habitat fragmentation, anthropogenic intervention, and invasive species has significantly affected biodiversity. *V. lanceifolia,* a Critically Endangered tree species in northeastern India, is experiencing drastic population

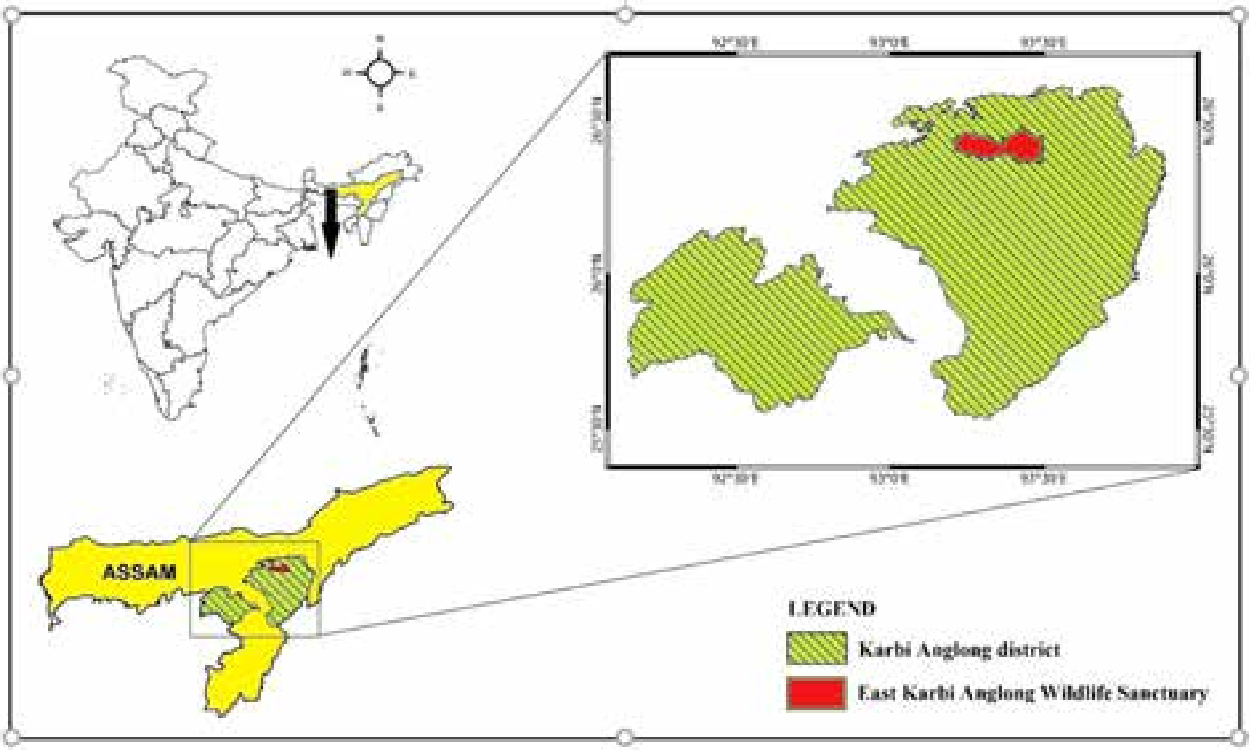

Figure 1. Map of the study area with geographic location.

declines due to over-exploitation and habitat loss. Understanding its potential distribution through habitat modelling would provide valuable insights for developing targeted conservation strategies.

MATERIAL AND METHODS

Study Area

East Karbi Anglong Wildlife Sanctuary is located in Karbianglong District of Assam, India. It is one of the major forests of the state covering an area of 221.81 km². It is situated in 24°33'–26°35' N and 92°10'–93°50' E and is 80–600 m (Figure 1). The site is an important component of the Karbi Anglong-Kaziranga landscape and Kaziranga-Karbi Anglong Elephant Reserve. It has also been recognized as one of the rich floral and faunal diversity region within the Indo-Burma biodiversity hotspots (WWF 2002). The region experiences a sub-tropical humid climate with an annual rainfall of 1,800 mm. The average maximum temperature is around 30 °C in August, and the minimum goes down to 6.5 °C in winter. The topography of the study site ranges from undulating hills to wide valleys and steep gorges with rivers and creeks, as well as annual and perennial streams. The soil is well-drained, sandy loamy to clayey loamy.

Description

Vatica lanceifolia is a middle canopy evergreen tree species which attains an average height of about 12 m. Its bark is smooth and mottled pale greyish-green in color. Mature leaves are elliptic or oblong measuring 10.15–22.9 cm in length and 3–8.9 cm in breadth. Leaves bear 11–15 slender and arched lateral nerves accompanying reticulated tertiary nerves on each half. Petioles are slightly swollen below the insertion of the blade. The pentamerous white flower is axillary, solitary or fascicled and pubescent with fragrance. The calyx is about 0.25 cm long with velvet aestivation having five segments that are deltoid-acute but are uniformly accreted in fruit. Petals are imbricate, oblanceolate or strap-shaped. Stamens are 15 with unequal anthers. The ovary is turbinate and puberulous and 0.20 cm long. The stout and clad style is as long as the ovary with a tridentate stigma. Fruit is ovoid, globose and brown velvety with fleshy cotyledons supported by thin ovate wings (Image 1).

Distribution: Assam, Bangladesh, eastern Himalaya, Myanmar, Tibet (POWO 2023).

Flowering and fruiting: April to May (Sharma et al. 2022).

Conservation status

Global assessment was based on IUCN Red List criteria A1cd, C2a which uses the geographic range size of a species and evidence of declining or fragmented population (Ashton 1998).

Method of studying population status

Field visits to East Karbi Anglong Wildlife Sanctuary were made in the first week of alternate months, during the period from 2019 to 2022. To record the existing population status, random sampling strategy was adopted. The assessment of *V. lanceifolia* was made by counting all individuals, including saplings (>1 m in height) and stems with a circumference of ≥10 cm at 1.35 m height, within 31.62 × 31.62 m quadrats located in each 250 × 250 m grid of occurrence across the study area.

Occurrence data and environmental variables

The occurrence coordinates of *V. lanceifolia* were recorded using GPS (Garmin eTrex H). A total of 14 occurrence coordinates of *V. lanceifolia* considering minimum proximity area of 1 km^2 for sampling were used for modelling suitable habitat across the entire study area. Maximum likelihood area of occurrence approach was adopted for collecting coordinates for the modelling purpose. A total of six environmental variables such as normalized difference vegetation index (NDVI), elevation, slope, stress index, soil type, and soil moisture were used to predict the distribution of the potential habitats of *V. lanceifolia*. Slope and elevation were derived from ASTER global digital elevation map (GDEM) with a spatial resolution of 30 m. NDVI, soil moisture, and stress index were derived from Landsat-8 OLI/TIRS data with a spatial resolution of 30 m. The soil type of the study area was determined from the Soil Series of Assam. Soil type 1 represents soil with deep somewhat excessively drained, loamy skeletal soil occurring on moderately sloping site, slopes of hill with severe erosion hazard and slight stoniness. Soil type 2 represents soil with characteristics of very deep well drained loamy skeletal soil occurring on moderately steeped sloping side and slopes of hills with severe erosion hazards. Soil type 3 represents soil with characteristics of moderately deep well drained clayey soil occurring on moderately sloping sites, slopes of hill with moderate erosion hazards and regoliths. The predictor variables were selected on the basis of their plausible ecological significance for habitat suitability analysis (Table 1).

Variables ranges and weightage assigning

All the six environmental variables in the final habitat suitability map shows different ranges such as elevation 175–890 m, slope 0.00–56.42 degree, NDVI 0.01–0.55, stress index 0.01–0.41 si, soil moisture 0.16–1.00 bar, and soil type 1–3. After reclassification of each of the parameters, the next important step during the multi-criteria analysis done was to assign a weightage percent to each of the parameter according to their importance. NDVI reflects vegetation type & health, and elevation influences climatic conditions. Slope affects plant growth and root stability. Soil moisture index is associated with the level of moisture available to plants. Leaf stress index indicates photosynthetic activity & water content of leaves, and soil type determines the availability of minerals, pH, drainage, and aeration (Table 1). The rationale behind the selection of environmental variables is based on interviews with field experts and local informants, using a standard analytical hierarchy process (AHP) questionnaire. It was used to estimate the significance of the selected parameters for identifying suitable sites for the species (Satty 1980). The highest weightage, 25% each, was assigned to elevation and soil moisture while NDVI, slope, stress index, and soil type were each assigned a weightage of 12.5% (Table 2).

Table 1. Model predictors and their plausible ecological relevance for habitat suitability.

Predictor variables	Ecological relevance
Normalized difference vegetation index (NDVI)	Linked with vegetation type and vigor (Xue & Su 2017)
Elevation	Related to climatic variation (Körner 2007)
Slope	Related to plant growth and root failure (Lan et al. 2020)
Soil moisture index	Moisture availability for plants (Veihmeyer & Hendrickson 1927)
Leaf stress index	Related to leaf photosynthetic response and leaf water content (Argyrokastritis et al. 2015)
Soil type	Linked with the availability of minerals, pH, drainage, aeration (Sharma et al. 1980)

Model calibration and evaluation

The models were ensembled using the weighted overlay model based on six variables NDVI, elevation, slope, soil moisture, stress index, and soil type as predictors of habitat suitability of *V. lanceifolia*. Species distribution maps were generated based on the variables considered. The attribute data of six criteria maps were prepared based on empirical data and classified into five classes to examine the study areas more clearly in different ranges. Weightage were assigned to the criteria based on field-based observations and through pixel count of the occurrence coordinates in each variable generated map. After the weightage assigned, the soil

Table 2. Parameters with their ranges and weightage (%).

Criteria	Ranges of values	Computed weightage %
Elevation	175–890 m	25
Slope	0.00–56.42 deg	12.5
Normalized difference vegetation index	0.01–0.55 (NDVI)	12.5
Stress index	0.01–0.41(SI)	12.5
Soil moisture	0.16–1.00 (Bar)	12.5
Soil type	1–2	25

series of Assam was over layered to compare the soil types of the species in the study site and generate the habitat distribution map with selected variables (Figure 2). For determining the appropriate weightage percentage to each of variables, AHP developed by Satty (1980) was applied. The model classification was performed from those generated maps with pixels count and a final map was obtained by using ArcGIS version 9.3. The final habitat distribution map was prepared adopting weighted overlay model from the six criteria reference maps and reclassified into four suitable habitat classes – Class 1 represents low, Class 2 moderate, Class 3 high, and Class 4 very high for *V. lanceifolia*, respectively.

RESULTS

Population status

Field survey and post modelling validation revealed that *V. lanceifolia* was present in 21 localities in the wildlife sanctuary. Overall, 112 individuals comprising of 40 seedlings, 27 saplings, and 45 adults were enumerated during the entire study period. The dominant species associated with *V. Lanceifolia* were *Bridelia retusa* (L) Spreng., *Bauhinia variegata* L., *Careya arborea* Roxb., *Dillenia indica* L., *Magnolia hodgsonii* (Hk.f. & Thomson) H.Keng and *Wrightia coccinea* (Roxb. ex Hornem.) Sims. The distribution of *V. lanceifolia* within the wildlife sanctuary was scattered due to the sporadic occurrence of bamboo patches over large areas. *Bambusa affinis*, *B. balcooa*, *B. pallida*, and *B. tulda* exhibited gregarious encroachment in the forest area leading to scattered and sparse distribution of the diverse tree species.

Habitat suitability

V. lanceifolia was distributed over an area of 217 km^2. The selected parameters NDVI, elevation, slope, soil moisture, stress index, and soil type recognized the optimal growth and establishment of *V. lanceifolia* in the study site. Among the six used variables, elevation and soil type with 50% computed weightage play a significant role for the successful establishment of the species in the final habitat map. Lower elevation (175–470 m) admits ample number of individuals across the elevation range of 175–890 m at the study area (Image 2). The regions with lower elevation with gentle slope are the favourable topography for reintroduction of *V. lanceifolia*. Considerable distribution of *V. lanceifolia* was encountered in the moderate slope of 10–30 degrees with excessively drained loamy soils within its present home range (Image 2). Excessively deep, drained, loamy skeletal soil occurring on moderately sloping site, slopes of hill with severe erosion hazard and regolith which represent the soil taxonomic type 1 Fine, Typic Hapludalfs and type 2 Loamy-skeletal, Umbric Dystrochrepts, which were found to be predominant in the site of species occurrence. In the study area, these two classes occupy more than 60% of land area with a promising potential of being suitable habitat for *V. lanceifolia* (Image 2). NDVI exhibited a crucial role with intermediate magnitudes of 0.2–0.43. This may be attributed to the dominating widespread bamboo patches in the moderate and higher elevation areas (Image 2). The species preferred lower elevation areas with soil moisture of 30–60% showcasing its preferable soil type across the sites observed (Image 2). Along the study site, physiological impact in the form of stress index was estimated in moderate magnitude with the value of 0.2–0.31 indicating the fragility of the ecosystem holding the species (Image 2). The formulated modelling delineated the study area with 51% of highly suitable, 46% as moderately preferred and 3% as least suitable habitat for *V. lanceifolia* (Image 3). Only 17% of the total area of East Karbi-Anglong Wildlife Sanctuary is under very high suitable zone followed by high suitable zone (33%), moderately suitable (47%), and low-level suitability (3%).

Model performance for distribution

The model formulated delineation of highly suitable areas at lower altitudes with moderate slope and excessively drained loamy soils having moderate magnitude of stress (33%), moderately preferred (47%) and least suitable habitat (3%) for *V. lanceifolia* for its survival and flourishing potential. Field study revealed that the density of *V. lanceifolia* in the sampling plots varied along with the area of suitability proposed by the model. Across the study area, *V. lanceifolia* density varied from 10 stem ha^{-1} to 140 stem ha^{-1} covering different habitat criteria. The mean density of *V. lanceifolia* estimated was 65 ± 11.86 stem ha^{-1} in the

Image 1. *Vatica lanceifolia*: A—Tree | B–C—Flowering inflorescences. © Puranjoy Mipun.

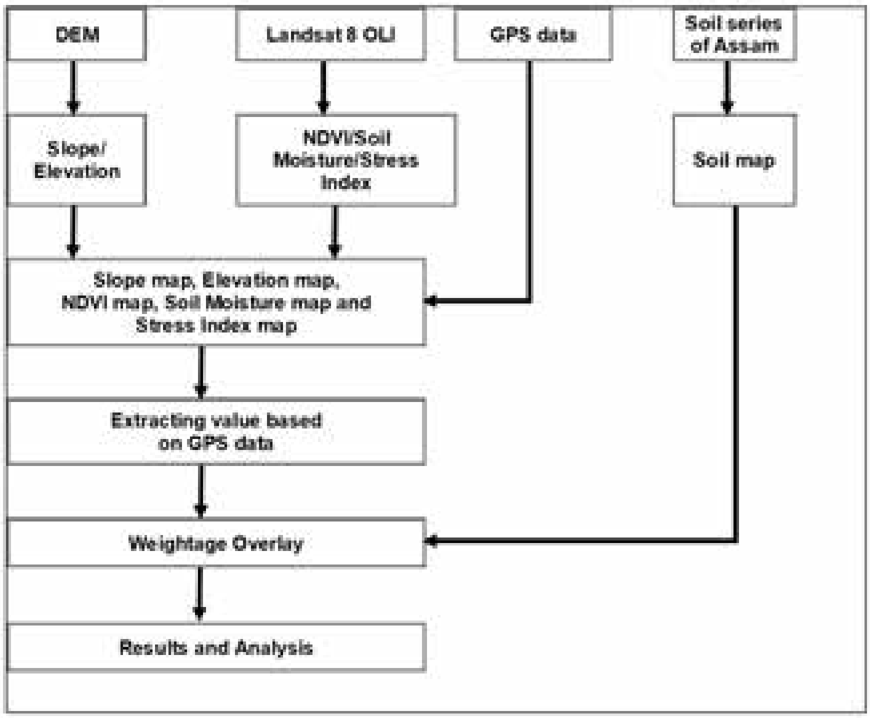

Figure 2. Flow diagram of weighted overlay modelling.

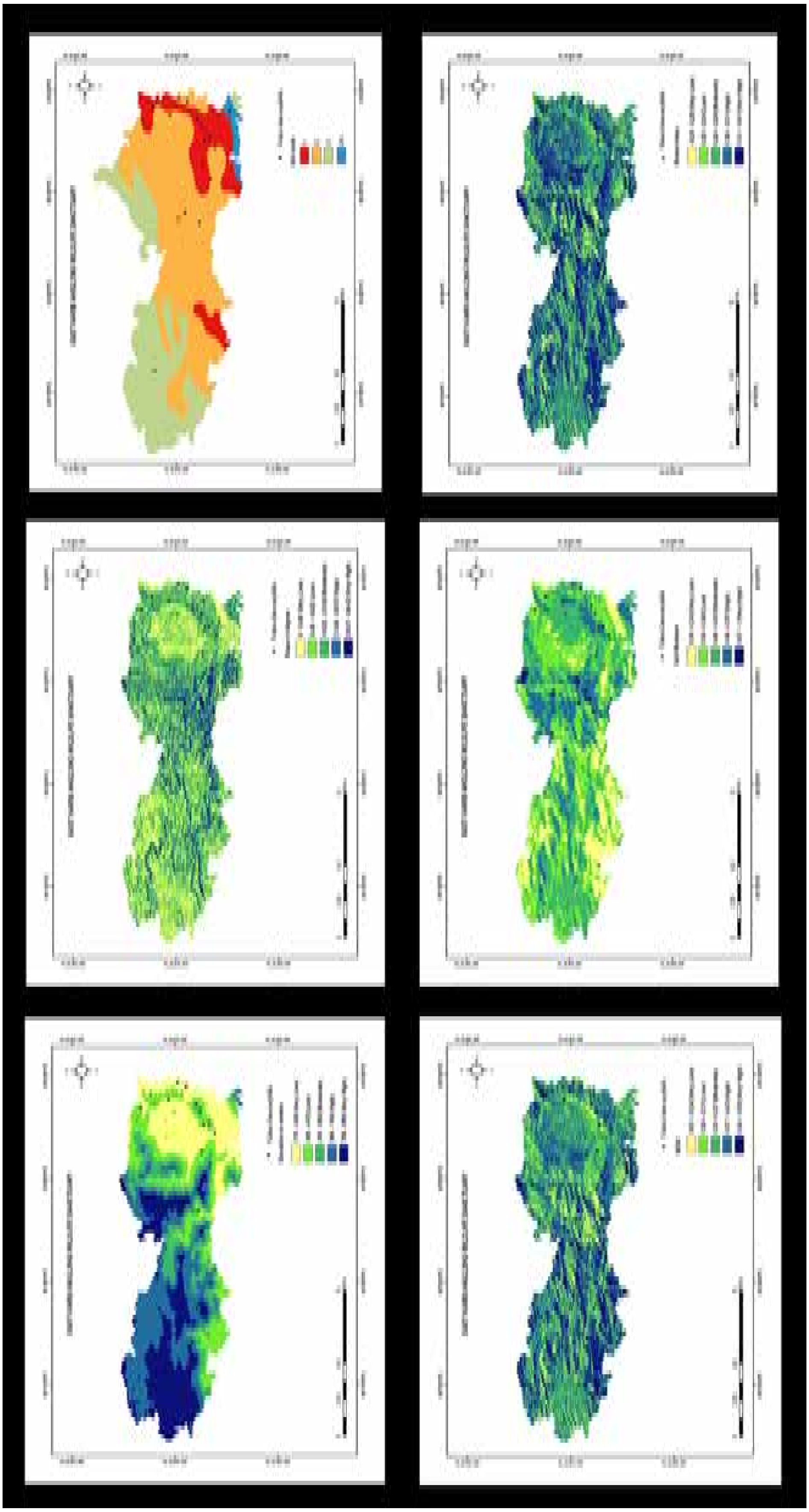

Image 2. Variable (elevation, slope, soil, NDVI, soil moisture and stress index) maps of the study site showing distribution of *Vatica lanceifolia*.

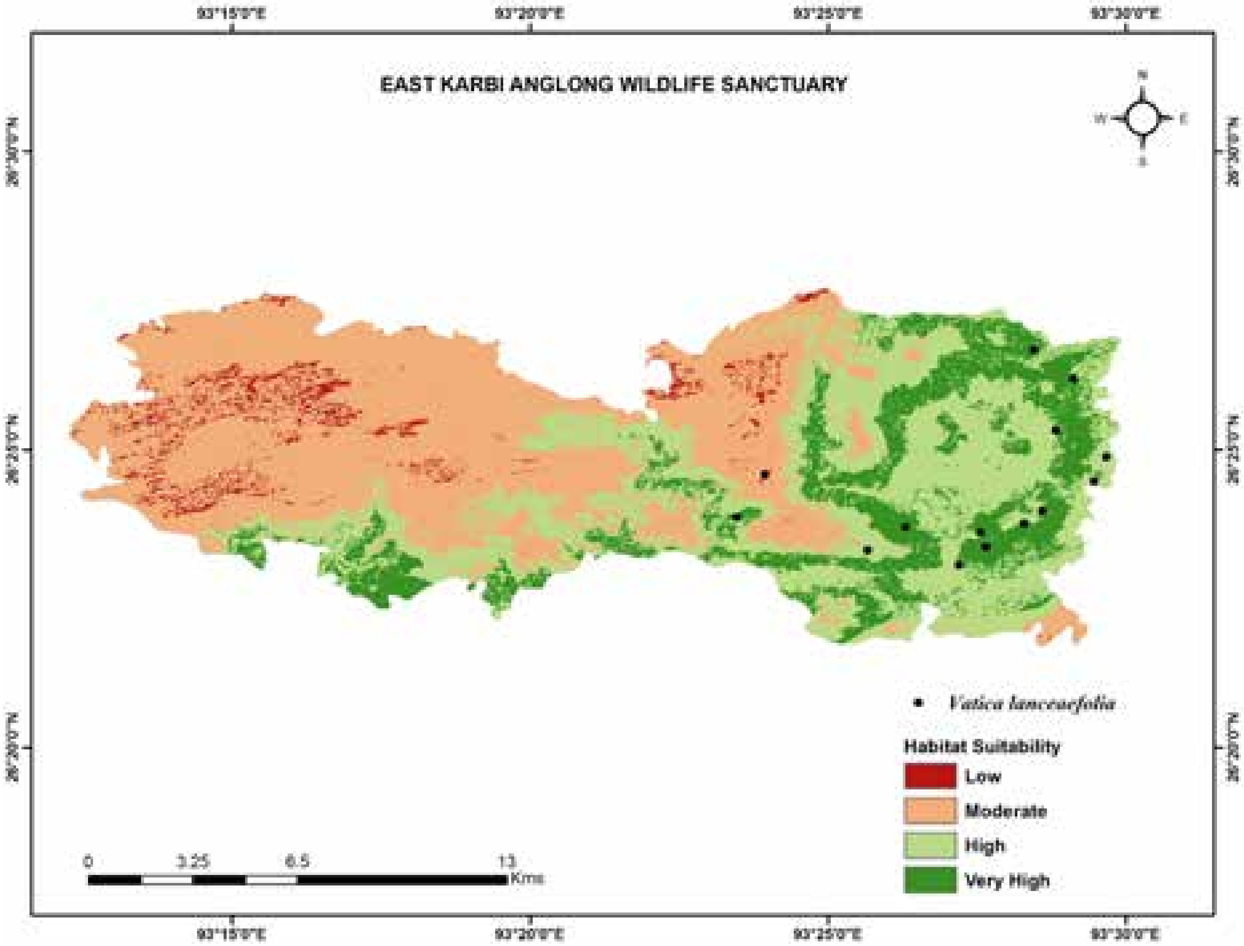

Image 3. Habitat suitability map of *Vatica lanceifolia* in the study site.

highly suitable sites followed by 30 ± 3.54 stem ha^{-1} and 15 ± 3.5 stem ha^{-1} in the moderately preferred and least suitable habitat sampling plots.

DISCUSSION

In this study, we performed a detailed analysis on the suitable habitat of the *V. lanceifolia* under current and future climate conditions, which will function as an important step in formulating sustainable strategies for its conservation. The present study explores both the habitat assessment of *V. lanceifolia* and its spatial distribution. Our model indicated that the suitable habitat area encompassed more than 50% of the total study area. Previous studies documented the habitat suitability for some species, namely, *Angelica glauca* Kitam. (Singh et al. 2020), *Rosa arabica* (Crép. ex Boiss.) Déségl. (Abdelaal et al. 2019), *Ixora* sp. (Banag et al. 2015), *Berkheya cuneata* (Thunb.) Willd. (Pots et al. 2013), *Acer cappadocicum* ssp. *lobelia* (Ten.) A.E. Murray (Sumarga 2011), *Pterocarpus santalinus* L.f. (Babar et al. 2012), *Aglaia bourdillonii* Gamble (Irfan-Ullah et al. 2006). In the Indian Himalayan region, a large number of studies have been carried out on the ecology, systematics, and inventorisation of phytodiversity (Dhar et al. 1997; Joshi & Samant 2004); however, a few studies are available on the population ecology and ecological niche modelling (ENM) (Adhikari et al. 2012; Yang et al. 2013; Samant & Lal 2015) in the region. The adopted weighted overlay modelling illustrates comparatively simplified approach compared to contemporary species distribution modelling (SDM). This simplified and easier approach may be adopted for better outcome through identification of suitable habitat areas and re-introduction of the species in the areas to regain the earlier status of the species in the native zone of occurrence. Habitat modelling illustrated that the area under high and very high zone have prime habitats for *V. lanceifolia*. These areas would act as an in-situ conservation area for the species and could be used for natural assisted regeneration sites. Field based surveys reveal that *V. lanceifolia* has more suitable habitats near the treeline. Moreover, the habitat is poor in some areas due to bamboo patches. Superimposing the predicted map on high-resolution satellite images revealed that mosaic of habitats are more suitable for *V. lanceifolia* in the study areas having 175–890 m elevation and soil type 1–2. Low population density may be due to over-exploitation for household utilization, ethno-medicinal purposes, poor regeneration, low seed germination, habitat loss, and anthropogenic pressure.

The maximum numbers of populations were represented by grassy slope habitats indicating that such habitats form the best platform for the overall development of the species. The high density of the species in grassy slope margin habitats indicated that such habitat is suitable for the germination of seeds and development of seedlings. Remotely sensing enabled landscape-level vegetation study could be an effective strategy for suitable habitat identification and prediction for threatened species. Anthropogenic alterations coupled with climate change lead to land cover fragility for holding the critically endangered species in its natural habitat. Fragmentation of forest and degradation of habitat expedite discontinuity in the distribution of species leading extinction which may be checked through re-establishment of the species in suitable habitable areas for its conservation (Krauss et al. 2003). The present study brings insight into the formulation of strategies for proper management and protection of critically endangered species in the habitable ecosystems. The scattered distribution has been driven by fragmentation of the habitat by other entities like bamboo patches which is better adapted and flourished in the study area. Along with other factors considered in the modelling, the biological and anthropogenic factors may be considered for reintroduction of the species in the favourable patches prevailing in the region as effective conservation strategies (Mirhashemi et al. 2023). In the Indian subcontinent, most of the studies were focused on potential distribution, habitat loss, or future range shifts of native species in changing climate. The investigations incorporated several variables or factors and highlighted efficient utility of findings to design native tree-based agroforestry systems, protected area network, endemic, endangered, or threatened species but analysis did not incline toward charismatic species that can affect the related species conservation and management process (Roy et al. 2022).

Habitat distribution models can relate the occurrences of taxa to their ecological conditions to quantify the realized niche, i.e., species known locations due to environmental tolerance observed in the field (Hutchinson 1957). These habitat distribution models generate geographic predictions of species habitat suitability that can be used to stratify and optimize sampling efficiency (Chiffard et al. 2020). Moreover, integrating the new spatial data from model-guided sampling can reduce spatial bias in subsequent modelling iterations, improve the predictive accuracy of habitat distribution models for rare species, and reliably identify biologically relevant environmental factors (Singh et al. 2009). The areas identified in the present study for the reintroduction of *V. lanceifolia* would not only help in eco-restoration of degraded forests and habitats where the species had existed before but also in rehabilitating the species population and improving its conservation status. Ecosystem destruction driven by habitat fragmentation, climate change, human intervention, and invasive species has profoundly impacted biodiversity. Species may be threatened in fragmented forest landscapes due to bamboo encroachment, physiological and other physiographic and human induced factors. *V. lanceifolia* population is undergoing drastic reduction because of over-exploitation and loss of suitable habitats. Predicting its potential distribution can contribute valuable insights for formulating conservation strategies. Understanding the species abundance and habitat suitability relationship could offer an effective approach for the reintroduction and successful establishment of the threatened species. Therefore, the results would be quite useful for natural resource managers in the management of this species and in-situ conservation of overall biological diversity in the region.

CONCLUSION

This study aimed to delineate suitable habitat for *V. lanceifolia* in East Karbi Anglong Wildlife Sanctuary on the basis of current spatial distribution and allied associated parameters. The study revealed that more than 50% of the area is highly or moderately suitable for the growth and survival of the species. The primal determinants of habitat suitability were elevation (175–470 m), soil type (excessively drained loamy soils), and moderate slopes (10–30 degrees), which create ideal conditions for the establishment of the species. Habitat fragmentation driven by bamboo encroachment, environmental stress, and anthropogenic disturbances has led to a scattered distribution of the species, posing a substantial threat to its natural regeneration. The findings underscore the urgent need for in situ conservation strategies, including habitat protection, restoration initiatives, and strategic reintroduction programs in highly suitable areas. A predictive framework to identify prime conservation zones, facilitate species recovery, and develop long-term management strategies was provided by the habitat modelling approach. The study further highlights the importance of steady population monitoring, climate impact assessments, and community involvement in conservation efforts to ensure the sustained survival of *V. lanceifolia*. The study offers a scientific ground for conservation and re-establishment of this critically endangered species connecting species abundance and habitat suitability. Integration of these insights into conservation planning will assist in habitat loss mitigation, raising ecosystem resilience, and ensuring the ecological stability of *V. lanceifolia* in its native range.

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ARTICLE

Patterns and economic impact of livestock predation by large carnivores in protected areas of southern Kashmir, India

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Abstract: Livestock predation by carnivores in and around protected areas poses a significant threat to the livelihoods of pastoralists and presents a major challenge to carnivore conservation efforts. In Kashmir, livestock predation by the Asiatic Black Bear *Ursus thibetanus* and the Leopard *Panthera pardus* has been documented, but its substantial impact on communities living near protected areas has remained understudied. We assessed livestock predation patterns in three protected areas of southern Kashmir: Overa-Aru Wildlife Sanctuary, Rajparian Wildlife Sanctuary, and Achabal Conservation Reserve. Using an exponential non-discriminative snowball sampling method, followed by a questionnaire survey of affected individuals, we documented predation incidents across all three protected areas, with varying intensity. We identified Sheep *Ovis aries*, Cattle *Bos taurus*, and Domestic Horse *Equus caballus* as the primary prey species. Both the Asiatic Black Bear and the Leopard predominantly preyed on Sheep. The Asiatic Black Bear also targeted Cattle, and the Leopard showed a preference for Domestic Horse. Most predation events occurred during the summer, primarily during the day and within forest areas. However, the Leopard also attacked livestock penned in corrals. Most respondents expressed a positive attitude towards wildlife conservation; a minority advocated for lethal control of the carnivores involved in livestock predation. To mitigate this negative interaction, we propose a comprehensive interaction management strategy aimed at reducing the financial burden on local communities and fostering the long-term conservation of carnivores.

Keywords: Achabal Conservation Reserve, Asiatic Black Bear, carnivore, conservation, human-wildlife interaction, Leopard, mitigation, Overa-Aru Wildlife Sanctuary, Rajparian Wildlife Sanctuary, seasonal variation.

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Author contributions: LR—writing original draft, validation, visualization, methodology, investigation, formal analysis, data curation, conceptualization, software. BAB—writing, review & editing, validation, supervision, methodology, conceptualization, project administration, resources.

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INTRODUCTION

Human-carnivore negative interaction is one of the most pressing challenges in global carnivore conservation (Khorozyan et al. 2015; Dhungana et al. 2019). This interaction is largely driven by the intrinsic traits of large carnivores, including their size, carnivorous diet, and extensive territorial range (Pooley et al. 2017; Kuiper et al. 2021). In agricultural landscapes, carnivores often resort to preying on ungulates or livestock to meet their high-protein dietary needs (Inskip & Zimmermann 2009; Thorn et al. 2012). Although humans and large predators have coexisted for thousands of years, this interaction has intensified in recent decades, particularly in regions where human and wildlife habitats overlap (Morehouse et al. 2020). Growing intolerance towards large carnivores has been fueled by frequent livestock predation and occasional attacks on humans (van Eeden et al. 2018; Khosravi et al. 2024). Consequently, retaliatory killings have emerged as the foremost threat to many carnivore species (Woodroffe et al. 2007; Le Flore et al. 2019; Kichloo et al. 2024).

A significant portion of large carnivore species share their habitats with economically vulnerable human communities, with over a third of their territories overlapping these areas (Braczkowski et al. 2023). This overlap intensifies human-carnivore interaction, especially in and around protected areas, which often harbour large and potentially disruptive mammal species (Karanth & Nepal 2012; Karanth et al. 2013; Hanson 2022). The socio-economic impact on rural livelihoods is profound, primarily due to predation on livestock by these carnivores. These losses pose a substantial obstacle to balancing rural development and biodiversity conservation efforts (Gusset et al. 2009; Loveridge et al. 2010; Khorozyan et al. 2015).

We explored livestock predation by the Asiatic Black Bear *Ursus thibetanus* and the Leopard *Panthera pardus* in and around some protected areas of Kashmir. These two carnivore species are increasingly involved in negative interactions with humans, frequently preying on livestock (Charoo et al. 2011; Dar & Bhat 2022; Dawood et al. 2025). This situation is particularly challenging for communities living near protected areas, where socioeconomic conditions are often fragile, and livelihoods heavily depend on livestock rearing and agriculture (Bhat et al. 2022; Islam et al. 2023). Despite the frequency and significant impact of these events, the issue has not received adequate attention in Kashmir. Farmers frequently endure livestock losses without compensation or support, which can lead to resentment and, in some cases, retaliatory killings of Asiatic Black Bears and Leopards, both of which are already in global decline (Garshelis & Steinmetz 2020; Stein et al. 2020).

To address this issue, it is essential to explicitly understand the patterns of livestock predation to identify regions and periods with high levels of predation. Both the ecological and social aspects of predation incidents, along with the economic losses they incur, need to be thoroughly assessed (Goodrich 2010; Dhungana et al. 2018, 2019). We investigated livestock predation across three protected areas in southern Kashmir: Overa-Aru Wildlife Sanctuary, Achabal Conservation Reserve, and Rajparian Wildlife Sanctuary. We focused on the ecological and social dimensions of livestock predation, without overgeneralizing the interaction aspect. Our objective was to evaluate the economic impact of livestock predation and to identify the spatial patterns of these events, which can provide a foundation for developing effective management strategies in the region.

Study Area

The study was carried out in and around three protected areas in southern Kashmir: Overa-Aru Wildlife Sanctuary, Rajparian Wildlife Sanctuary, and Achabal Conservation Reserve. These three study areas were selected based on varying levels of human-wildlife interactions, the number of villages in the vicinity, diverse land cover types, and differences in the socioeconomic status of the surrounding communities. Overa-Aru Wildlife Sanctuary, located in Anantnag District of Jammu & Kashmir, is nestled between the Zanskar and Pir Panjal mountain ranges, approximately 96 km south of Srinagar (Figure 1A). It spans an area of 425 km^2, with elevations ranging 2,000–5,425 m (Islam et al. 2023). It is surrounded by eight villages situated in and around its boundaries.

Achabal Conservation Reserve is also located in Anantnag District, with elevations ranging 1,636–2,434 m (Figure 1B). The reserve is about 65 km south-east of Srinagar and has nine villages within its buffer zone (Farooq et al. 2021). Rajparian Wildlife Sanctuary, also known as Daksum Wildlife Sanctuary, is located in Anantnag District of Jammu & Kashmir at an elevation ranging 2,360–4,270 m (Figure 1C). Located about 41 km south-east of Anantnag along the Anantnag-Semthan-Kishtwar National Highway 1B, the sanctuary covers an area of 48.27 km^2 (Bhat et al. 2023). There is only one village in the vicinity of the sanctuary, however, livestock from nearby villages are often grazed within the protected area.

MATERIAL AND METHODS

Data on livestock predation by the Asiatic Black Bear and the Leopard in villages in and around three protected areas were collected using the exponential non-discriminative snowball sampling method (Noy 2008; Akrim et al. 2023). Initially, we obtained information on livestock loss incidents from the village heads and subsequently verified with other residents. Where possible, we cross-checked incidents by visiting the sites and authenticating the kills. Monthly visits to village heads were conducted over a two-year period to gather information on any new incidents.

We interviewed affected livestock owners using semi-structured questionnaires to collect data on their socioeconomic status, details of the attacked livestock such as age, gender, time, and date of attack, the predator species involved, and the location of the attack. We visited incident sites and recorded coordinates using a handheld Garmin Oregon-750 GPS device. In cases, where the sites were difficult or dangerous to access, we inferred coordinates using Google Earth (Zarco-González et al. 2013). Additionally, we obtained data on the total livestock owned by village inhabitants from the Veterinary Department of Jammu & Kashmir.

We conducted all statistical analyses using R software (R Core Team 2022) and employed Pearson's chi-square test to analyse data related to patterns of Asiatic Black Bear and Leopard predation, including the livestock species attacked, as well as the time, place and seasons of attacks. Differences between Leopard and Asiatic Black Bear regarding these patterns were also examined using Pearson's chi-square test. We used a polynomial regression model to determine if carnivores showed a preference for any particular age group of the prey. We performed linear regression to investigate whether livestock losses were proportional to their relative availability in the selected villages. Additionally, we generated a livestock predation map, showing the predation sites of Asiatic Black Bear and Leopard using ArcMap 10.5.

RESULTS

From January 2021 to December 2022, we surveyed a total of 50 respondents from three protected areas, encompassing 29 in Overa-Aru Wildlife Sanctuary, 19 in Achabal Conservation Reserve, and two in Rajparian Wildlife Sanctuary. They all had experienced at least one case of livestock predation during this period. The majority of respondents (80%) earned their income from farming or daily labour, followed by those involved in business (6%), government jobs (6%), tourism (4%) and private jobs (4%). They primarily kept Sheep *Ovis aries*, Domestic Goat *Capra hircus*, Cattle *Bos taurus* followed by Domestic Horse *Equus caballus,* except in Overa-Aru Wildlife Sanctuary, where Cattle were more common (Table 1).

A total of 92 livestock losses were reported by respondents, encompassing 59 in Overa-Aru Wildlife Sanctuary, 30 in Achabal Conservation Reserve, and three in Rajparian Wildlife Sanctuary (Figure 2). In Overa-Aru Wildlife Sanctuary, there were 32 incidents of livestock predation. The Leopard was responsible for 53.12% of the attacks, the Asiatic Black Bear for 34.37%, and 12.5% of the attacks were of unknown origin. Of the 59 livestock lost, most were Sheep (64.41%), followed by Domestic Horse (16.95%), Cattle (15.25%), and Domestic Goat (3.39%). Both predators primarily preyed on Sheep, with the Asiatic Black Bear also targeting Cattle and the Leopard preferring Domestic Horse. Notably, neither Asiatic Black Bear attacks on Domestic Horse nor Leopard attacks on Cattle were reported.

In Achabal Conservation Reserve, 20 incidents of livestock predation were reported. The Leopard was responsible for 85% of the attacks and the Asiatic Black Bear for 15%. The 30 livestock lost included Cattle (50%), Sheep (43.33%), and Domestic Horse (6.67%). The Asiatic Black Bear exclusively attacked Cattle, while the Leopard primarily targeted Sheep, followed by Cattle. In Rajparian Wildlife Sanctuary, only two incidents were reported, resulting in the loss of three Cattle over a two-year period. Respondents identified the Asiatic Black Bear as responsible for both attacks.

A significant difference was observed in the livestock species attacked in Overa-Aru Wildlife Sanctuary (χ^2 = 19.052; p < 0.001; Cramer V = 0.594) and in the livestock species attacked by the Leopard in Achabal Conservation Reserve (χ^2 = 8.222; p = 0.016). There was also a significant difference between the livestock species attacked by Asiatic Black Bear and Leopard across the

Table 1. Total livestock kept by residents in three protected areas: Overa-Aru Wildlife Sanctuary (OAWS), Achabal Conservation Reserve (ACR), and Rajparian Wildlife Sanctuary (RWS).

Protected area	Cattle	Domestic horses	Sheep and domestic goats
OAWS	2,665	862	2,421
ACR	1,265	30	1,420
RWS	275	8	300

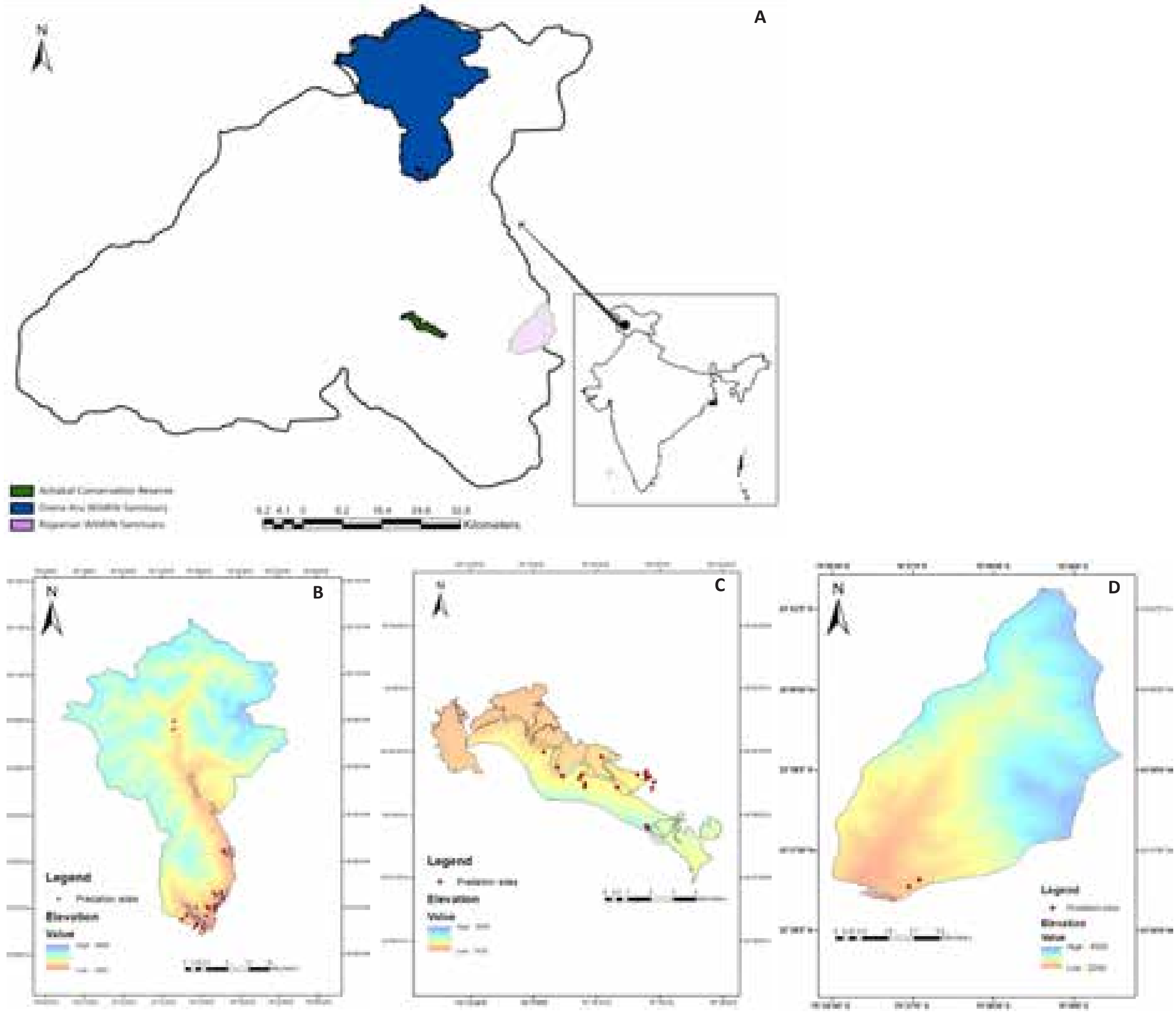

Figure 1. A—Selected protected areas of southern Kashmir | B—Overa-Aru Wildlife Sanctuary | C—Achabal Conservation Reserve | D—Rajparian Wildlife Sanctuary.

three protected areas (χ^2 = 12.186; p = 0.007; Cramer V = 0.374).

The ages of the livestock attacked ranged from less than 1–7 years for Sheep, 2–6 years for Domestic Goat, less than 1–8 years for Cattle, and less than 1–11 years for Domestic Horse. Regression analysis revealed that the predators did not significantly prefer any specific age group, although the 4–6 years age group experienced slightly more attacks (Figure 3).

Asiatic Black Bear attacks in three protected areas occurred predominantly during the day (62.5%), followed by unknown times (25%), night (6.25%), and morning (6.25%). Leopard attacks were most common during the day (70.59%), followed by night (20.59%), evening (5.88%), and morning (2.94%). There was no significant difference in the timing of attacks between the Asiatic Black Bear and the Leopard (χ^2 = 3.819; p = 0.282). Most Asiatic Black Bear attacks (92.59%) occurred inside the forest, with 7.41% just outside it, and none near the respondents' homes or livestock pens. In contrast, the majority of Leopard attacks (61.67%) occurred in the forest, followed by 33.33% inside corrals or near the respondents' homes, and 5% just outside the forest. The difference in attack locations between the Asiatic Black Bear and the Leopard was statistically significant (χ^2 = 11.687; p = 0.003; Cramer V = 0.366).

The majority of Asiatic Black Bear (85.19%) and Leopard attacks (45%) occurred during the summer. For the Asiatic Black Bear, this was followed by autumn (11.11%) and spring (3.7%), with no attacks in winter. For the Leopard, the subsequent seasons were spring (41.67%), autumn (8.33%), and winter (5%). There was

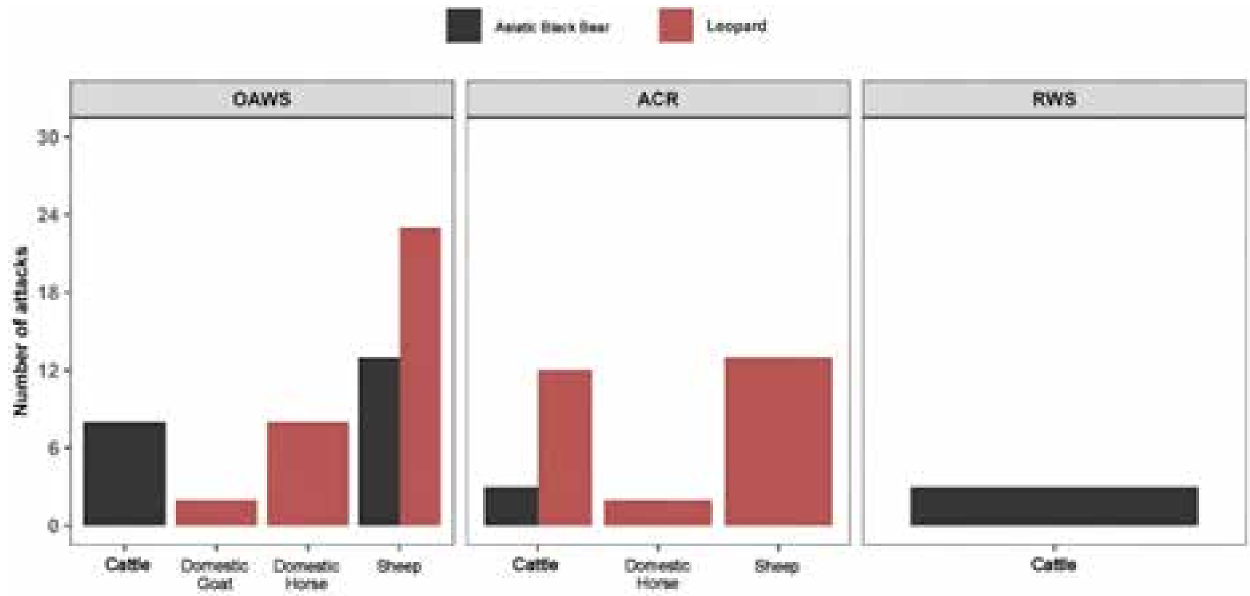

Figure 2. Livestock attacks by Asiatic Black Bear and Leopard in three protected areas during a two-year period from January 2021 to December 2022: Overa-Aru Wildlife Sanctuary (OAWS), Achabal Conservation Reserve (ACR), and Rajparian Wildlife Sanctuary (RWS).

a significant difference in the seasonal distribution of attacks between the Asiatic Black Bear and the Leopard (χ^2 = 15.718; p = 0.001; Cramer V = 0.425). Additionally, a significant difference was observed in the seasonal distribution of attacks for both Asiatic Black Bear (χ^2 = 32.889; p < 0.001) and Leopard (χ^2 = 32.533; p < 0.001). The livestock species attacked also varied significantly across seasons (χ^2 = 22.253; p = 0.008; Cramer V = 0.292) (Figure 4). However, no significant relationship was observed between the location of the attack and the seasons (χ^2 = 8.312; p = 0.216).

Linear regression analysis showed a significant correlation between the frequency of livestock killings and their relative availability (r^2 = 0.71, p = 0.018) (Figure 5).

The estimated economic loss resulting from livestock predation by Leopard and Asiatic Black Bear over two years was substantial across the three surveyed protected areas. In Overa-Aru Wildlife Sanctuary, the total loss amounted to 1,295,500 INR, representing an annual loss per respondent of 22,336.21 INR (1,861.35 INR/month/respondent). In Achabal Conservation Reserve, the total loss was 878,000 INR, averaging 23,105.26 INR per respondent annually (1,925.44 INR/month/respondent). In Rajparian Wildlife Sanctuary, the losses were relatively lower, totalling 160,000 INR, with an average of 40,000 INR per respondent annually (3,333.33 INR/month/respondent).

When asked about mitigation measures, most respondents favoured the translocation of predators to other areas (24%), followed by compensation (22%), while some offered no specific suggestions (18%). Other proposed measures included fencing of protected areas (16%), habitat restoration for wildlife (12%) and the elimination of problematic individuals (8%).

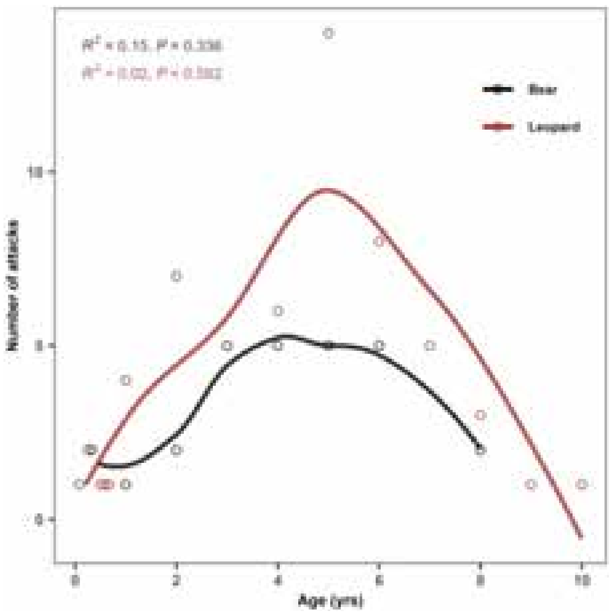

Figure 3. Quadratic polynomial regression illustrating the relationship between the ages of livestock and the frequency of attacks by Asiatic Black Bear and Leopard.

Table 2. Total livestock lost to predation in three protected areas: Overa-Aru Wildlife Sanctuary (OAWS), Achabal Conservation Reserve (ACR), and Rajparian Wildlife Sanctuary (RWS).

Predator	OAWS				ACR			RWS	Total
	Sheep	Cattle	Domestic Horses	Domestic Goats	Sheep	Cattle	Domestic Horses	Cattle	
Asiatic Black Bear	13	8	0	0	0	3	0	3	27
Leopard	23	0	8	2	13	12	2	0	60
Unknown	2	1	2	0	0	0	0	0	5
Total	38	9	10	2	13	15	2	3	92

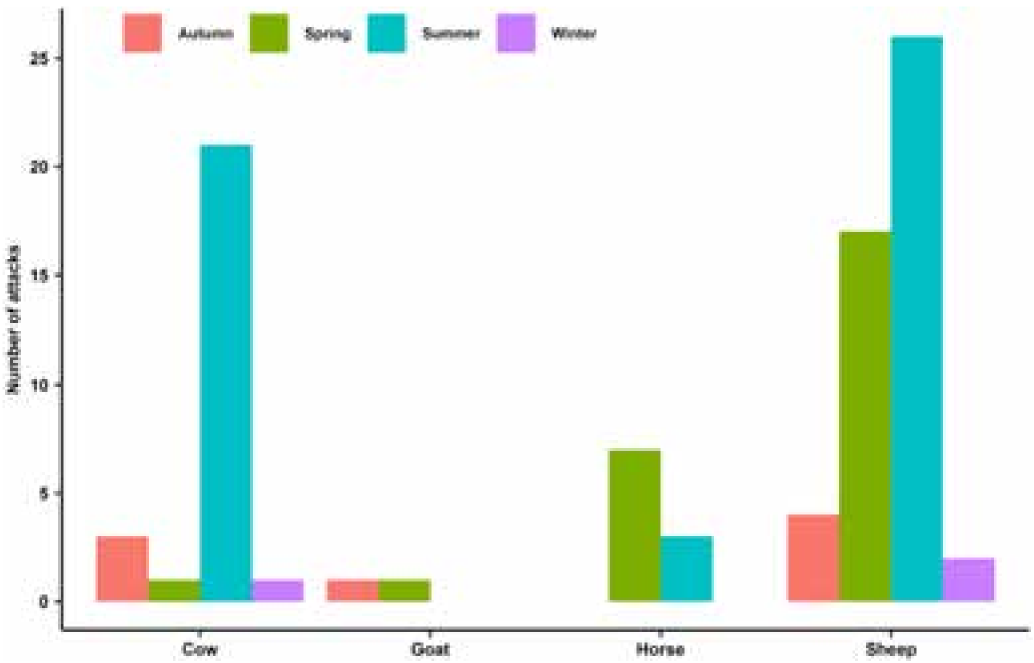

Figure 4. Livestock attacks by carnivores in different seasons across three protected areas.

DISCUSSION

Livestock predation was reported across all three surveyed protected areas, though cases in Rajparian Wildlife Sanctuary were minimal. This may be attributed to the proximity of Rajparian Wildlife Sanctuary to only one village, resulting in fewer livestock grazing inside the sanctuary. Additionally, a well-guarded sheep farm within the sanctuary possibly deterred predator movements in the area. Notably, no cases of livestock predation were reported in Aru and Mandlan villages in Overa-Aru Wildlife Sanctuary, and in Sahibabad, Jogigund, Khundroo, and Sombroona villages in Achabal Conservation Reserve. This suggests reduced predator activity in the Mandlan-Aru stretch of Overa-Aru Wildlife Sanctuary compared to the Khelan-Dahwatoo stretch, and, similarly, less activity in the Sahibabad-Sombroona stretch of Achabal Conservation Reserve. Most incidents were recorded in Andoo village in Achabal Conservation Reserve and Nala Overa in Overa-Aru Wildlife Sanctuary likely due to their proximity to forests, making them more vulnerable to predator incursions.

Sheep were the most frequently preyed upon livestock by both the Leopard and the Asiatic Black Bear. The Asiatic Black Bear primarily preyed on cattle, while the Leopard targeted Domestic Horse in addition to sheep. The preference for Sheep can be attributed to their optimal size, non-defensive behaviour, ease of killing, and high availability. Surplus killing, where multiple individuals are killed in a single attack, was observed primarily by the Leopard, a behaviour also documented in other studies (Sangay & Vernes 2008). This phenomenon contributed to the majority of kills during the study being attributed to the Leopard. The

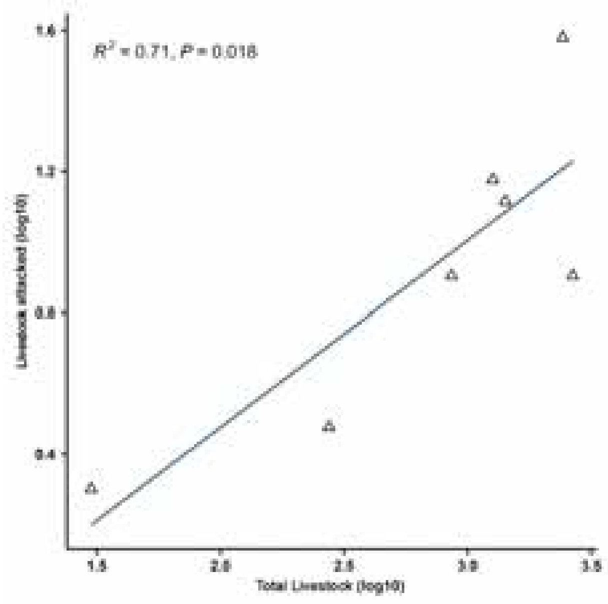

Figure 5. Linear regression illustrating the relationship between livestock attacks by Asiatic Black Bear and Leopard, and the total number of livestock present in three protected areas.

Leopard typically prefers prey species weighing 10–40 kg and 2–25 kg (Dhungana et al. 2019), while the Asiatic Black Bear has been reported to target all livestock species (Sangay & Vernes 2008; Jamtsho & Wangchuk 2016).

Both the Asiatic Black Bear and the Leopard were observed to attack livestock across various age groups, with a slight preference for the 4–6 age range. This age group might be more attractive due to the optimal size and vulnerability of the animals. A more detailed study with a larger dataset could provide clearer insights into age-related predation patterns.

Asiatic Black Bear attacks mostly occurred in the summer, followed by the autumn, with predation peaking in June and July. Most Leopard attacks were also reported in the summer, closely followed by the spring. No Asiatic Black Bear attacks were recorded during the winter, likely due to their inactivity in this season. In the summer, an abundance of forage in forests leads local communities to graze their livestock in these areas, increasing their vulnerability to predation (Akrim et al. 2023). Additionally, the peak cropping season keeps people busy, resulting in livestock being left unguarded and more susceptible to attacks (Sangay & Vernes 2008).

Livestock kills by both the Asiatic Black Bear and the Leopard were predominantly diurnal, with a smaller percentage occurring at night. This contrasts with results of similar studies conducted in Pakistan (Qamar et al. 2010) and India (Gujarat) (Mesaria et al. 2023), where Leopard attacks were mostly nocturnal. However, it aligns with findings from the Indian Himalayan Region, where livestock predation occurs more often during the day when livestock are taken for grazing and left unguarded (LeFlore et al. 2019; Naha et al. 2020).

Dense vegetation cover often leads to an increased risk of predation by large carnivores (Kolowski & Holekamp 2006; Beattie et al. 2020). We observed similar patterns in our study area, with the majority of Asiatic Black Bear and Leopard attacks occurring inside forests. While these incidents may not be classified as human-wildlife negative interaction (IUCN 2023), they still have a profound impact on the financial well-being of local residents, highlighting the need for focused attention and effective mitigation efforts. A significant proportion of Leopard attacks also occurred inside corrals, possibly due to its hunting behaviour and the multi-use nature of the landscape, which includes both forests and agricultural areas (Naha et al. 2020).

The perception of local people towards carnivores was generally positive, although a small portion advocated for their elimination. Given the hesitance of respondents to express their opinions more clearly, evidenced by 18% not suggesting any preventive measures, it can be inferred that more local people might hold this view. The negative attitude stems from substantial economic losses caused by livestock predation, which is especially significant for people from lower socioeconomic classes who depend on livestock for their sustenance, increasing the risk of retaliatory killings and posing a conservation concern.

Respondents suggested various mitigation measures, including translocation of predators, compensation for livestock losses, fencing of protected areas, and habitat restoration. While not all measures may be feasible, habitat restoration is particularly important as a healthy wild prey base can reduce conflicts (Khorozyan et al. 2015; Khan et al. 2018). A fair and speedy compensation scheme could minimize economic losses and support long-term wildlife conservation. Additionally, providing financial assistance to farmers for building better corrals and increased guarding of livestock, especially during summer, could significantly reduce predation rates (Le Flore et al. 2019; Akrim et al. 2023; Samelius et al. 2021; Ullah et al. 2024).

Authorities, in collaboration with local communities, should implement a comprehensive conflict management strategy to alleviate the financial burden on people living near protected areas and ensure the long-term conservation of wildlife.

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ARTICLE

People perception on use patterns and conservation of Chinese Pangolin in and around Yangoupokpi Lokchao Wildlife Sanctuary, Manipur, India

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Abstract: The current study targeted people's perceptions and knowledge regarding the use patterns of Chinese Pangolins among the communities residing in and around the Yangoupokpi Lokchao Wildlife Sanctuary (YLWS). The sanctuary lies at the Manipur border with Myanmar is in range of Indo-Burma Biodiversity Hotspot. A pre-structured questionnaire survey was conducted between October 2019 and December 2023 to collect information about the use pattern of Chinese Pangolin by consulting 71 local people, particularly traditional hunters from selected villages. The results revealed the use of Chinese Pangolins in bushmeat, medicine (piles, sore throat, asthma, smallpox, allergy), and social beliefs (to keep termites and ants away from wooden houses, gun proof jackets, sighting pangolins as unlucky). Many respondents lack knowledge on medicinal uses and social belief about the species in the study area. In addition, the treatment of sinuses and the excessive control of saliva in nursing babies by using the scales are the two novel findings recorded. Usage of scales to keep ants and termites away from wooden and bamboo house was common in all communities Prior to the COVID-19 pandemic in 2020, there was a rising trend in cost of pangolin body parts like scales. The results of this study indicate that the main threats to the conservation of the Chinese Pangolin species in Manipur, especially in YLWS, are mainly due to the traditional uses of the animal and the trade of its scales for medicinal purposes. As the selected species is Critically Endangered worldwide hence requires immediate conservation and management strategies.

Keywords: Bushmeast, hunting method, illegal hunting, *Manis pentadactyla,* medicine, scales, socio-cultural belief, Tengnoupal, threatened, trade.

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INTRODUCTION

Millions of tons of animals are estimated to be hunted throughout tropical forest regions for wild or bushmeat and trade each year (Bahuchet & Loveva 1999; Fargeot & Dieval 2000; Bodmer & Lozano 2001; Bodmer et al. 2004; Newton et al. 2008; Nasi et al. 2011; Katuwal et al. 2013; Zhang et al. 2017). The large quantities of illegal hunting and poaching are leading several animal species towards threatened categories worldwide, with the majority being large and small mammals (Davies 2002; Holland & Bennett 2007; Chalender et al. 2012; Abernethy et al. 2013). The trade amount of pangolin scales was estimated to be in tons, which equals the number of thousands of pangolins (Wu & Ma 2007; Challender & Hywood 2012; Challender et al. 2015; Aisher 2016). Rural tribal people inhabiting in and around the protected area use wild meat and body parts of animals as essential sources of food, medicine, socio-cultural belief, and cash income (Altrichter 2006; Fa & Brown 2009; Challender et al. 2012; Mohapatra et al. 2015; Ingram et al. 2018; Yang et al. 2018; Xing et al. 2020; Sexton et al. 2021). This is especially true for local communities in remote areas, who often depend on natural forest resources for their livelihood. Pangolins are illegally traded in Asia, including Chinese Pangolins (McMurray 2009). Before 1990, the quantity of pangolin consumed for meat, scales, and medicine purposes was relatively small and limited to domestic uses (Van et al. 2009). But, after the early 1990s, the illegal trade of Chinese Pangolin was boosted due to increased demand for meat (Heinrich et al. 2016; Cheng et al. 2017; Zhang et al. 2017; Sharma et al. 2020). In the region of southern and southeastern Asia, the demand for pangolin scales and meat for medical attention has pressured the pangolin populations to decline almost to the level of extinction (Aisher 2016).

The scales of pangolins (around 110- to 150-thousand per year) are used in traditional Chinese medicines (Wu & Ma 2007; Pantel & Chin 2009; Challender et al. 2015; Nash et al. 2016; Trageser et al. 2017) as well in clinical medicines (Wu & Ma 2007). Both meat and scales are used for treatment of various ailments (Challender 2011; Katuwal et al. 2013; Mohapatra et al. 2015; Aisher 2016; Xu et al. 2016). In India, it was not a surprise that people utilized pangolin parts and had traditional superstitious beliefs because of the relation between pangolin and the local community (Mohapatra et al. 2015; D'Cruze et al. 2018). Across the northeastern part of India, traditional remedies associated with ethno-zoological practices are linked to wild animals and their body parts, which are imbedded for generations in some local cultural practices (Solanki et al. 2005; Chutia 2006; Parbo et al. 2023). Katuwal et al. (2013) had reported the use of pangolin scales in treating communicable diseases in children. Similarly, various societal beliefs are also reported about the scales of Chinese Pangolins, such as cure in vomiting, protecting wood properties from termites, lucky charm, and magical power (Nash et al. 2016; D'Cruze et al. 2018). In contrast, the sighting of a Chinese Pangolin during the day is reported as a sign of an unlucky or bad omen (Nash et al. 2016). The skin and scales of Chinese Pangolin were used in the making of garland, jewelry, rings, bags, purses, and musical instruments (Katuwal et al. 2013; D'Cruze et al. 2018). Pangolin derivatives were used as an item in religious ceremonies and for decorative purposes (Mahmood et al. 2012; Mohapatra et al. 2015).

Earlier, eight species of pangolins were reported (Challender et al. 2012; Bao et al. 2013; Katuwal et al. 2013; Bhandari & Chalise 2014; Trageser et al. 2017; Yang et al. 2018), of which four species were from Asian countries (Challender et al. 2012; Mahmood et al. 2012; Nijman 2016; Trageser et al. 2017). In recent years, two new species of pangolins were added namely Asian Mysterious Pangolin *Manis mysteria* and Indo-Burmese Pangolin *Manis indoburmanica* from the Asian continent (Gu et al. 2023; Wangmo et al. 2025). These two additions makes six species of pangolins in Asia and total 10 species of pangolins globally. In India, two species of pangolins, namely Indian Pangolin *Manis crassicaudata* and Chinese Pangolin *Manis pentadactyla* are reported (Mohapatra et al. 2015; D'Cruze et al. 2018). The Indian Pangolin is distributed all over India (Mohapatra et al. 2015), while the Chinese Pangolin is restricted to the northeastern states (Mohapatra et al. 2015). The global distribution of Chinese Pangolin is reported in Bangladesh, Bhutan, Nepal, Myanmar, China, Lao PDR, Taiwan, Thailand, Vietnam, and India (Srinivasulu & Srinivasulu 2004; Shrestha 2005; Katuwal et al. 2013; Challender et al. 2015; Mohapatra et al. 2015; Sharma et al. 2020).

Pangolins (Pholidota: Manidae) are one of many animal groups used for ethnozoological purposes, and they are globally threatened with local extinction in many areas in its distribution range due to numerous anthropogenic threats (Wu et al. 2004; Liou 2006; Yang et al. 2007; Bhandari & Chalise 2014; Nijman et al. 2016). Conservation status of Chinese Pangolin is reviewed in 2019 by IUCN Red List of Threatened Species and listed the species as 'Critically Endangered' under criteria A3d+4d (Challender et al. 2019). Chinese Pangolin is also listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 2017 (Challender & O'Criodain 2020) and Schedule I species under Indian Wildlife (Protection) Act, 1972 (Mohapatra et al. 2015). In order to draw attention to its current conservation concerns facing the species, we planned to investigate how communities living in and around the Yangoupokpi Lokchao Wildlife Sanctuary (YLWS), Manipur, India, perceive and use Chinese Pangolins. Our research is based on local people's understanding on the significance and utility of this species. In particular, the responses of various communities were emphasized according to their patterns of use, which could be helpful in creating conservation policies that are more equitable and successful.

MATERIALS AND METHODS

Study area: Yangoupokpi Lokchao Wildlife Sanctuary (YLWS)

Yangoupokpi Lokchao Wildlife Sanctuary is located within the Tengnoupal District of Manipur, covering an area of 184.80 km^2. The sanctuary was established in 1989 in the Chandel District and is now in Tengnoupal District after bifurcating from Chandel in 2016. It lies on the border between Burma (Myanmar) and Manipur, which is also a part of the Indo-Malayan biodiversity hotspot. The important town of Moreh, which is a commercial town located on the border of India and Myanmar, is also a part of the sanctuary, and trade occurs between the two countries, i.e., India and Myanmar. The temperature recorded in January goes down to 4^oC, and in June it reaches up to 40^oC, with varying humidity fluctuating from 35% in winter to 80% in monsoon season. The annual average temperature recorded was 24.3 °C, and the average rainfall measure around 2,263 mm annually (Bungnamei & Saikia 2020). The sanctuary is home to various flora and fauna due to the convergence of Indo-Malayan biodiversity hotspots. Four types of forest are found in the sanctuary: tropical semi-evergreen forest, scrub forest, sub-tropical pine forest, and moist bamboo brakes. Some of the important floral species found in the sanctuary are *Tectona grandis*, *Dipterocarpus turbinatus*, *Terminalia tomentosa*, *Gmelina arborea*, *Bauhinia* spp., *Daubanga sonnoroedes*, bamboo, and orchid species. This sanctuary also nurtures a diverse group of wildlife resources, starting with birds, mammals, reptiles & amphibians, fishes, and insects. A total of 40 species of mammals, 65 species of birds, 27 species of reptiles, six species of amphibians, and 65 species of fish were recorded from the sanctuary (Bungnamei & Saikia 2020). Some of the important wildlife found in the sanctuary includes Leopard *Panthera pardus*, Jungle Cat *Felis chaus*, Asian Grey Mongoose *Urva edwardsii*, Sāmbhar Deer *Rusa unicolor*, Wild Boar *Sus scrofa*, Red Serow *Capricornis rubidus*, Capped Langur *Trachypithecus pileatus*, Stump-tailed Macaque *Macaca arctoides*, Western Hoolock Gibbon *Hoolock hoolock*, Porcupine *Hystrix brachyura*, Chinese Pangolins *Manis pentadactyla*, Tokay Gecko *Gekko gecko*, Burmese Python *Python bivittatus*, Indian Monitor Lizard *Varanus bengalensis*, King Cobra *Ophiophagus hannah*, Common Krait *Bungarus caeruleus*, Great Indian Hornbill *Buceros bicornis*, Rose-ring Parakeet *Psittacula krameria*, Red Jungle Fowl *Gallus gallus*, Blyth's Tragopan *Tragopan blythii*, Burmese Peafowl *Pavo muticus* (Sunil 2016).

Data collection and methods

The study area was surveyed with a structured open and closed questionnaire between October 2019 and December 2023. The respondents were selected using a snowball sampling technique based on their experiences with wildlife, particularly the Chinese Pangolin. Later on, the questionnaire survey was conducted by taking prior appointments from the selected respondents from nine established villages around the YLWS (Table 1). These nine villages were represented by three communities, namely Naga Maring, Meitei, and Kuki. The questionnaire sheet comprised mainly of the following questions: (i) name, (ii) age, (iii) gender, (iv) occupation, (v) hunting reason, (vi) hunting method, (vii) trade, (viii) use pattern, and (ix) conservation issues or threats (Babbie 2013). The individuals were not asked direct questions; instead, an interactive communication approach was used.

. The conversation was conducted in Manipuri, with a translator assisting in communicating a local Kuki dialect. This was then immediately translated into English and written down on data sheets.

RESULTS

Respondents' Socio-Demographic Characteristics

In the present study, we interviewed 71 respondents who were basically traditional male hunters. The age of respondents ranged between 36–65 years, with a mean age of 52.3 ± 5.80 years. Majority (65%) of the respondent's age ranged between 46–55 years (Figure 2a). Furthermore, most respondents had lived in the area since their birth. Most of the selected respondents were

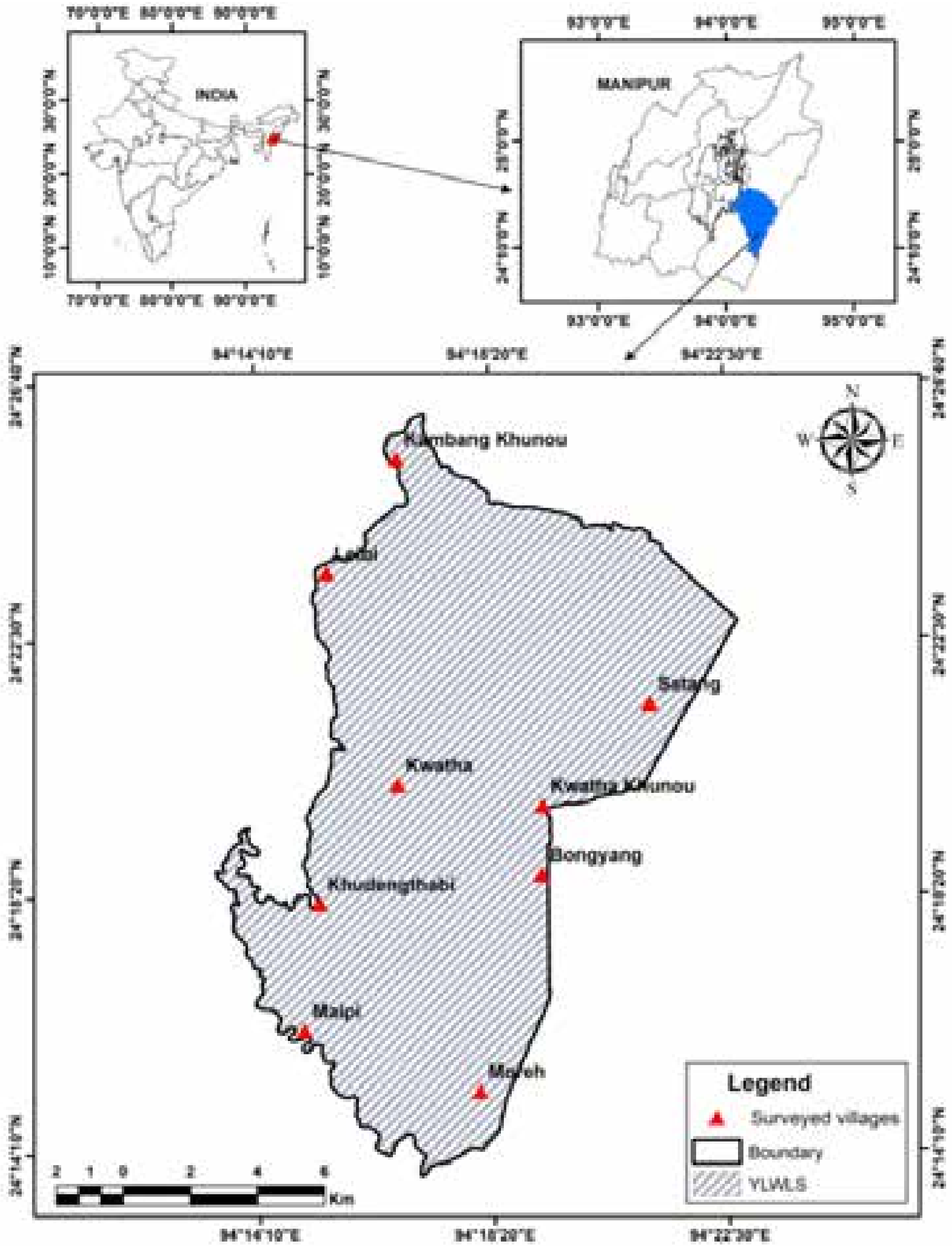

Figure 1. Map of the Yangoupokpi Lokchao Wildlife Sanctuary along with locations of surveyed villages.

uneducated (37%), followed by those having education up to class 10 (31%), class 12 (18%), and less than class 8 was 14% (Figure 2b). Most of the respondents were involved in hunting and poaching activities of wildlife in the past, but nowadays only a few (15%) are still active in hunting and poaching of Chinese Pangolin opportunistically or only if there is demand for scale or whole animal.

Hunting methods and reasons

The findings showed that, in addition to dogs, the most common weapons used for hunting and poaching were spades, teiyon, spears, rifles, and traps. According to the respondents' opinions, the noose trap was the most widely used method (68%) for Chinese pangolin hunting and poaching, followed by the spear (46%), the gun (38%), the spade, and teiyon (41%) each, and the least popular method was the use of dogs 23% (Figure 3). The respondents categorized the motives for hunting and poaching of Chinese Pangolins into three groups: meat, scales, and whole animal. Seven percent of the 61% of hunters who go pangolin hunting also target and

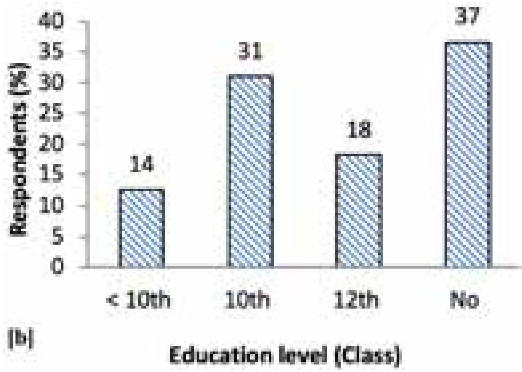

Figure 2a&b. Descriptive profile of survey respondents in study area.

Table 1. Number of respondents, their gender, and community selected for interview and questionnaire survey from villages established in and around Yangoupokpi Lokchao Wildlife Sanctuary, Manipur.

	Name of villages	No. of respondents	Gender	Community
1.	Moreh	15	M	Mixture of communities
2.	Kwatha	7	M	Meitei
3.	Kwatha khunou	5	M	Meitei
4.	Khambang Khunou	12	M	Maring Naga
5.	Leibi	10	M	Maring Naga
6.	Satang	7	M	Maring Naga
7.	Maipi	5	M	Kuki
8.	Khudengthabi	5	M	Kuki
9.	B. Bongjang	5	M	Kuki

sell entire pangolins based on middlemen's demands. All respondents (100%) said that the Chinese Pangolin is hunted for its flesh, which is perceived to be extremely tasty (Choudhary et al. 2018).

It was found that most respondents (84%) had hunted pangolin either for bushmeat or to sell for cash income, with 7% hunting them when a middleman offered advance money for the species. During the survey, only in four incidents, the sale of live pangolins were recorded with prices ranging from Rs. 15,000 per animal in 2014 to Rs. 25,000 in 2019, prior to the COVID-19 pandemic. According to respondents, the Chinese Pangolin hunting and poaching have decreased in the present research area due to difficulties in spotting the species, possibly as a result of historical overhunting, declining forest cover, and changes in land use patterns. In addition, many respondents stated that other factors contributing to decline in hunting in the area included the migration of residents to towns for employment or settlement, as well as increased education and awareness of wildlife and wildlife laws.

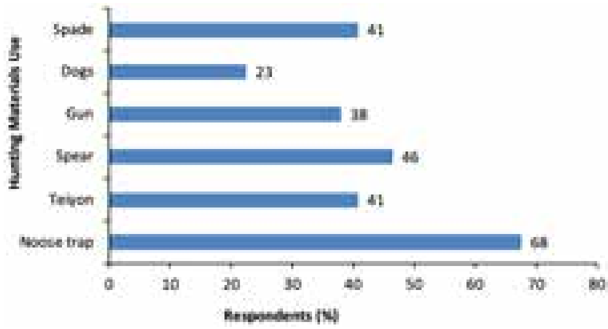

Figure 3. Hunting methods used for Chinese Pangolin in the study area.

Price of scales

The correlation analysis of price and scale shows 0.873, which is significant at the 0.01 level. This suggests that as the year went on, the price of scales also increased. According to an elderly respondent, in the early 1980s, he used to sell pangolin scales for Rs. 400/kg. In the mid- and late-1990s, the cost of Chinese pangolin's scale grew significantly at the rate of average price per kg from Rs. 7,000–Rs. 8,000. According to the current analysis, the peak average price of pangolin scale selling was Rs. 23,000/kg before the Covid-19 epidemic (Figure 4). But, immediately after the COVID-19 pandemic, people were willing to sell pangolin's scale at the rate of Rs. 3000 to Rs. 5000 per kg. Despite this, no purchasers appeared due to the upheaval in Manipur and Myanmar.

Medicinal Uses

Chinese pangolins were generally used in Manipur, especially in the current study area, to treat a variety of ailments. The highest medicinal uses of body parts of Chinese Pangolin were in treatment of piles (29%) followed by asthma (18%), throat pain (14%), allergy

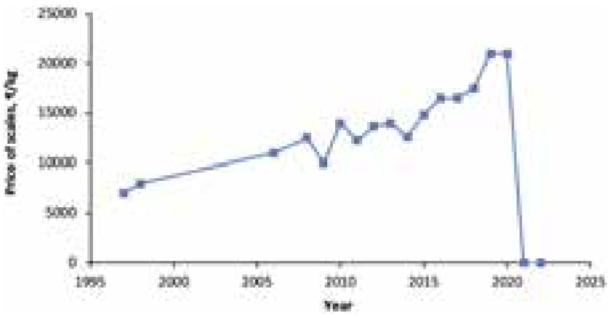

Figure 4. Average price of pangolin scale reported by respondents of study area.

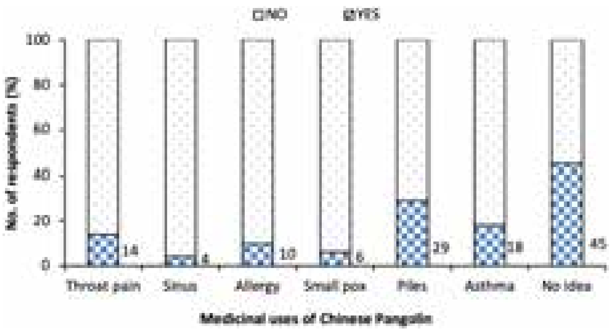

Figure 5. Respondents' knowledge on traditional medicinal uses of Chinese Pangolin.

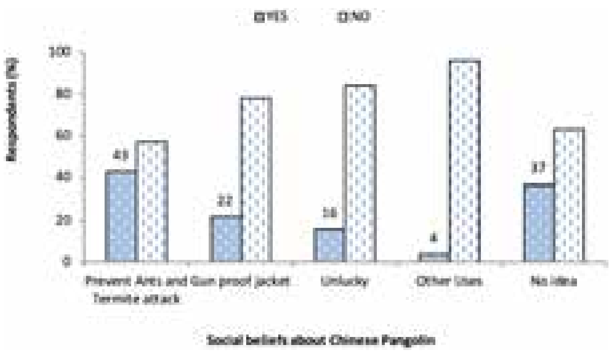

Figure 6. Respondent's knowledge on social beliefs about Chinese Pangolin.

(10%), Smallpox (6%), and the lowest use was in curing sinus (4%) while majority of hunters (45%) are unaware of the traditional medicinal uses of Chinese Pangolin (Figure 5).

Social Beliefs and other Uses

The understanding of medicinal uses is significantly impacted by age (p = —0.041), as observed by the odd ratio and confidence interval (OR = 3.25; 95% CI:1.02–10.40). The relationship between age and the mode of medicinal uses was also shown to be significant (p = 0.045) (OR = 4.0; CI:0.96–16.61). The current occupation and knowledge of medicinal uses did not significantly correlate (p = 0.097) (OR = 0.37; CI:0.11–1.28). For the modalities of uses knowledge, the influence of profession is significant (p = 0.003) (OR = 0.11; CI:0.02–0.5). Data presented in Table 2 maintains a significance threshold of 0.05. There was no significant (p = 0.054) relationship observed with current occupation (OR = 1.13; CI:0.35–3.71) while there was a significant (p = 0.006) correlation with social views and age (OR = 5.34; CI:1.57–18.11) (Table 2).In order to prevent termites and ants from destroying their wooden and bamboo homes, the majority of respondents (43%) said they buried pangolin scales beneath the main pillar (Figure 6). Twenty-two percent of the respondents claimed that they used to stitch pangolin scales into clothing, believing it would protect against bullet from traditional weapons, although this belief is no longer relevant. The respondents who believe in seeing pangolin as unlucky were 16%, and 4% of respondents believe other uses like keeping pangolin scale on chest of milking baby during sleep stops excess saliva drops from mouth. A total of 37% respondents reported that they have no idea about social belief since they do not practice it in their society (Figure 6). Figure 7 depicts the Chinese Pangolin's community-wise use pattern, which reveals that the three groups solely shared the use of scales to keep out ants and termites from wooden and bamboo made houses.

DISCUSSION

The average age of respondents who participated in the survey was 52.3 ± 5.80 years, ranging from 36 years to 65 years with most comparable to the research findings reported by Phuyal et al. (2023). Additionally, respondents stated that there has been a decreased trend in Chinese Pangolin hunting and poaching compared to previous years in the present study area. It is recorded that younger generations said to be leaving their villages for cities and towns to pursue higher education, better careers and livelihood that provide a steady income as opposed to occasionally making money from hunting and selling wild animals as well as increased wildlife awareness and strict implementation of wildlife laws and policies in the state. As a result, Chinese Pangolin hunting and poaching have declined in the study villages. Besides these, there could be some other factors for declining the Chinese Pangolin's

Table 2. Respondents' opinions on knowledge of social belief and medicinal uses.

	Social belief		Medicinal uses		Modes of uses	
	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value	OR (95% CI)	*p*- Value
Age	5.34 (1.57–18.11)	0.006	3.25(1.02–10.40)	0.041	4.0 ((0.96–16.61)	0.045
Present occupation	1.13 (0.35–3.71)	0.54	0.37 (0.11–1.28)	0.097	0.11(0.02–0.5)	0.003

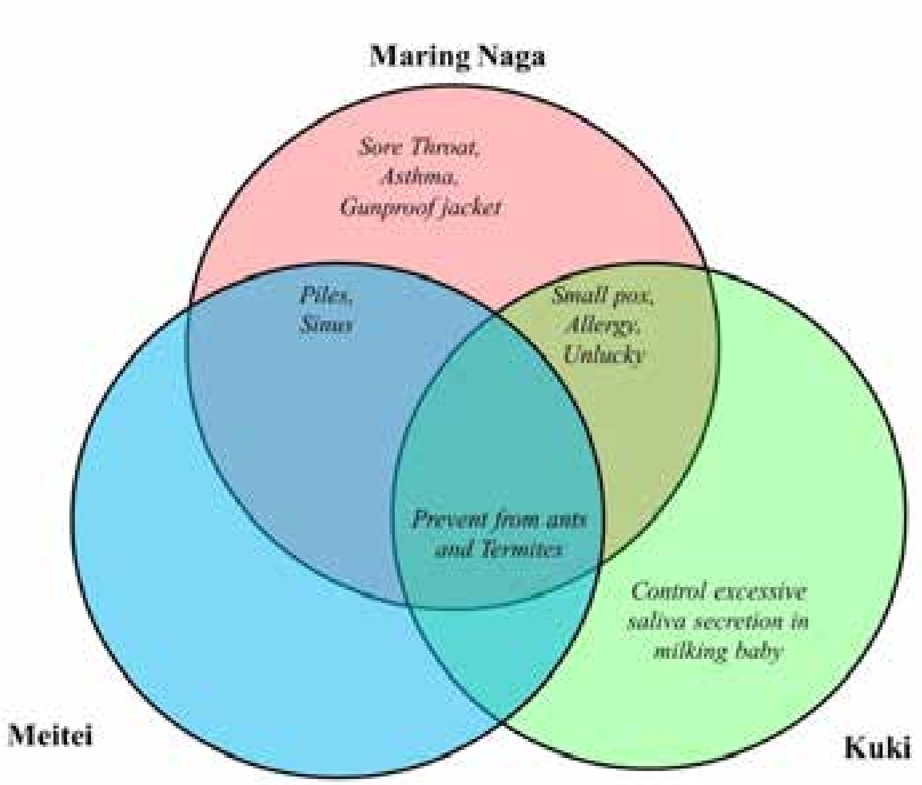

Figure 7. Community-wise uses of Chinese Pangolin in the study area.

hunting, viz., decreasing quality and quantity of forest cover or the habitat of species, changes in land use and cover patterns, and possibly historical overhunting or low population density. These factors might be making it more difficult to spot or locate the species, which would further discourage hunting.

The results of the present study (Figure 3) showed that the noose trap was the most often used method for hunting and poaching Chinese Pangolins, which was corroborated by the results of several studies (Newton et al. 2008). Similarly, Aisher (2016) reported that Nyishi hunters in Arunachal Pradesh also used the same trapping method to hunt Chinese Pangolins. In contrast, just one respondent was reported in the study area utilizing a trap and digging out from a burrow to hunt Chinese Pangolins, which can be corroborated by other studies (Newton et al. 2008; Nash et al. 2016; Katuwal et al. 2017; Zhang et al. 2017). Additionally, the present study recorded the use of trained dogs in Chinese Pangolin hunting. Similar observation was also reported by Archer et al. (2021). Although it was said that the usage of firearms for hunting had decreased following the early 1990s ban on private firearms (Sterling et al. 2006), most hunters at the present study area continue to use firearms to hunt various animals, including Chinese Pangolins. Numerous studies have also documented the usage of firearms for pangolin hunting (Friant et al. 2015; Mambeya et al. 2018). The shovel, spear, and 'Teiyon' (traditional digging tools) used for pangolin hunting in the past were also documented in this study and were not found to have been mentioned in other studies. Respondents also mentioned that because pangolin sightings are rare these days, they mostly concentrate on capturing whenever a new tunnel or other evidence of a pangolin's presence is discovered, as they believe it to be much simpler and more successful (Figure 3). Most

Table 3. Utilization pattern of Chinese Pangolin reported from the present and other studies.

Categories	Reported in the present study	Reported in other studies	Sources
Used in treatment of diseases	Piles	Piles	Mohapatra et al. 2015; D'Cruze et al. 2018
	Sinus	-	-
	Sore throat	Sore throat	Nash 2016
	Asthma	Asthma	Kaspal 2009; Boakye et al. 2015; Maurice et al. 2019; Mouafo et al. 2021; Sexton et al. 2021
	Small pox	Small pox	Sexton et al. 2021
	Allergy	Allergy	Sopyan 2009; Sexton et al. 2021
Used in social belief	Prevent from termites and ants in wooden house	Prevent from termites and ants in wooden house	D'Cruze et al. 2018
	Gun proof jacket	Gun proof jacket	Soewu & Ayodele 2009; Mouafo et al. 2021
	Unlucky	Unlucky	Katuwal et al. 2013; Khatiwada 2016; Nash et al. 2016; D'Cruze et al. 2018; Mouafo et al. 2021
Others uses	Controls excessive saliva secretion in milking baby while sleeping)	-	-

respondents had previously engaged in wildlife hunting and poaching, but today very few continue to hunt and poach Chinese Pangolins opportunistically or only when the demand for a large or entire animal exists.

Mouafo et al. (2021) reported in their finding that the majority of the hunters' aim for hunting pangolin was income generation in contrast to the present study where domestic consumption of meat was the primary reason for hunting pangolin. Pangolin meat is widely consumed locally and is thought to be among the best meats (Choudhary et al. 2018). A number of studies have revealed that people sold the meat to make money, but only a small number of them hold the opinion that people who can afford to eat pangolin meat come from higher social classes, have pride in their culture, and become unique individuals (Nasi et al. 2011; Mohapatra et al. 2015; Ichikawa et al. 2016; Archer et al. 2021). Shepherd (2009) noted that middlemen frequently make village visits, and Chinese Pangolin buyers and sellers get together at a hidden location. According to D'Cruze et al. (2018), hunters typically travel to cities to hunt for potential customers of pangolin scales. The current study revealed that the vendor purposefully avoided travelling to another town or village in search of a buyer, instead gathering information indirectly from reliable sources ahead of time for the sale of pangolins. Rather than engaging in open trade in the village or local market, they set up a rendezvous in a designated hidden location.

Several studies revealed that pangolins were stolen for their scales, which are thought to be connected to traditional Chinese and Vietnamese remedies (D'Cruze et al. 2018; Sexton et al. 2021). Giant Pangolin scales were said to be used in times of conflict since people traditionally believed them to be bulletproof (Mouafo et al. 2021). A similar observation made in the current study is on the use of Chinese Pangolin scales to make a bulletproof garment that was utilized in Manipur during the 1992 Naga-Kuki war (Butalia 2008). The cost of pangolin scales is estimated to range from \$100–120 per kg in international trade (Challender et al. 2015). In Dima Hasao, the average cost of scale is Rs. 17,000 per kg according to D'Cruze et al. (2018) which is in line with the present study. Chinlampianga et al. (2013) reported a rise in scale prices in Mizoram between 1996 and 2012, from Rs. 1,000 per kg to Rs. 13,000 per kg. Wu et al. (2007) reported that the price of scales in China increased between the 1980s and 2000s, going from RMB (Renminbi) 8–12 in the early 1980s to RMB 420–450 in the early 2000s. In contrast, the current study reports that Chinese Pangolin scales sold for Rs. 800/kg in the late 1980s and as high as Rs. 23,000/kg by 2020. As proposed by Thapa et al. (2014) the price of pangolin scales varies not only between villages and individuals but also between sizes, with adult pangolin scales being preferred over younger ones. This variation in scale prices is also dependent on the level of knowledge about the value of the pangolin scales in the illegal trade market. According to Newton et al. (2008), respondents claimed that all pangolins that are caught are now sold to traders; however, the current investigation observed that the alive or whole body of pangolins are only sold when customers specifically request them.

Table 3 summarizes the utilization pattern of Chinese Pangolins from both the current study and previous research. According to earlier research, there

Image 1. Interaction with respondents and Chinese Pangolin's scales and cooked meat: a—interaction with respondent | b—cooked meat of Chinese Pangolin | c—old pangolin scale | d—fresh pangolin scale. © Yengkhom Roamer Zest.

is a generational transfer of information regarding the traditional medicinal usage of pangolins in therapeutic practices, viz., kidney stones, asthma, dermatological issues, and tuberculosis (D'Cruze et al. 2018; Mouafo et al. 2021). According to Chinlampianga et al. (2013) and Mohapatra et al. (2015), bile is used to treat splenomegaly, or spleen enlargement, however a study participant claimed that bile is also used to treat smallpox in youngsters. According to Nash et al. (2016), some hunters claimed that Chinese pangolin parts could be used to treat sore throats. They also reported that scales and bile were used in traditional medicine, which is consistent with the results of the current study, which show that scales are typically used in treatment, with bile being used in a small number of cases (Table 3).

In contrast to the current study, which has no accounts of this concept, some investigations have suggested that pangolin scales are worn as rings to ward off evil spirits. A few people claimed that termites could be warded off with scale (D'Cruze et al. 2018). The results of the current survey indicated that pangolin scales were used to keep ants & termites away from the bamboo & wooden materials used to build houses. According to several studies (Nash et al. 2016; D'Cruze et al. 2018; Mouafo et al. 2021), seeing a pangolin is said to be unfortunate. In contrast, sighting a pangolin once a year was reported as fortunate in the Philippines (Archer et al. 2021). According to the current study, seeing a Chinese Pangolin was once thought to bring bad luck, but this belief has since faded. But, Sharma et al. (2020) state that seeing a pangolin is only unlucky if a living one is slain or a dead one is spotted. Conversely, pangolin parts were used as a means of driving away ill luck (Ingram et al. 2018). Thus, use pattern of pangolins and its body parts varied place to place in their distribution range.

CONCLUSIONS

From the present study it is concluded that only male local peoples belonging to an average age of 52 years old were mostly involved in hunting and poaching of Chinese Pangolin in the area. Most respondents had previously got engaged in wildlife hunting and poaching, but today a very few continue to hunt and poach Chinese Pangolins opportunistically or only when the demand for a large or entire animal exists. As anticipated, similar to certain previous research (Mohapatra et al. 2015; D'Cruze et al. 2018; Xing et al. 2020), the investigation also looked into the applications of Chinese Pangolin in meat, traditional medicine, and in social beliefs. The present study also revealed two novel findings that had not been reported in previous studies: the treatment of sinuses and the excessive control of saliva in nursing babies by using the scales. Using scales to keep out ants and termites was one feature that all the communities had in common in the study area. Although some respondents may not have been aware, the Chinese Pangolins are highly sensitive and trafficked animals (Challender et al. 2015; Nash et al. 2016). The average price shows an increasing trend through 2020, right before the Covid-19 outbreak. Respondents said that the pangolin trade had abruptly decreased, presumably as a result of intermediaries' restrictions, and that traders were endangered because of political upheaval in Manipur and Myanmar.

Overall, the study suggests that a combination of social, economic, and environmental factors have contributed to a decline in the hunting and poaching of Chinese Pangolins in the study area. However, this species in Manipur, particularly population of YLWS is highly threatened and need urgent conservation and management approach, as globally it is a 'Critically Endangered' species. Therefore, further exploration of these trends could provide more insight into the long-term sustainability of these changes for species.

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COMMUNICATION

Population status, threats, and conservation of *Trachycarpus takil*: an endemic and threatened plant species in western Himalaya, India

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Abstract: Population status and endemism are important concepts in biogeography and conservation biology. Given the dataset's importance and limited availability, we studied the population status and distribution pattern as per the IUCN Red List categories and criteria for *Trachycarpus takil* in Uttarakhand. The study aimed to identify the targeted species' location-specific population status, distribution, area of occupancy (AOO), extent of occurrence (EOO), and resource use patterns. An intensive field visit was conducted in remote areas of Pithoragarh District, Uttarakhand, to identify location-specific information on *T. takil* in the wild. The AOO was recorded at 28 km^2 and the EOO was 2,078.80 km^2. *T. takil* is used by locals to prepare ropes, brooms, and seeds from the wild, which are collected for trade. The study suggests that, as per the IUCN Red List categories and criteria, the species can be included under the 'Endangered' category [B1ab(iii,v) and B2ab(iii,v)] and requires immediate conservation actions to save the wild population.

Keywords: Area of occupancy, conservation, distribution, diversity, extent of occurrence, Indian Himalayan region, native, thakil palm, threatened palm, Uttarakhand.

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INTRODUCTION

Diversity of endemic plants is one of the prime criteria for determining the global biodiversity hotspot. The Himalaya, one of the 36 global biodiversity hotspots, is well known for its unique repository of biodiversity and unique & rich endemic plants (MAPs) (Singh et al. 2021; Tiwari et al. 2024). Indian Himalayan Region (IHR) covers the major part of Himalaya Biodiversity Hotspot and is represented by 11,743 native plant species including 11,695 angiosperms, 48 gymnosperms (Wani et al. 2024). Among these, 1,466 trees (Bhatt et al. 2021), 1,748 medicinal (Samant et al. 1998; Mehta et al. 2023), 456 threatened (Mehta et al. 2020), and 1,076 endemic plants (Tiwari et al. 2024) have been reported from IHR. Himalayan endemic plants are confined to highly fragile ecosystems and will almost certainly be the first to be hit by extinction processes. Hence, they require proper assessment and effective conservation plan for restoration. Among the reported endemic plants of IHR, the conservation related studies conducted only around 7% of total endemic plants and highlights the requirement for more conservation efforts (Tiwari et al. 2024).

Trachycarpus takil is one of the threatened and endemic palm species of IHR belonging to the family Arecaceae. The species has been reported from only three locations in Kumaun Himalaya at 2,000–2,500 m altitude growing as undergrowth in the mixed forest of *Quercus* spp. (Khan 2016; Kholia 2009; Husain & Garg 2004). Earlier reports revealed that two small populations with less than 500 individuals are found in the Pithoragarh District (Thal Kedar Hills, Kalamuni Ridge) and third population is found in the Almora District of Kumaon Hills and is nearly on the verge of extinction due to forest fire (Lorek 2007; Gibbons & Spanner 2009; Khan 2016). As per the literature (Kholia 2009; POWO 2024), the species also recorded from Nepal, although we could not find the valid specimen records. So, the distribution of *T. takil* in Nepal is doubtful. As per the IUCN, the population trend is also unknown (www.iucnredlist.org/species/236274959/236274961). Efforts have been made to study the species' flowering phenology, pollination, and breeding behaviour (Kholia 2009). However very little information on the ecology, and population status is available for threat assessment of the species. Therefore, the present study aimed to assess the population, location-specific diversity, distribution, area of occupancy (AOO), extent of occurrence (EOO), resource use patterns, and threats in the wild habitat of *T. takil* in Uttarakhand.

MATERIAL AND METHOD

Species Description

Trachycarpus takil is a medium-sized, evergreen, rare, and endemic palm species of Indian Himalayan Region, commonly known as '*Thakil'.* The species grows as undergrowth in mixed forests of *Quercus* spp., up to an elevation of 2,500 m (Gibbons & Spanner 2009; Kholia 2009). It is a solitary palm of about 9–12 m height and flowering starts from April–May and fruits from September–October (Kholia 2009). Flowers are yellow, small trimerous cyclic, stalked or subsessile, and polygamously monoecio-dioecious (Kholia 2009). The leaves are fan shaped, persistent, 1.2 m long, and are arranged as a crown on the top of the trunk. The palm is distinguished by a network of fibres that cover the trunk up to the base and whorl of persistent dry leaves below the crown of fresh ones.

Vegetation sampling

The occurrence data about species presence was obtained from the existing literature (Kulkarni & Mulani 2004; Gibbons et al. 2008; Kholia 2009, 2010; Gibbons & Spanner 2009; Khan 2016), herbarium records and online datasets (GBIF 2024; POWO 2024). All the identified places (i.e., Thal Kedar, Baravey, Kalamuni, Ratapani, Giniband) were surveyed extensively during September 2022–October 2023 for diversity and distribution pattern (Figure 1). Information about indigenous resource utilization, emerging threats were documented by direct field-based observation and questionnaire survey methods (Malik et al. 2014). A handheld GPS (Garmin eTrex 30x) was used to record the geo-coordinates and altitude of each site. As the species is recorded as endemic to Kumaun Himalaya (Gibbons & Spanner 2009; POWO 2024), efforts are made to assess the population as per the IUCN Red List categories and criteria (Keith et al. 2024). The flowering individuals are only considered as mature individuals and recorded accordingly.

Area of Occupancy (AOO) & Extent of Occurrence (EOO)

To calculate the AOO and EOO of species, geo-coordinates were collected during field visits and also supplemented through secondary literatures (Gibbons & Spanner 2009; Kholia 2009, 2010). Further, the extent of occurrence for *T. takil* is measured by delimiting a polygon that encompassed all the known localities of a taxa (known as minimum convex polygon or convex hull) using Geospatial Conservation Assessment Tool (GeoCAT) and QGIS version 3.32 (Tali et al. 2015). Area of

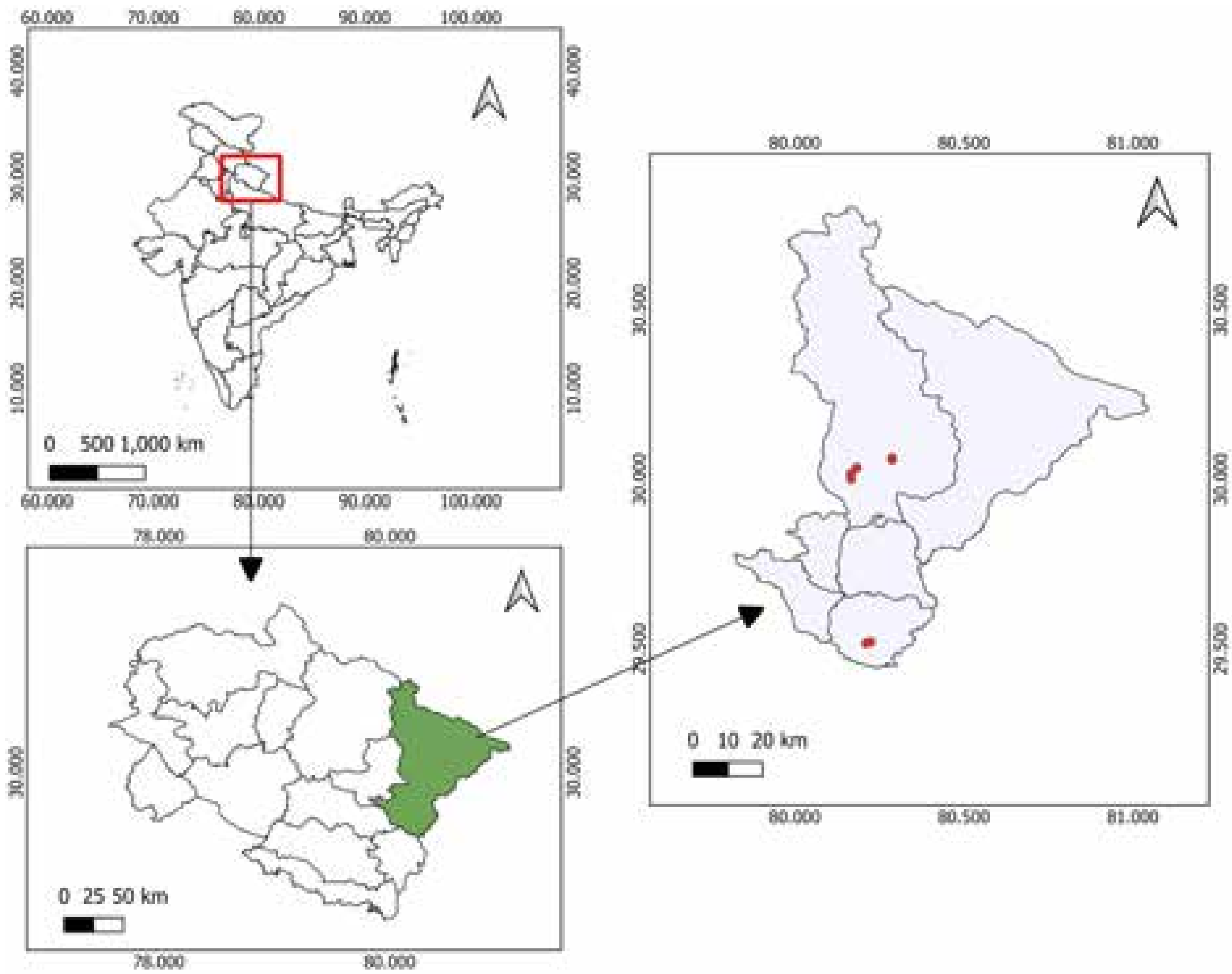

Figure 1. Map of study area for field survey.

occupancy of the species was calculated by overlaying a uniform grid over the entire range of the taxon and then tallying the number of all the grids occupying species' presence. Grid size of 2*2 km^2 size was used to calculate the AOO of *T. takil* (Tali et al. 2015; IUCN 2024) using the below provided formulae:

Area of occupancy = No. of occupied cells × area of individual cell.

RESULTS

Distribution of the species

The population of *Trachycarpus takil* recorded between 1,900 m and 2,500 m elevation in the rocky and moist, shady habitat as undergrowth of mixed oak forest. Total mature individuals of the species are varying significantly in different location. Presently, the species recorded in Almora (Bhatkot) and Pithoragarh (Thal Kedar, Baravey, Kalamuni) districts, Uttarakhand, India. Currently, the mature individuals have recorded only in three places, namely, Kalamuni, Thal Kedar, and Baravey, whereas, no mature individuals are found in Bhatkot area. The Kalamuni- Ratapani recorded 243 mature individuals (adult trees in flowering stage), while the Thal Kedar recorded five mature individuals. The Gini band-Samkot recorded 49 mature individuals, and the Baravey had eight mature individuals. *T. takil* is growing in association with *Buxus wallichiana*, *Cupressus torulosa*, *Quercus semecarpifolia*, and *Taxus wallichiana* at Kalamuni, Ratapani, and Gini band-Samkot. At Thal Kedar, the species is mainly associated with *Arundinaria falcata, Quercus floribunda*, and *Quercus leucotricophora* (Table 1).

Resource use pattern and threats

Traditionally, the locals of the nearby villages use the fibres and leaves of *T. takil* to prepare ropes and brooms,

Table 1. Site characteristics and threats on mature individuals of *Trachycarpus takil*.

	Sites	Altitude (m)	Geo-coordinates	Habitat type	Associated species	Threats
1	Thal Kedar	2,430	N 29.518, E 80.211 N 29.526, E 80.196 N 29.521, E 80.203	Mixed Oak Forest	*Quercus floribunda, Q. leucotricophora, Arundinaria falcata*	Lopping
2	Baravey	1,910	N 29.522, E 80.224	Along barren grazing land	*Quercus leucotricophora*	Lopping
3	Kalamuni-Ratapani	2,220–2,320	N 30.016, E 80.166 N 30.033, E 80.183 N 30.020, E 80.180 N 30.036, E 80.191	Moist rock slopes, under dense canopy of mixed forest	*Q. semecarpifolia, Cupressus torulosa, Taxus wallichiana*	Lopping, seed collection
4	Gini band- way to Samkot	2,259	N 30.017, E 80.167 N 30.000, E 80.167	Moist rocky slopes, under dense canopy of mixed forest	*Q. semecarpifolia, Taxus wallichiana, Buxus wallichiana, Abies pindrow*	Lopping, seed collection

for which they cut down the tree at the base, posing a serious threat to the species in the wild. The paste of flowers with young flowers of *Bombax ceiba* are being used as a medicine to cure gonorrhoea and vaginal infections. *T. takil* is also cultivated for ornamental purposes, therefore, the seeds are collected and sold at the village level (Rs. 500–1000 /kg). Ripe seeds are edible and also consumed by the local people. The destructive methods used by locals to collect the leaves, fibres, and seeds of the species and forest fire occurrences are major threats to the wild population.

Extent of occurrence & Area of occupancy

In Uttarakhand State, *T. takil* was found distributed between 30.06611–30.09250° N and 80.38861–80.42805° E along an altitudinal range of 1,900–2,500 m. The total extent of occurrence (EOO) of *T. takil* is 2,078.80 km^2. The AOO of the species is 28 km^2. The EOO of *T. takil* encompasses only 3.95% area of Uttarakhand and 29.29% area of Pithoragarh District (Figure 2,3).

Threat Assessment of *Trachycarpus takil*

As per the IUCN Red List categories and criteria, the *Trachycarpus takil* has been assessed. The EOO of the species recorded 2,078.80 km^2, which is less than the threshold value (<5000 km^2) and aligns with criterion 'B1' for 'Endangered category'. The AOO of the species was estimated 28 km^2, which meets again criterion 'B2'. Data collected from secondary sources and field visits indicates that the species is restricted to only four places (Thal Kedar, Baravey, Kalamuni, Bhatkot) in Uttarakhand, aligning with sub-criterion 'a'. The multiple threats across its distribution range are leading to continuous decline in the habitat of the species. In Bhatkot and Thal Kedar, forest fire causes degradation in its habitat and direct collection of seeds from natural population also affects the regeneration of the species aligning with the sub-criterion 'b(iii)' (continuous decline in area, extent,

Figure 2. Extent of occurrence of *Trachycarpus takil*.

and/or quality of habitat). A continuous decline in the number of mature individuals is also recorded from these locations due to forest fire and anthropogenic pressure, qualifying the species for sub-criterion 'b(v)' (decline in number of mature individuals).

Keeping the above, the endemic *Trachycarpus takil,* recorded in restricted number of location, limited AOO, EOO, declining in habitat quality and mature individuals justify its IUCN Red List assessment as 'Endangered' under B1ab(iii,v) & B2ab(iii,v) (Table 2).

DISCUSSION

The population assessment is essential to quantifying the threat status, especially for endemic and threatened elements. In absence of quantifiable datasets, we were not able to analyse the population threat and distribution

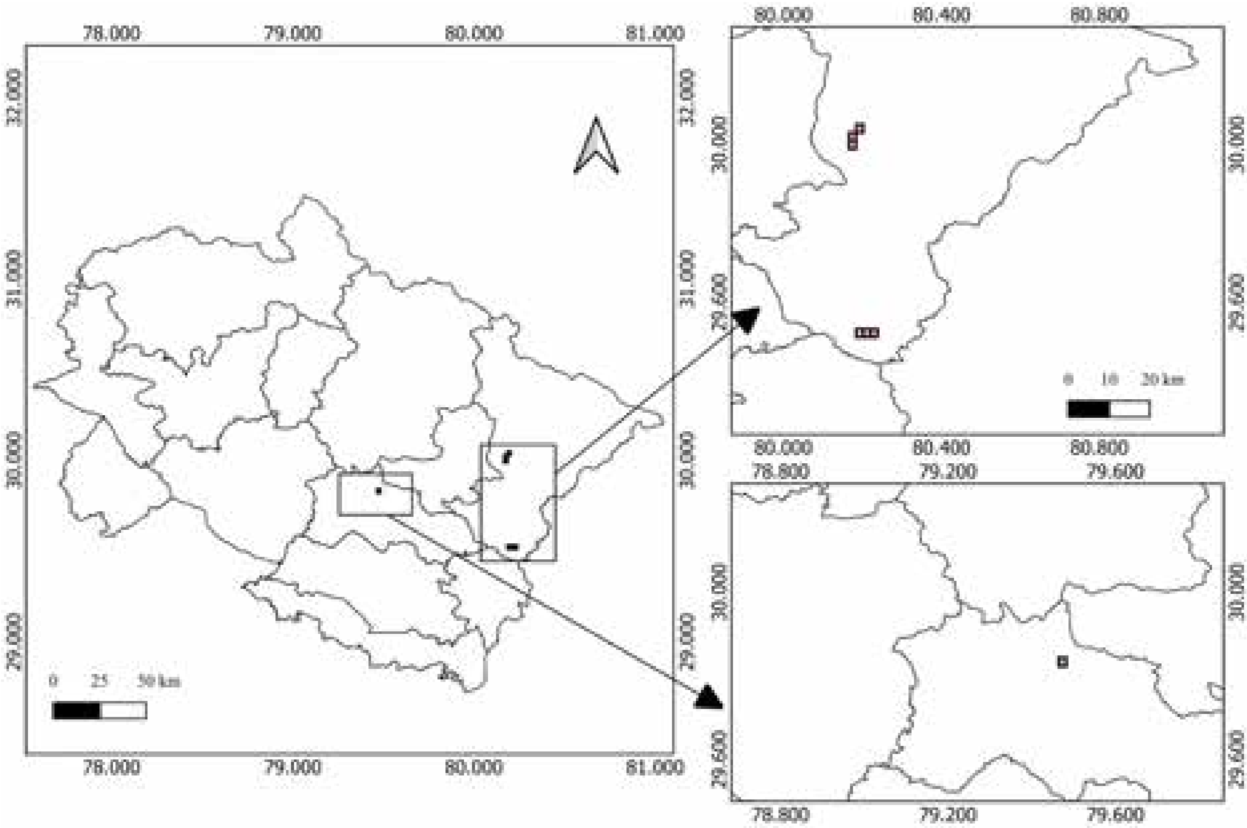

Figure 3. Area of occupancy (2 km²) of *Trachycarpus takil*.

Table 2. Threat categorization of *Trachycarpus takil*.

Criteria	IUCN categories	*T. takil* values	Status / reference	IUCN Red List proposed
B. Geographic range	**1. Extent of occurrence** (<5000 km²)	2,078.80 km² EOO, recorded in 04 location only, habitat degradation due to forest fire, decline of mature individuals (from approx. 500–305)	Present study; Kholia (2009), Kholia (2010), Gibbons & Spanner (2009)	Endangered (EN) EN B1ab(iii,v)
	a. Known to exist at no more than five locations			
	b. Continuing decline, observed, inferred iii. area, extent and/or quality of habitat v. number of mature individuals			
	2. Area of occupancy (<500 km²)	28 km² AOO, recorded in 04 locations only, habitat degradation due to forest fire, decline of mature individuals (from approx. 500–305)	Present study; Kholia (2009), Kholia (2010), Gibbons & Spanner (2009)	EN B2ab(iii,v)
	a. Known to exist at no more than five locations			
	b. Continuing decline, observed, inferred iii. area, extent and/or quality of habitat v. number of mature individuals			

pattern. *T. takil* is one among the species having limited/quantitative datasets to conclude the population trend and distribution range (Tali et al. 2015). To strengthen the quantification of the dataset, we surveyed all the places where the species recorded in Uttarakhand State, India. Extensive survey revealed a total of four areas, namely, Kalamuni, Thal Kedar, Baravey, Bhatkot (Almora and Pithoragarh districts, Uttarakhand, India), we recorded the presence of *T. takil* in natural condition. The Kalamuni region recorded highest number of individuals (243) and the interior population of Samkot (49) is reported first time in the present study. Due to forest fire and presence of few juveniles (<10), the population of Bhatkot is having higher threat (Kholia 2009). Further,

Image 1. *Trachycarpus takil*: a—Habitat | b—Sapling | c—Seedling | d—Lopping of leaves | e—Brooms prepared by locals | f—Fibre used for ropes | g—Ligules.

the present study could not able to consider the *T. takil* recorded in China, due to non-availability of quantitative dataset on population, area of occupancy, distribution range (Ding et al. 2022). Currently, the *T. takil* is very restricted distribution in India (Uttarakhand) and placed in the 'Rare' category of Red Data Book of India (Nayar & Sastri 1988). The larger population recorded in Kalamuni and Ratapani may be due to lesser accessibility in the hill region. During the survey, a good number of seedlings (>50) were observed in the Thal Kedar forest showing good regeneration potential. But due to continuous extraction of leaves and seeds, and occurrences of forest fires, the survival of these saplings is questionable (Kholia 2010). Therefore, there is a need to develop effective propagation protocols along with *in situ* conservation efforts. However, present study reported good number of mature individuals at Kalamuni area as compared to the previous studies (Kholia 2009), but due to increasing demand of seeds, continuous leaf extraction and forest fires, this species is under severe threat. *T. takil* is native, endemic to Indian Himalayan Region, and having only four populations, thus requires immediate attention and conservation measures, before vanishing from the natural forest area.

CONCLUSION

Threatened and endemic species are confined to restricted range and certainly be the first to be hit by extinction processes therefore such species require effective conservation strategies. *Trachycarpus takil* is an endemic and threatened palm of western Himalaya, India. The species is reported from four locations of Uttarakhand. The locals use the species as medicine, for making ropes, brooms, and curd churners. Destructive harvesting and forest fires are posing serious threats to the species. The AOO and EOO of the species is calculated and finds 28 km^2 and 2,078.80 km^2, respectively. On the basis of restricted distribution, number of locations, individuals and threats, the study recommends inclusion of *T. takil* in IUCN Red List threat categories, under 'Endangered', and inclusion of the identified locations into the protected area network to ensure the effective *in-situ* conservation of the species.

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COMMUNICATION

A checklist of fishes of Haiderpur wetland, western Uttar Pradesh, India

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Abstract: River-associated floodplains and wetlands provide natural spawning and nursery grounds for many freshwater fishes. Haiderpur wetland is one of such important river-associated wetlands of the Ganga River located in Bijnor District of western Uttar Pradesh. Considering its ecological significance, an inventory of fish species inhabiting in the Haiderpur wetland was carried out between June and July 2020. A total of 57 species of fishes belonging to 44 genera, 10 orders, and 27 families were recorded. Three exotic species, namely, *Hypothalmichthys molitrix*, *Oreochromis niloticus*, and *Ctenopharyngodon idella*, were recorded from the wetland. Based on the fish record, a checklist of the fish species of the Haiderpur wetland is being prepared and presented herewith with updated information on the current valid names, vernacular names, and IUCN Red List status.

Keywords: Exotic species, fish diversity, freshwater, floodplains, Ganga River, ichthyofauna, river associated, spawning, threatened fish, vernacular.

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Competing interests: The authors declare no competing interests.

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Author contributions: RR surveyed the study site and collected samples, identification and JAJ and SAH supervised the work and interpreted taxonomic information gathered by the RR.

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INTRODUCTION

Wetlands are amidst the most productive ecosystems on the Earth and provide many vital services to human society (Ghermandi et al. 2010; Brink et al. 2012). Wetlands also play a valuable role as breeding grounds for a wide variety of species of fish and other invertebrates. In any wetland, fish typically represent a significant biological part, playing a critical role in energy flow between lower and higher trophic levels and control energy and nutrient-flow via predation. It also serves as a valuable fishery resource for the local community residing around the wetlands.

In India, the Gangetic plain has many large-sized natural and man-made wetlands, which are connected with the Ganga River during the monsoon months and serve as flood buffering systems. In addition to that, they form a natural reserve for maintaining fish genetic resources. Haiderpur wetland is one of those wetlands located in the floodplain region of the Upper Ganga basin in western Uttar Pradesh. The wetland is ecologically important since it provides refugia habitats to many freshwater organisms, including fishes and is hydrologically different because of slow-moving water creates favorable conditions for many lentic organisms. This wetland is a trove in terms of fish species and supports the livelihood of many people living around the wetland. Even though it is a well-known aquatic habitat, there is no comprehensive information on the Ichthyofauna species associated with this wetland. Thus, an intensive survey was carried out from June 2020 to July 2020 to prepare the fish checklist in this wetland. A checklist of fish species residing in this wetland and their current conservation status is presented in this communication. We also provide site-specific catch per unit efforts so that this information can be used as a baseline for future fish conservation efforts in the region.

MATERIALS AND METHODS

Study Area

Haiderpur wetland is a man-made wetland that came into existence in 1984 after the construction of Madhya Ganga barrage on the mighty Ganga River and it falls in Muzaffarnagar District and also part of Hastinapur Wildlife Sanctuary (HWS) of western Uttar Pradesh (Image 1). It lies in the Upper Gangetic Plains biogeographic zone (7A) of India in the state of Uttar Pradesh (Rodgers & Panwar 1988). This wetland comprises of 3,000 acres and adjoining 1,532 ha of the forest area of different blocks of Haiderpur, Nizampur, Jedhpur, Gorsiwal, Kasampur, Eashqwala, and Nawalpur. It includes various deep upstream reservoirs of Madhya Ganga Barrage, associated shallow flooded land, stretches of river Ganga and its tributary, river Solani. Six sampling locations were fixed randomly depending on the accessibility for exploring fish diversity in the wetland (Image 1). GPS coordinates of sampling sites and the mean depth of sampling points are given in Table 1.

The population composition of wetland areas comprises of Bengali fisherman community and gurjars primarily engaged in fishing for their livelihoods.

Fish Sampling

Our sampling sites are situated mostly in the southern part of the Wetland because of accessibility and other practical constraints. Importantly, our sites are well-distributed in the space to represent the wetland well. Fish sampling was conducted in the selected sampling points using 180 m long mono-filamentous gill nets of various mesh sizes measuring (0.5 inch, 1 inch, 2 inch, 3 inch, 4 inch, 5 inch, 10 inch and 12 inch). Cast net and trap nets were also used. An average of 4 net/hours was given continuously for 10 days from 0600 h to 0800 h, and 1600 h to 1800 h, and each site was sampled twice, once in the morning and then in the evening during the monsoon months (July 2020). Constant fishing efforts using all the six different gill nets for equal duration were maintained throughout the sampling period. Different types of fishing gears used are given in Image 2.

After the sampling, fishes were collected, and they were photographed using a digital SLR Camera -Nikon D5300. Colour, colour patterns, spots/blotches, stripes, and other characteristics of the fishes were noted in the field. Some of the unidentified fishes were preserved in a 10% formalin solution for species confirmation. All specimens were deposited in the National Repository Museum of Wildlife Institute of India, Dehradun. The species were identified in the laboratory using the taxonomic keys of Talwar & Jhingaran (1991), Jayaram (2010), and Bleher (2018). Valid species and valid nomenclatural names were adopted as per the Catalogue of Fishes of the California Academy of Sciences (Frickie et al. 2018). The current conservation status of fishes was accessed from IUCN Red List data (IUCN 2021). A checklist of fishes recorded in the Haiderpur wetland is presented in Table 2. Catch per unit efforts (CPUE) was calculated as the number of captured fishes per hour in all applied gill nets.

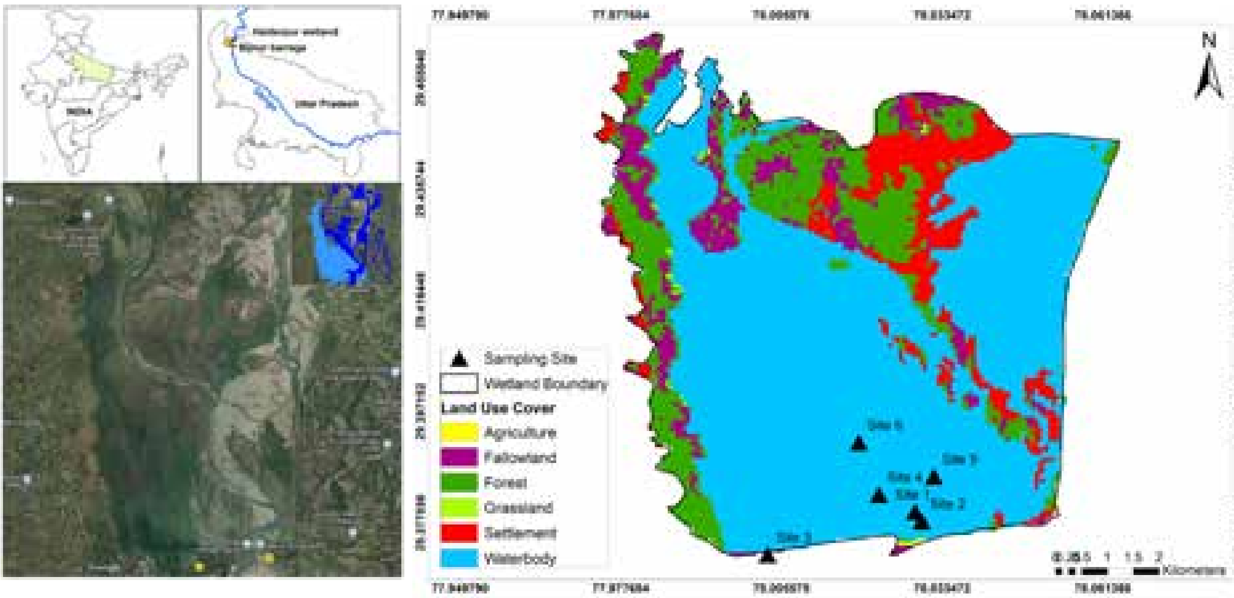

Image 1. Study area and fish sampling sites.

Table 1. Details of fish sampling locations in Haiderpur wetland, western Uttar Pradesh.

	Site	GPS coordinates		Mean depth (m)
		Latitude (N)	Longitude (E)	
1	Site 1	29.3797	78.0287	2.9
2	Site 2	29.3781	78.0299	3.4
3	Site 3	29.3723	78.0031	2.1
4	Site 4	29.3827	78.0225	1.8
5	Site 5	29.3858	78.0320	1.5
6	Site 6	29.3918	78.0190	3.2

RESULTS

The present study revealed that 57 species of fishes belonging to 44 genera, 10 orders, and 27 families inhabit in Haiderpur wetland. Cyprinidae was the most abundant family with 13 species, followed by Bagridae with five species (Images 4–60). The checklist presented in this study represents the most updated list of freshwater fishes from the Haiderpur wetland compared to the earlier studies conducted in the entire Bijnor district. Prior to this study, only the presence of 36 fishes from the Bijnor District has been reported by (Khan et al. 2013). The present study includes economically important fish species like *Wallago attu*, *Chitala chitala*, *Notopterus notopterus*, *Bagarius bagarius*. The other significant findings of the study reveal that many species like *Labeo bata*, *Wallago attu*, *Notopterus notopterus*, *Ophicthys cuchia* are of high ecological significance since it is valued remedy in oriental medicine (Ray 1988). The study, however, has also been able to detect the presence of some of the exotic species of fishes such as *Cyprinus carpio*, *Hypothalmichthys molitrix*, *Ctenopharyngodon idella*, and *Oreochromis niloticus*, which are disturbing the habitat for the native fish species by competing in terms of food, space and tolerant extreme conditions. Haiderpur wetland inhabits nearly half of the freshwater fish species reported from the main Ganga River. Recent studies revealed that main course of Ganga River inhabits 117 species of native freshwater species (Dwivedi et al. 2019).

Haiderpur wetland, like any other wetland has an almost entirely tropical climate 29^{o} N surrounded by the human settlements. In the process of rapid urbanisation, various species are going under mass extinction from their native habitats (Mckinney 2002). Among 57 species of fishes recorded from Haiderpur wetland, only three species, namely, *Chitala chitala*, *Ompok pabda*, and *Bagarius bagarius*, were found to be in 'Near Threatened' category of IUCN Red List 2021, whereas three were exotic species, and only one species namely, *Clarias magur* was found to be in IUCN Red List 'Endangered' category and the remaining 50 fish species were in IUCN Red List 'Least Concern' category. Habitat degradation and anthropogenic pressure like cultivation of water chestnut and use of chemicals by farmers have seriously affected the fish fauna of the entire Haiderpur wetland. During the survey, various types of invasive

Image 2. Different types of fishing gears used for fish sampling in the Haiderpur wetland, western Uttar Pradesh. © Rahul Rana.

weeds, e.g., *Pontederia*, *Pistia*, *Hydrilla* spp., and *Potamogeton*, have adversely affected the wetland by encroaching and disturbing the fish habitat (Image 3).

Wallago attu and *Chitala chitala* which thrives well and hides in the submerged aquatic vegetation and Haiderpur wetland, therefore, provides the suitable habitat. *Bagarius bagarius* are amongst some of the indicator species depicting the pristine habitat of the wetland serving as the breeding grounds and sustaining large fish population. On the other hand, few areas are under stress due to the effluent and sewage discharge compelling only species like *Trichogaster fasciata* and *T. lalia* surviving in those areas. For long-term monitoring and conservation of wetlands and sustaining aquatic species curbing the challenges in wetland conservation will play a key role in maintaining a healthy ecosystem for the fish population.

Relative Abundance

Relative abundance showed abundance of small-sized indigenous species in the study area. The most abundant species as per relative abundance was *Amblypharyngodon mola* having relative abundance of 0.30, followed by *Puntius sophore* 0.16, *Trichogaster lalius* 0.15, and *Trichogaster fasciatus* 0.13.

Table 2. Site wise catch per unit effort values.

	Site no.	Mean CPUE (fish/h)
1	S1	4
2	S2	15.25
3	S3	83
4	S4	14
5	S5	5.5
6	S6	114.5

Catch per unit efforts

CPUE was observed maximum at site-6 – 114.55 and minimum at site-1 – 4.

Family wise representation (pie chart) of individual species at each site is presented in Figure 1.

DISCUSSION

Haiderpur wetland is a variegated wetland of swampy vegetation and tall grasses. Floodplain wetlands are

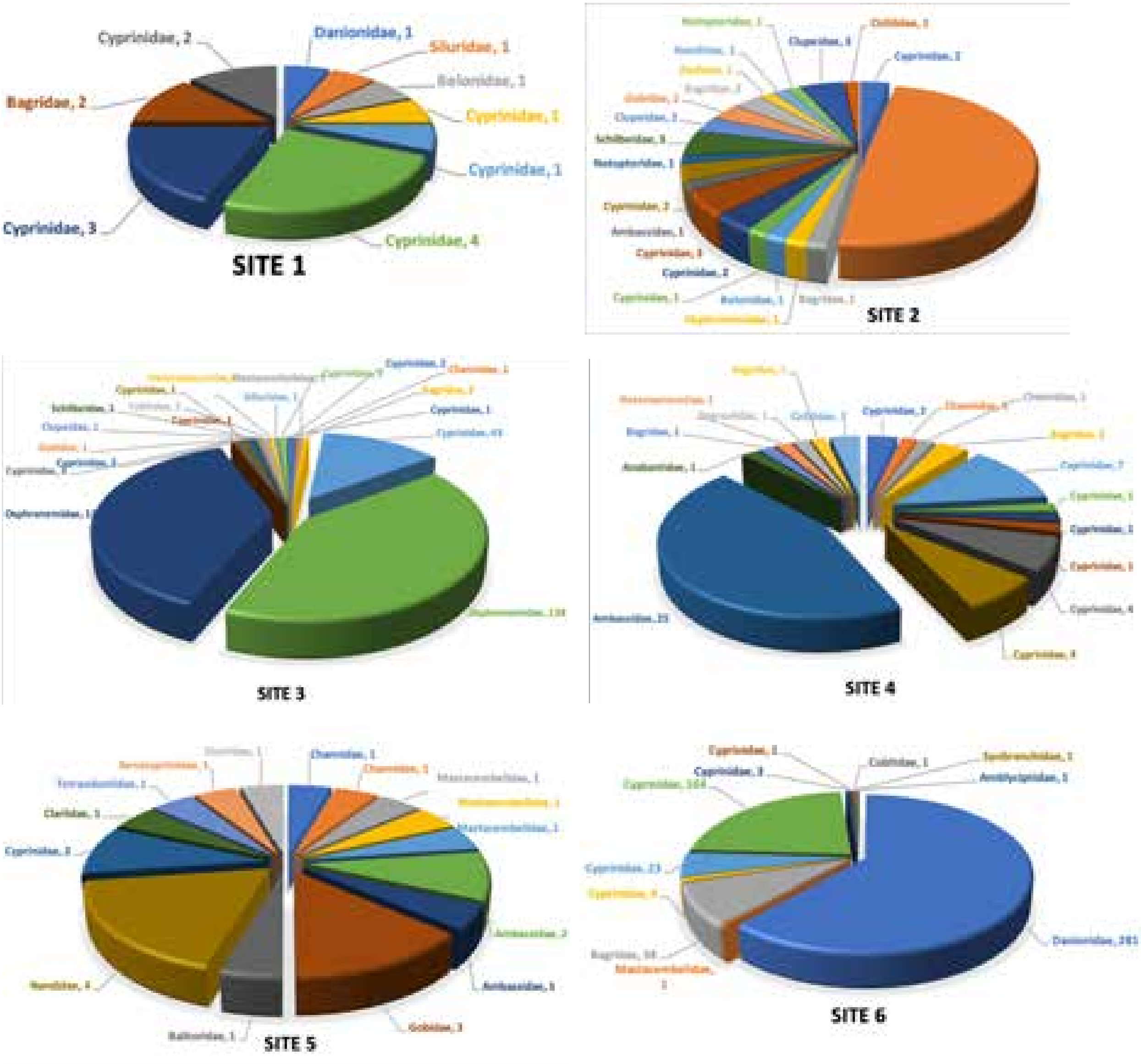

Figure 1. Family wise representation (pie chart) of individuals species at each site.

one of the most productive and species-rich lacustrine ecosystems (Kingsford et al. 2016). It also forms an important site for the conservation of water birds and swamp deer. Previous studies conducted in Banganga wetland (Sivakumar 2017), recorded presence of 40 fish species during the survey whereas Khan et al. (2013) reported presence of only 36 fish species from the entire Bijnor District. Therefore, the present study carried out in the Haiderpur wetland reveals the unexplored diversity which is a first of its kind since it has not been assessed in terms of fish diversity earlier. No previous studies have been conducted explicitly in the Haiderpur wetland.

This distinctive hydrological system and having a variety of submerged aquatic vegetation provides suitable breeding grounds and habitat for fish populations an ichthyological baseline inventory of Red Listed species of the wetland and for biodiversity conservation point of view. It also provides unreported and unexplored diversity of fish species and scope for trend analysis of the population of these fish species in the future. It is imperative that the sites, where threatened species are recorded should be monitored regularly for future. On the other hand local anthropogenic pressures like seasonal cultivation of water chestnut by locals and use of chemicals in the crops gets washed off directly into the wetland, grazing of cattle during the dry spell are other local disturbances affecting the wetland. Merging

Table 3. Checklist of fish species of Haiderpur wetland.

	English name	Species	Authority	Vernacular name	IUCN Red List
I. ORDER OSTEOGLOSSIFORMES					
1. Family Notopteridae					
1	Bronze Featherback	*Notopterus notopterus*	(Pallas, 1769)	Pholi	LC
2	Clown Knifefish	*Chitala chitala*	(Hamilton, 1822)	Chital	NT
2.Family Clupeidae					
3	Indian River Shad	*Gudusia chapra*	(Hamilton, 1822)	Suiya	LC
II. ORDER CYPRINIFORMES					
3. Family Cobitidae					
4	Guntia Loach	*Lepidocephalichthys guntea*	(Hamilton, 1822)	Guntea	LC
4. Family Nemacheilidae					
5	Mottled Loach	*Paracanthocobitis botia*	(Hamilton, 1822)	Chitai	LC
5. Family Cyprinidae					
6	Mrigal Carp	*Cirrhinus mrigala*	(Hamilton, 1822)	Mrigal	LC
7	Reba Carp	*Cirrhinus reba*	(Hamilton, 1822)	Rewah	LC
8	Common Carp	*Cyprinus carpio*	(Linnaeus, 1758)	-	Exotic
9	Bata	*Labeo bata*	(Hamilton, 1822)	Bhagan	LC
10	Orangefin Labeo	*Labeo calbasu*	(Hamilton, 1822)	Kalbons	LC
11	Kuria Labeo	*Labeo gonius*	(Hamilton, 1822)	Khursa	LC
12	Roho Labeo	*Labeo rohita*	(Hamilton, 1822)	Rohu	LC
13	-	*Labeo dyocheilus*	(McClleland, 1839)	Kali	LC
14	Rosy Barb	*Pethia conchonius*	(Hamilton, 1822)	Pothi	LC
15	Ticto Barb	*Pethia ticto*	(Hamilton, 1822)	Pothia	LC
16	Pool barb	*Puntius sophore*	(Hamilton, 1822)	Pottiah	LC
17	Stone Roller	*Tariqilabeo latius*	(Hamilton, 1822)	Kala bata	LC
18		*Osteobrama cotio*	(Hamilton, 1822)	Cotio	LC
6. Family Danionidae					
19	Mola Carplet	*Amblypharyngodon mola*	(Hamilton, 1822)	Mola	LC
20	Morari	*Cabdio morar*	(Hamilton, 1822)	Morari	LC
21	Slender Rasbora	*Rasbora daniconius*	(Hamilton, 1822)	Rasbora	LC
22	Large Razorbelly Minnow	*Salmostoma bacaila*	(Hamilton, 1822)	Chela	LC
7. Family Xenocyprinidae					
23	Grass Carp	*Ctenopharyngodon idella*	(Valenciennces, 1844)	Carp	Exotic
24	Silver Carp	*Hypothalmichthys molitrix*	(Valenciennes, 1844)	Silver	Exotic
III. ORDER SILURIFORMES					
8. Family Bagridae					
25	Gangetic Mystus	*Mystus cavasius*	(Hamilton, 1822)	Kavasi	LC
26	Tengara Catfish	*Mystus tengara*	(Hamilton, 1822)	Tengara	LC
27	Rita	*Rita rita*	(Hamilton, 1822)	Rita	LC
28	Long Whiskered Catfish	*Sperata aor*	(Hamilton, 1822)	-	LC
29	Giant River-Catfish	*Sperata lamarrii*	(Sykes, 1839)	Seenghala	LC
9. Family Siluridae					
30	Pabdah Catfish	*Ompok pabda*	(Hamilton, 1822)	Pabda	NT
31	Wallago	*Wallago attu*	(Bloch & Schneider, 1801)	Parhin	VU
10.Family Amblycipitidae					
32	Biting Catfish	*Amblyceps mangois*	(Hamilton, 1822)	-	LC
11. Family Sisoridae					
33	Goonch	*Bagarius bagarius*	(Hamilton, 1822)	Goonch	NT

	English name	Species	Authority	Vernacular name	IUCN Red List
12.Family Erethistidae					
34	Giant Moth Catfish	*Erethistes pussilus*	(Muller & Troschel, 1849)	-	LC
13.Family Clariidae					
35	Magur	*Clarias magur*	(Hamilton, 1822)	-	EN
14. Family Heteropneustidae					
36	Stinging Catfish	*Heteropneustes fossilis*	(Bloch, 1794)	Singhi	LC
15. Family Schilbidae					
37	Garua Bachcha	*Clupisoma garua*	(Hamilton, 1822)	Garua	LC
38	Vacha, Tunti	*Eutropiichthys vacha*	(Hamilton, 1822)	Bachwa	LC
IV. ORDER SYNBRANCHIFORMES					
16. Family Mastacembelidae					
39	Lesser Spiny Eel	*Macrognathus aral*	(Bloch & Schneider, 1801)	Aral	LC
40	Barred Spiny Eel	*Macrognathus pancalus*	(Hamilton, 1822)	Baim	LC
41	Zig-zag Eel	*Mastacembelus armatus*	(Lacepede, 1800)	Baam	LC
17. Family Synbranchidae					
42	Cuchia	*Ophicthys cuchia*	(Hamilton, 1822)	Kuchia	LC
V. ORDER ANABANTIFORMES					
18. Family Anabantidae					
43	Climbing Perch	*Anabas testudineus*	(Bloch, 1792)	Kawai	LC
19. Family Osphronemidae					
44	Dwarf Gourami	*Trichogaster lalius*	(Hamilton, 1822)	Khosti	LC
45	Banded Gourami	*Trichogaster fasciata*	(Bloch & Schneider, 1801)	Gourami	LC
20. Family Channidae					
46	Dwarf Snakehead	*Channa gachua*	(Hamilton, 1822)	Bothua	LC
47	Great Snakehead	*Channa marulius*	(Hamilton, 1822)	Pumuri	LC
48	Spotted Snakehead	*Channa punctata*	(Bloch, 1793)	Phool-dhok	LC
49	Striped Snakehead	*Channa striata*	(Bloch, 1793)	Soura	LC
21. Family Nandidae					
50	Gangetic Leaffish	*Nandus nandus*	(Hamilton, 1822)	Debari	LC
22. Family Badidae					
51	Badis	*Badis badis*	(Hamilton, 1822)	Badis	LC
VI. ORDER GOBIFORMES					
23. Family Gobiidae					
52	Tank Goby	*Glossogobius giuris*	(Hamilton, 1822)	Tank goby	LC
VII. ORDER CICHLIFORMES					
24. Family Cichlidae					
53	Nile Tilapia	*Oreochromis niloticus*	(Linnaeus, 1758)	Tilapia	Exotic
VIII. ORDER BELONIFORMES					
25. Family Belonidae					
54	Freshwater Garfish	*Xenentodon cancila*	(Hamilton, 1822)	Kauwa	LC
IX. ORDER TETRAODONTIFORMES					
26. Family Tetraodontidae					
55	Ocellated Pufferfish	*Leiodon cutcutia*	(Hamilton, 1822)	Pufferfish	LC
X. ORDER PERCIFORMES					
27. Family Ambassidae					
56	Elongate Glass-perchlet	*Chanda nama*	(Hamilton, 1822)	Chanda	LC
57	Highfin Glassy-perchlet	*Parambassis lala*	(Hamilton, 1822)	Lala	LC

LC—Least Concern | EN—Endangered | VU—Vulnerable | NT—Near Threatened.

Image 3. Aquatic vegetation showing *Pontederia crassipes* with *Euryale ferox* in Haiderpur wetland, western Uttar Pradesh. © Rahul Rana.

of the domestic effluents during floods directly into the wetland adds to the threats. Educational tours and tourism activities also provide revenue generation which can be utilised for more upgradation of the wetland and awareness of aquatic flora and fauna residing in the wetland.

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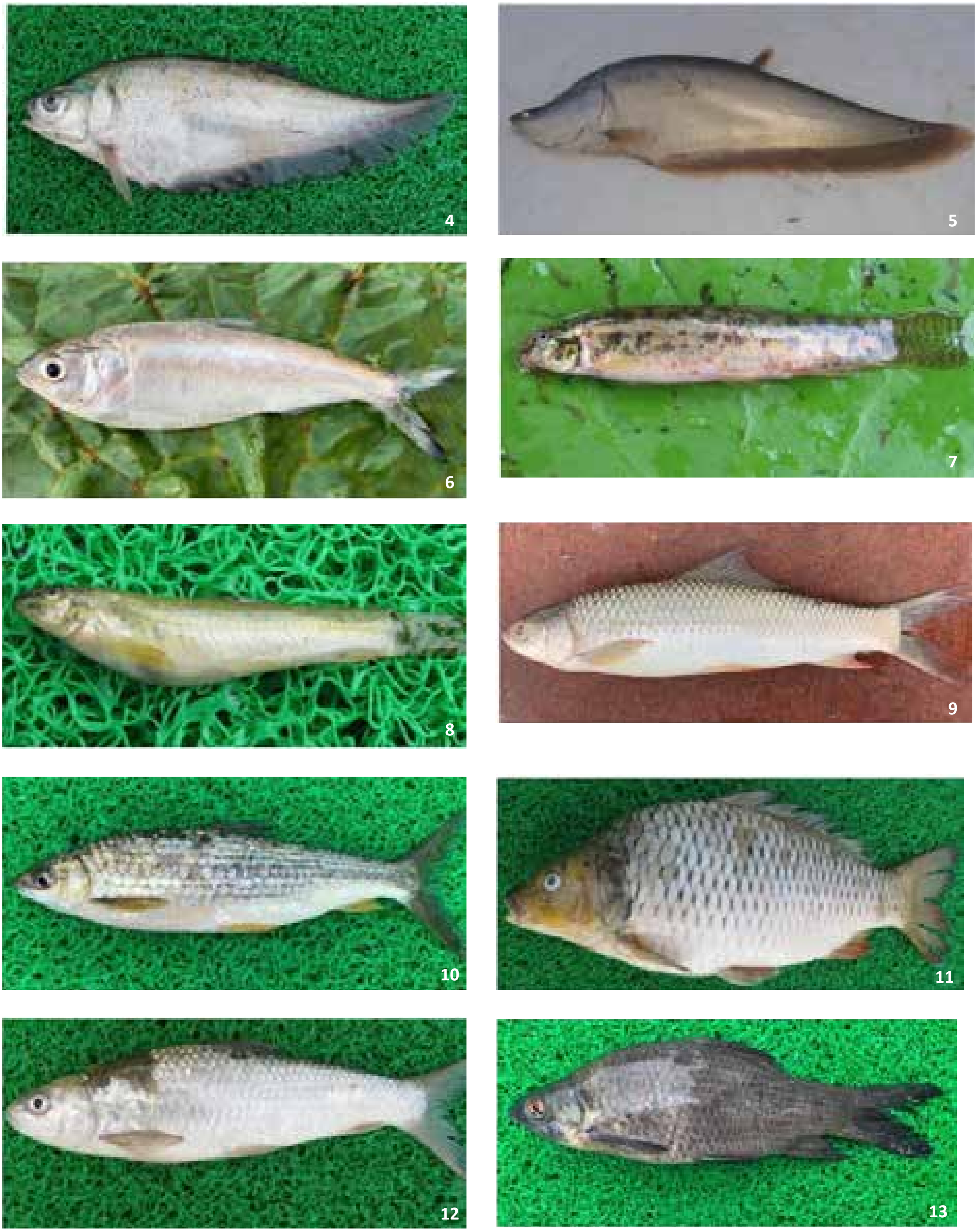

Image 4–13. 4—*Notopterus notopterus* | 5—*Chitala chitala* | 6—*Gudusia chapra* | 7—*Lepidocephalichthys guntea* | 8—*Paracanthocobitis botia* | 9—*Cirrhinus mrigala* | 10—*Cirrhinus reba* | 11—*Cyprinus carpio* | 12—*Labeo bata* | 13—*Labeo calbasu*. © Rahul Rana.

Image 14-23. 14—*Labeo gonius* | 15—*Labeo rohita* | 16—*Labeo dyocheilus* | 17—*Pethia conchonius* | 18—*Pethia ticto* | 19—*Puntius sophore* | 20—*Tariquilabeo latius* | 21—*Osteobrama cotio* | 22—*Amblypharyngodon mola* | 23—*Cabdio morar.* © Rahul Rana.

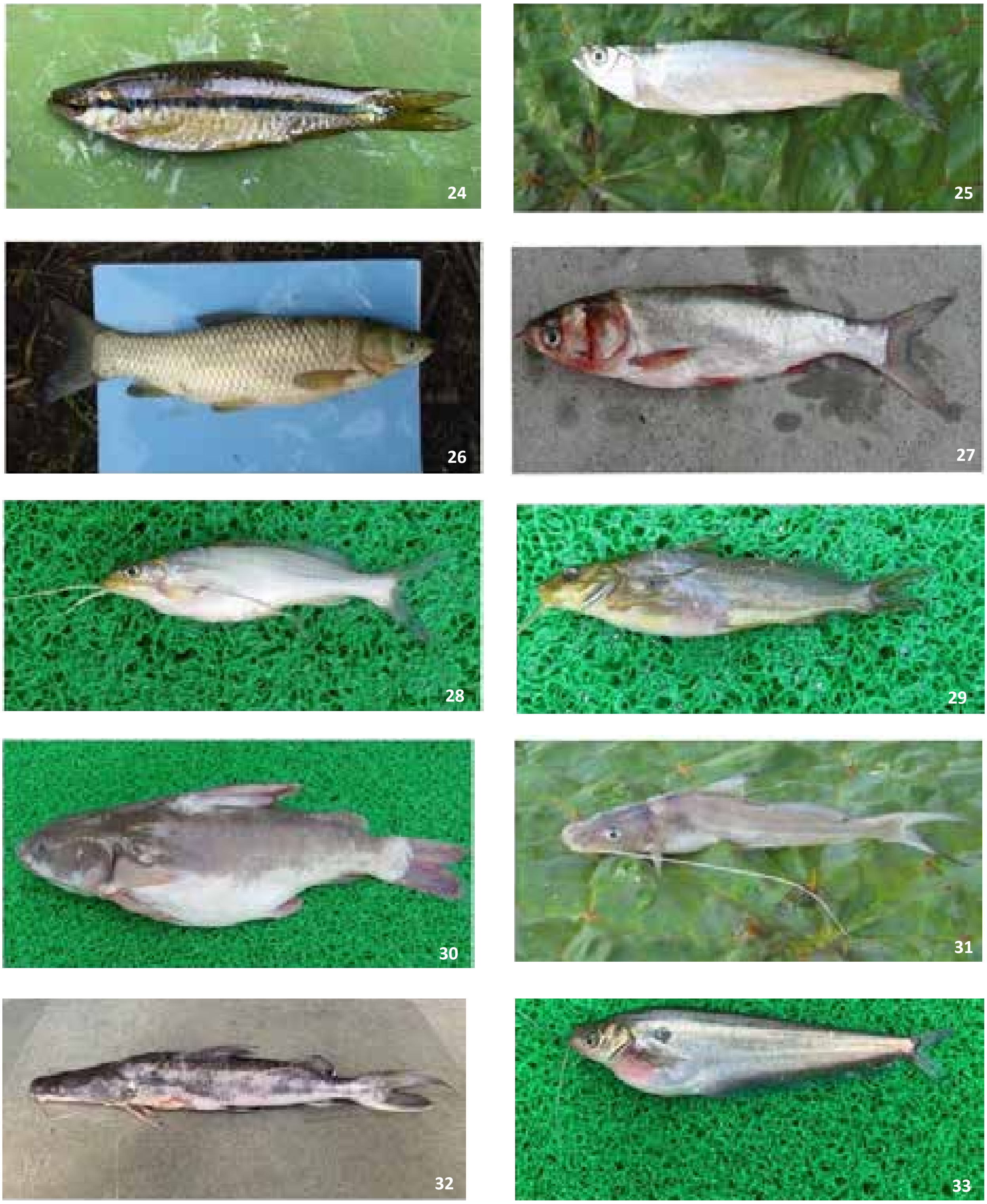

Image 24-33. 24—***Rasbora daniconius*** | 25—***Salmostoma bacaila*** | 26—***Ctenopharyngodon idella*** | 27—***Hypothalmicthys molitrix*** | 28—***Mystus cavasius*** | 29—***Mystus vittatus*** | 30—***Rita rita*** | 31—***Sperata aor*** 32—***Sperata lamarrii*** | 33—***Ompok pabda.*** © Rahul Rana.

Image 34-43. 34—*Wallago attu* | 35—*Amblyceps mangois* | 36—*Bagarius bagarius* | 37—*Erethistes pussilus* | 38—*Clarias magur* | 39—*Heteropneustes fossilis* | 40—*Clupisoma garua* | 41—*Eutropichthys vacha* | 42—*Macrognathus pancalus* | 43—*Macrognathus aral.* © Rahul Rana.

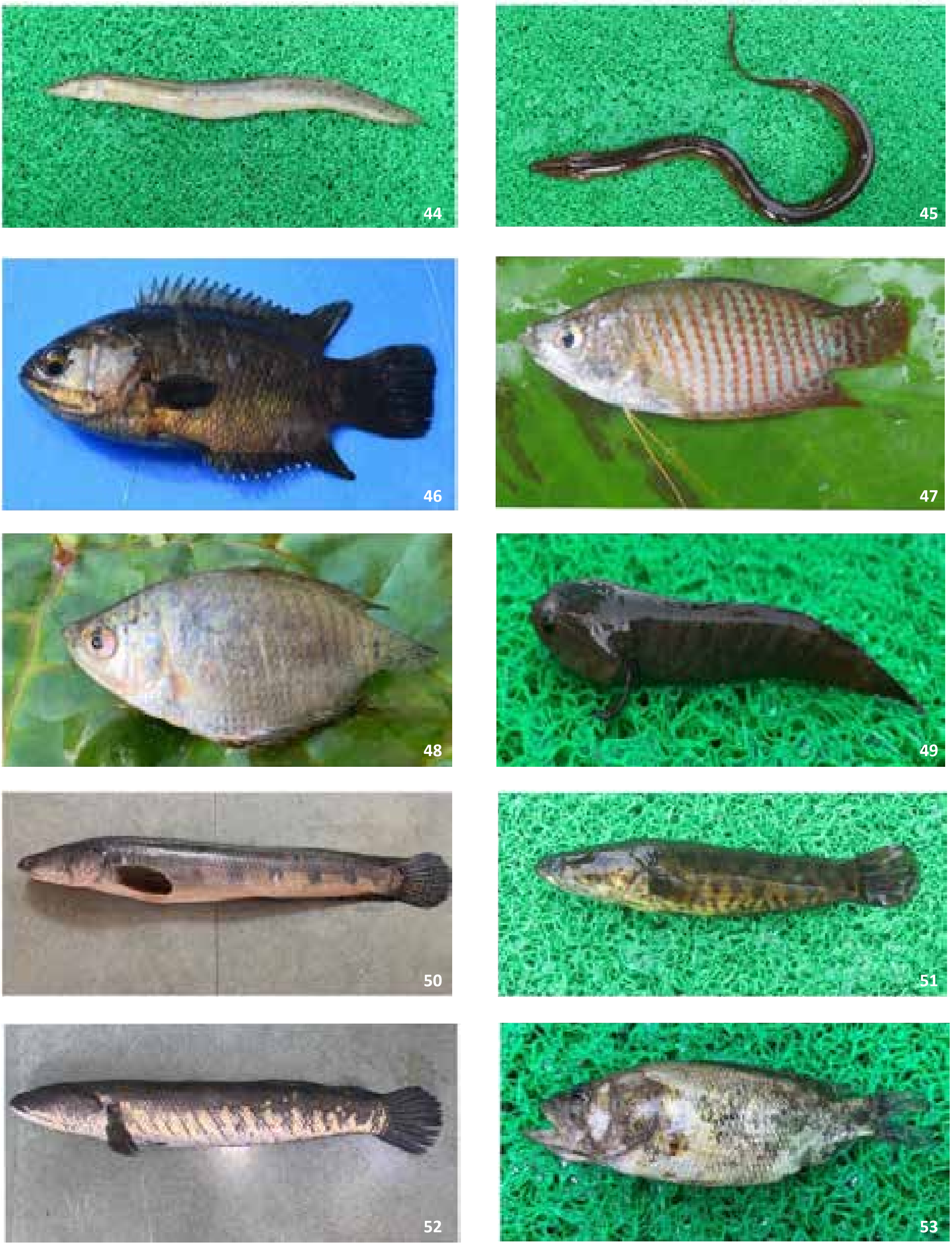

Image 44-53. 44—*Mastacembelus armatus* | 45—*Opichthys cuchia* | 46—*Anabas testudineus* | 47—*Trichogaster lalia* | 48—*Trichogaster fasciata* | 49—*Channa gachua* | 50—*Channa marulius* | 51—*Channa punctata* | 52—*Channa striata* | 53—*Nandus nandus.* © Rahul Rana.

Image 54-60. 54—*Badis badis* | 55—*Glossogobius giuris* | 56—*Oreochromis niloticus* | 57—*Xenentodon cancila* | 58—*Leiodon cutcutia* | 59—*Chanda nama* | 60—*Parambassis lala.* © Rahul Rana.

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COMMUNICATION

An avifaunal checklist of the Zanskar Region, Ladakh Himalaya, India

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Abstract: The present study highlights the significant records of the avifauna of the Zanskar Region of Ladakh Trans Himalaya and forms a first record of its kind. The study was conducted from 1 July 2023 to 30 June 2024, focusing on early morning and late evening observations. Using line transect and random encounter methods, around 81 bird species across 11 orders, and 27 families were recorded. Passeriformes emerged as the predominant order with (44 species). Among the avifauna, 45 species were identified as summer visitors, 27 as residents, six as passage migrants, and three as vagrants. Habitat-specific distribution patterns revealed 53 species in alpine meadows and grasslands, 16 in wetlands and riverine areas, and 12 in rocky cliffs and gorges. Notably, all species, except the Lammergeier *Gypaetus barbatus* and the Himalayan Griffon *Gyps himalayensis*, are categorized as 'Least Concern' according to the IUCN Red List. Both the Lammergeier and Himalayan Griffon are classified as 'Near Threatened', underscoring the region's biodiversity conservation importance.

Keywords: Avifauna, biodiversity, conservation status, habitat distribution, line transect, migratory patterns, random encounter methods.

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Author contributions: AH—contributed to the study design, identification of species, conceptualization and supervision, draft writing, review editing and photography. ZH—contributed to data collection, survey work , photography and table preparation. MA—contributed to data collection , graph preparation and bibliographic study.

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INTRODUCTION

Birds are valuable bioindicators of environmental changes, as shifts in their populations, behaviors, and reproductive patterns often reflect the impacts of habitat fragmentation and ecological disturbances (Harisha & Hosetti 2009). Thus, understanding the diversity and structure of bird communities is crucial for avian conservation and landscape management (Kattan & Franco 2004).

India, one of the 17 mega-biodiversity countries, is home to 1,358 of the 11,000 bird species identified globally. A study conducted between 2011 and 2020 recorded 226 bird species in Ladakh, comprising 96 summer visitors, 83 passage migrants, 40 residents, and seven winter visitors. These species span 19 orders and 50 families, representing 72.90% of all species known in Ladakh and 18.23% of those in the Indian subcontinent. Among these, one species is classified as 'Endangered', eight as 'Near Threatened', two as 'Vulnerable', and 215 as 'Least Concern' on the IUCN Red List of threatened Species (Spengku et al. 2021).

Located within the Central Asian Flyway, the Union Territory of Ladakh in India serves as a critical stopover for migratory birds. Positioned just to the northern side of the Himalayan range, it provides essential resting and feeding grounds during spring and autumn migrations (Namgail & Yom-Tov 2009). The significance of this region is well-documented (Ali & Ripley 1971; Pfister 2004; Prins & Namgail 2017; Spengku et al. 2021; Newton 2023). According to (Pfister 2004), Ladakh's avian diversity can be categorized into four groups based on seasonal occurrence: resident birds, summer visitors, winter birds, and migrants.

Early avian studies in Ladakh commenced with (Adam 1859), followed by significant surveys throughout the 20th century (Mallon 1987; Mishra & Humbert-Droz 1998; Namgail 2005; Sangha & Naoroji 2005; Hussain & Pandav 2008; Namgail et al. 2013; Motup & Sahi 2013). The majority of research has concentrated on eastern and central Ladakh, with western regions receiving comparatively less attention. Western Ladakh has been primarily documented through sporadic observations rather than comprehensive surveys (Ahmed et al.2015). It has reported 69 bird species in the Rangdum Valley, comprising six passage migrants, 25 resident species, 36 summer visitors, and three vagrants. These species belong to seven orders and 24 families, representing approximately 23% of all documented species in Ladakh (Ahmed et al. 2015).

The Zanskar Valley, part of the Suru Valley in Kargil District of Ladakh, is recognized as an Important Bird and Biodiversity Area (IBA) under the A3 criterion (Rahmani et al. 2016), indicating its significance for species unique to specific biomes. This study aims to document the avian diversity of the Zanskar Region, which remains largely unexplored with sparse documentation on its bird diversity.

MATERIAL AND METHOD

Study area

The Zanskar Valley, situated in the Kargil District of the Union Territory of Ladakh, India, is renowned for its distinctive geography and diverse biodiversity. It is nestled between the Great Himalayan and Zanskar mountain ranges, covering an area of approximately 7,000 km^2. This remote region features a high-altitude desert landscape, with elevations ranging 3,500–7,000 m (Kumar 2020). Zanskar experiences an extreme climate characterized by long, harsh winters and short, cool summers, with minimal precipitation, making it one of India's driest regions (Bhattacharya 2018).

Vegetation in Zanskar is sparse and predominantly consists of cold desert shrubs, alpine grasses, and occasional willow and poplar trees along watercourses. Despite its limited vegetation, the area supports a diverse array of plant life crucial for sustaining various bird species, especially those adapted to high-altitude conditions.

Zanskar's diverse habitats, including river valleys, wetlands, rocky cliffs, and alpine meadows, host a wide variety of bird species. Key avian habitats in the region include wetlands and riverine areas, alpine meadows and grasslands, and rocky cliffs and gorges. These habitats provide critical ecosystems for a range of bird species adapted to the challenging conditions of this remote and rugged terrain (Sharma 2019).

Data collection

The present study was conducted from 01 July 2023 to 30 June 2024, and involved systematic field surveys carried out daily during specific time intervals. Surveys were conducted early in the morning (before 0800 h) and late in the evening (after 1500 h). During the peak winter months of January and February, random surveys were conducted between 1000 h and 1500 h to avoid the extreme cold temperatures. Avifaunal observations were made using both the line transect and random encounter methods (Sutherland et al. 2006). Observations and photographs were captured

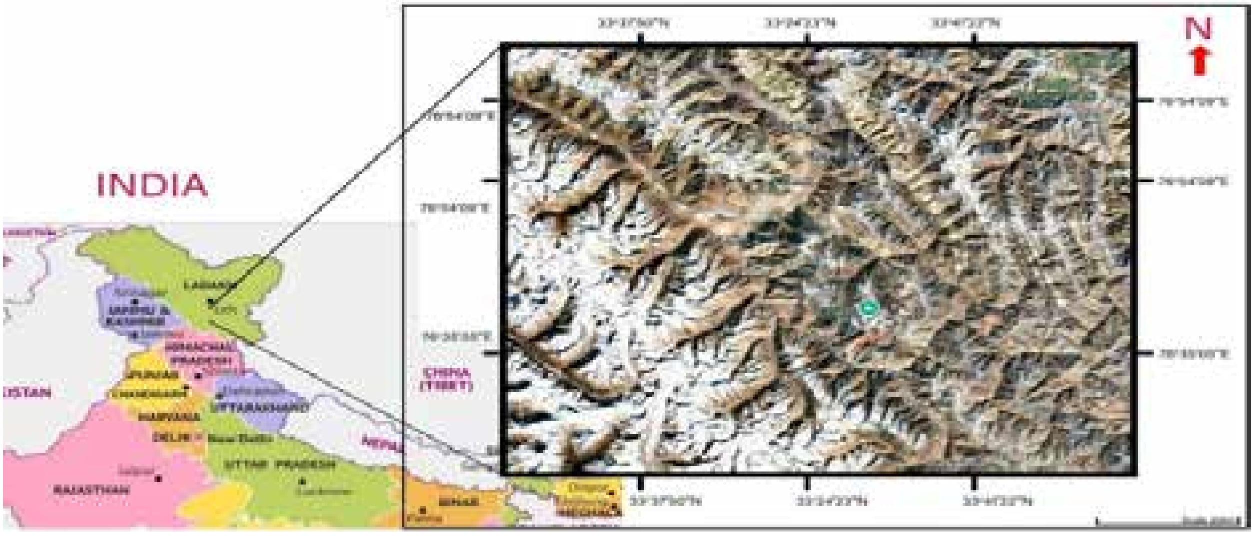

Image 1. Location of the study area (Zanskar).

using a Nikon 10 × 50 binoculars paired with a 200–500 mm lens. Bird identification was facilitated through the use of standard field guides (Ali & Ripley 1987; Grimmett et al. 2016).

The classification of bird sightings considered their threatened status according to the IUCN Red List (IUCN 2022). Birds were categorized based on their frequency of sighting: A – abundant (sighted more than 30 times), C – common (sighted up to less than 15 times), O – occasional (sighted less than 10 times), and R – Rare (sighted less than 5 times), following guidelines adapted from (Mackinnon & Philips 1993) and (Thakur 2008).

RESULTS AND DISCUSSION

In the present study, a total of 81 bird species belonging to 11 orders and 27 families were documented. It accounts for about 27% of the species reported till date from Ladakh. The present findings align with the earlier study conducted by Holmes (1986), Motup & Sahi (2013), Ahmed et al. (2015), and Ajaz et al. (2021). Some similar studies were conducted on the avifauna of Ladakh. Tsewang & Sahi (2013) reported 91 bird species in the Kargil District. Ajaz et al. (2021) documented 136 species in Zanskar and Suru Valley. Ahmed et al. (2015) reported 69 bird species from Rangdum Valley. Holmes (1986) published a checklist of 128 species in Suru Valley. Khan & Kumar (2022) reported 140 bird species in Suru Valley.

Among these, Passeriformes was the most dominant order (50 species) followed by Charadriiformes (nine species), Columbiformes and Anseriformes (five species each), Accipitriformes (four species), Apodiformes and Galliformes (two species each), Bucerotiformes, Cuculiformes, Falconiformes and Pelecaniformes (one species each). The order Passeriformes was reported as the most dominant order in different regions of Ladakh in general and the Zanskar Valley in particular (Holmes 1986; Tsewang & Sahi 2013; Ahmed et al. 2015; Ajaz et al. 2021).

Among these, 45 species were summer visitors, 27 species were residents, six species were passage migrants, and three species were vagrants. The data analysis revealed that the majority of bird species observed were summer visitors (55.6%), followed by resident species (33.3%), passage migrants (7.4%), and vagrants (3.7%). Similar findings were reported by Ahmed et al. (2015) and (Holmes 1986). The availability and accessibility of resources during the summer season can be correlated with a higher percentage of summer visitor birds in the region provide breeding and feeding habitat (Holmes 1986; Hussain & Pandav 2008; Namgail et al. 2009; Ahmed et al. 2015). Further, Ahmed et al. (2015) recorded 69 species in Rangdum Valley in which the resident status of *Passer domesticus* contradicts the present finding as it was found that the *Passer domesticus* is a summer visitor.

Among the 81 recorded species, 53 were found in alpine meadows and grasslands, 16 species were observed in wetlands and riverine areas, and 12 species were spotted in rocky cliffs and gorges. The majority of the bird's species were found in the Alpine meadows and grasslands (65.4%) followed by wetland and

Table 1. List of avifauna found in the Zanskar Region and their IUCN Red List status.

	Species	Common name	Status	IUCN Red List status	Sighting status	Habitat status
	Order (Family) **Anseriformes (Anatidae)**					
1.	*Mergus merganser*	Common Merganser	Resident	LC	Common	WL & RA
2.	*Tadorna ferruginea*	Ruddy Shelduck	Summer Visitor	LC	Occasional	WL & RA
3.	*Mareca penelope*	Eurasian Wigeon	Summer Visitor	LC	Occasional	WL & RA
4.	*Anas querquedula*	Garganey	Passage \Migrant	LC	Rare	WL & RA
5.	*Anas acuta*	Northern Pintail	Passage migrant	LC	Rare	WL & RA
	Apodiformes (Apodidae)					
6.	*Apus apus*	Common Swift	Summer visitor	LC	Common	RC & GL
7.	*Apus pacificus*	Fork-tailed Swift	Summer Visitor	LC	Common	RC & GL
	Passeriformes (Cinclidae)					
8.	*Cinclus cinclus*	White-throated Dipper	Resident	LC	Rare	WL & RA
9.	*Cinclus pallasii*	Brown Dipper	Resident	LC	Rare	WL & RA
	Bucerotiformes (Upupidae)					
10.	*Upupa epops*	Common Hoopoe	Summer visitor	LC	Abundant	AM & GL
	Cuculiformes (Cuculidae)					
11.	*Cuculus canorus*	Eurasian Cuckoo	Summer visitor	LC	Common	AM & GL
	Galliformes (Phasianidae)					
12.	*Alectoris chukar*	Chukar Partridge	Resident	LC	Abundant	RC & G
13.	*Tetraogallu shimalayensis*	Himalayan Snowcock	Resident	LC	Occasional	RC & G
	Columbiformes (Columbidae)					
14.	*Columba livia*	Rock Pigeon	Resident	LC	Abundant	AM & GL
15.	*Columba rupestris*	Hill Pigeon	Resident	LC	Abundant	RC & G
16.	*Columba leuconota*	Snow Pigeon	Resident	LC	Abundant	AM & GL
17.	*Streptopelia orientalis*	Oriental Turtle Dove	Summer visitor	LC	Abundant	AM & GL
18	*Streptopelia senegalensis*	Laughing Dove	Passage migrant	LC	Rare	AM & GL
	Charadriiformes (Pteroclidae)					
19.	*Tringa totanus*	Common Redshank	Summer visitor	LC	Common	WL & RA
20.	*Tringa nebularia*	Common Greenshank	Summer Visitor	LC	Abundant	WL & RA
21.	*Actitis hypoleucos*	Common Sandpiper	Passage migrant	LC	Occasional	WL & RA
22	*Calidris minuta*	Little Stint	Summer Visiter	LC	Occassional	WL & RA
23.	*Tringa glareola*	Wood Sandpiper	Summer Visitor	LC	Common	WL & RA
	Charadriiformes (Charadriidae)					
24.	*Ibidorhycha struthersii*	Ibis-bill	Summer visitor	LC	Common	WL & RA
25.	*Himantopus himantopus*	Black-winged Stilt	Passage migrant	LC	Abundant	WL & RA
26.	*Charadrius mongolus*	Lesser Sand Plover	Summer visitor	LC	Common	WL & RA
	Charadriiformes (Laridae)					
27.	*Sterna hirundo*	Common Tern	Summer visitor	LC	Rare	AM & GL
	Accipitriformes (Accipitridae)					
28.	*Gypaetus barbatus*	Lammergeier	Resident	NT	Rare	RC & G
29.	*Gyps himalayensis*	Himalayan Griffon	Resident	NT	Rare	RC & G
30.	*Accipiter nisus*	Eurasian Sparrow Hawk	Summer visitor	LC	Common	RC & G
31	*Aquila chrysaetos*	Golden Eagle	Resident	LC	Rare	RC & G

	Species	Common name	Status	IUCN Red List status	Sighting status	Habitat status
	Falconiformes (Falconidae)					
32	*Falco tinnunculus*	Common Krestel	Summer visitor	LC	Rare	RC & G
	Pelecaniformes (Ardeidae)					
33	*Ardeola grayii*	India Pond Heron	Summer visitor	LC	Rare	WL & RA
	Passeriformes (Laniidae)					
34	*Lanius schach*	Long-tailed Shrike	Summer visitor	LC	Common	AM & GL
35	*Lanius tephronotus*	Grey-backed Shrike	Summer visitor	LC	Common	AM & GL
36	*Lanius minor*	Lesser Gray Shrike	Summer visitor	LC	Common	AM & GL
	Passeriformes (Muscipidae)					
37	*Monticola solitariius*	Blue Rock Thrush	Summer visitor	LC	Rare	AM & GL
38	*Myophonus caeruleus*	Blue Whistling Thrush	Summer visitor	LC	Occasional	AM & GL
39	*Calliope pectoralis*	Himalayan Ruby Throat	Summer visitor	LC	Rare	AM & GL
40	*Luscinia svecica*	Bluethroat	Summer visitor	LC	Rare	AM & GL
41	*Phoenicurus ochruros*	Black Redstart	Summer visitor	LC	Abundant	AM & GL
42	*Phoenicurus leucocephalus*	White-capped Redstart	Summer visitor	LC	Occasional	AM & GL
43	*Phoenicurus erythrogastrus*	White-winged Redstart	Resident	LC	Common	AM & GL
44	*Phoenicurus phoenicurus*	Common Redstart	Resident	LC	Common	AM & GL
	Passeriformes (Corvidae)					
45.	*Pica pica*	Eurasian Magpie	Resident	LC	Occasional	AM & GL
46.	*Pyrrhocorax pyrrhocorax*	Red-Billed Chough	Resident	LC	Abundant	AM & GL
47.	*Pyrrhocorax graculus*	Yellow-Billed Chough	Resident	LC	Abundant	AM & GL
48.	*Corvus splendens*	House Crow	Vagrant	LC	Rare	AM & GL
49.	*Corvus corone*	Carrion Crow	Resident	LC	Rare	AM & GL
50.	*Corvus corax*	Common Raven	Resident	LC	Rare	AM & GL
	Passeriformes (Sturnidae)					
51.	*Sturnia pagodarum*	Brahminy Starling	Summer visitor	LC	Rare	AM & GL
	Passeriformes (Paridae)					
52.	*Parus cinereous*	Cinereous Tit	Resident	LC	Rare	AM & GL
	Passeriformes (Hirundinidae)					
53.	*Hirundo rupestris*	Eurasian Crag Martin	Summer visitor	LC	Common	RC & G
54.	*Delichon urbicum*	Northern House Martin	Summer visitor	LC	Common	RC & G
	Passeriformes (Fringillidae)					
55.	*Serinus pusillus*	Fire-fronted Serin	Resident	LC	Common	AM & GL
56.	*Carduelis carduelis caniceps*	European Goldfinch	Summer visitor	LC	Abundant	AM & GL
57.	*Leucosticte nemoricola*	Plain Mountain Finch	Summer visitor	LC	Abundant	AM & GL
58.	*Leucosticte brandti*	Brandts's Mountain Finch	Resident	LC	Abundant	AM & GL
59.	*Carpodacus erythrinus*	Common Rosefinch	Summer visitor	LC	Abundant	AM & GL
60.	*Carpodacus rubicilla*	Great Rosefinch	Resident	LC	Abundant	AM & GL
61.	*Carpodacus puniceus*	Red-fronted Rosefinch	Resident	LC	Abundant	AM & GL
	Passeriformes (Turdidae)					
62.	*Turdus unicolor*	Tickell's Thrush	Resident	LC	Occasional	AM & GL
	Passeriformes (Alaudidae)					
63.	*Alauda gulgula*	Oriental Skylark	Summer visitor	LC	Common	AM & GL
64.	*Eremophila alpestris*	Horned Lark	Resident	LC	Abundant	AM & GL
65.	*Galerida cristata*	Crested Lark	Summer visitor	LC	Abundant	AM & GL

	Species	Common name	Status	IUCN Red List status	Sighting status	Habitat status
66.	*Melanocorypha maxima*	Tibetan Lark	Summer visitor	LC	Occasional	AM & GL
	Passeriformes (Passeridae)					
67.	*Passer domesticus*	House Sparrow	Summer Visitor	LC	Abundant	AM & GL
68.	*Montifringilla adamsi*	Tibetan Snowfinch	Resident	LC	Rare	AM & GL
	Passeriformes (Prunellidae)					
69.	*Prunella rubeculoides*	Robin Accentor	Resident	LC	Common	AM & GL
	Passeriformes (Emberizidae)					
70.	*Emberiza cia*	Rock Bunting	Summer visitor	LC	Abundant	AM & GL
	Passeriformes (Motacillidae)					
71.	*Motacilla alba*	White Wagtail	Summer visitor	LC	Abundant	AM & GL
72.	*Motacilla citreola*	Citrine Wagtail	Summer visitor	LC	Abundant	AM & GL
73.	*Motacilla flava*	Yellow Wagtail	Summer visitor	LC	Occasional	AM & GL
74.	*Motacilla cinerea*	Grey Wagtail	Summer visitor	LC	Rare	AM & GL
	Passeriformes (Sylviidae)					
75.	*Phylloscopus collybita*	Common Chiffchaff	Passage migrant	LC	Abundant	AM & GL
76.	*Phylloscopus sindianus*	Mountain Chiffchaff	Summer visitor	LC	Common	AM & GL
77.	*Phylloscopus neglectus*	Plain Leaf Warbler	Vagrant	LC	Rare	AM & GL
78.	*Phylloscopus affinis*	Tickell's Leaf Warbler	Summer visitor	LC	Occasional	AM & GL
79.	*Phylloscopus griseolus*	Sulphur-bellied Warbler	Summer visitor	LC	Common	AM & GL
80.	*Phylloscopus fuscatus*	Dusky Warbler	Vagrant	LC	Rare	AM & GL
81.	*Sylvia curruca*	Lesser Whitethroat	Summer visitor	LC	Occasional	AM & GL

WL—Wetlands | RA—Riverine areas | AM—Alpine meadows | GL—Grasslands | RC—Rocky cliffs | G—Gorges | LC—Least Concern | NT—Near Threatened.

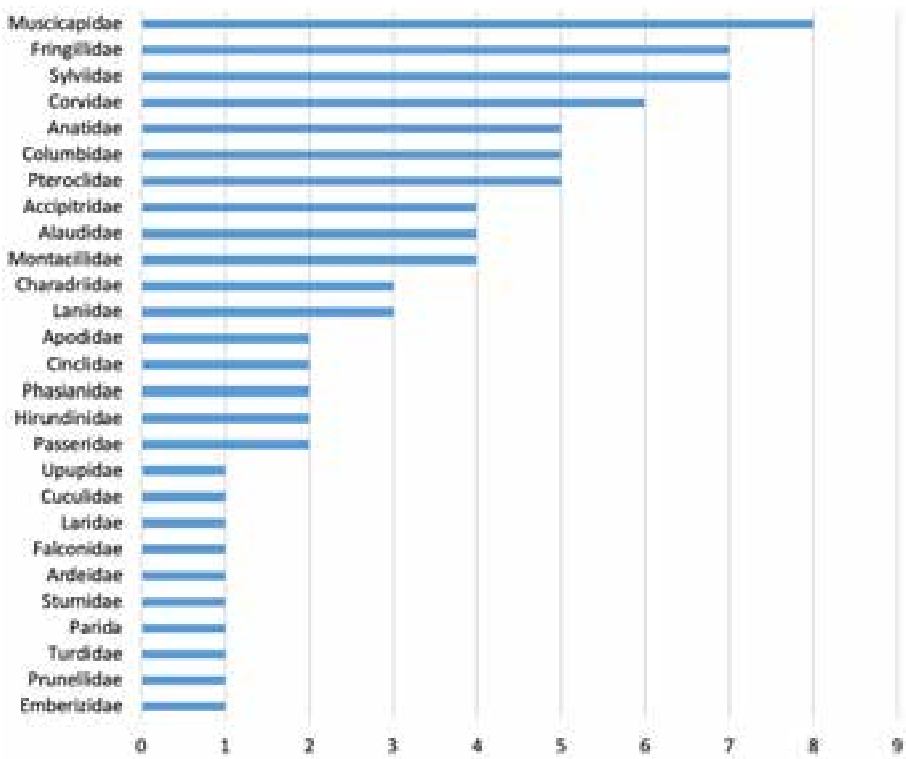

Figure 1. Species richness across different bird families.

riverine areas (19.8%) and least in the rocky cliffs and gorges (14.8%.). Ahmed et al. (2015) also reported the maximum number of bird species along the herbaceous meadows of Zanskar Region.

All bird species identified in the Zanskar Region are classified as 'Least Concern' according to the IUCN Red List, except for two species, the *Gypaetus barbatus* Lammergeier and the *Gyps himalayensis* Himalayan Griffon, which are categorized as 'Near Threatened'. Khan & Kumar (2022) also reported *Gypaetus barbatus* and *Gyps himalayensis* in addition to *Umenius arquata* and *Locustella* species in the Suru Valley of Ladakh Region.

The Zanskar Valley harbor is home to several bird species found in the Indian subcontinent. It also acts as an important stopover and important summer migration site for the summer visitor birds of the Valley. Besides, the occurrence of 'Near Threatened' species like *Gypaetus barbatusa* and *Gyps himalayensis* listed under IUCN Red list shows the importance of the valley regarding avifaunal diversity. A low diversity of avifauna in Zanskar Valley can be attributed to its fragile ecosystem with harsh climatic conditions, low vegetative cover, freezing temperatures, and scanty rainfall. In addition, overgrazing, urbanization, and habitat destruction pose significant threats to the valley's bird species diversity. The forest cover is mainly in the form of salix and poplar trees, which are often preferred habitats for birds, and is utilized on a larger scale for construction purposes, thereby reducing the bird diversity in the valley. The agricultural expansion by the native people is disrupting the local ecosystem. Moreover, the Zanskar Valley is a beautiful and unique tourist destination and the rising influx of tourists at an enormous scale poses a significant concern for the native birds and the wildlife populations of the Zanskar Valley.

It is the need of the hour to protect the avifauna diversity and the fragile environment of the Zanskar Valley. It is the joint responsibility of the administration as well as the local community to conserve the avifauna and its habitats in the Zanskar Valley from the impacts of unchecked development, uncontrolled grazing, and the rising tourism influx. The Ladakh region comprises three protected areas namely Hemis National Park, Karakoram Wildlife Sanctuary, and Changthang Wildlife Sanctuary. It also features two Ramsar sites. The Tsomoriri and Tso-Kar are situated in the Leh District. The Zanskar Valley is concerning in terms of lack of protected areas which poses a threat to the local wildlife population including the bird species. For the conservation of the avifaunal diversity of Zanskar Valley, it is crucial that the administration takes a significant part in establishing these protected areas. It is also the responsibility of every native person to actively contribute to the preservation of avifaunal diversity and its habitats in the Valley.

CONCLUSION

The present survey provides a checklist of the avifauna of the Zanskar Valley, listing 81 bird species belonging to 11 orders and 27 families. Passeriformes was the most dominant order with 50 species. The majority of the birds were summer visitors with 45 species. They migrate to the area as it offers a suitable environment for feeding and breeding needs. The Zanskar Valley is a paradise for avifaunal diversity, the increasing pressure on the delicate ecosystem poses a threat to bird diversity. The agricultural expansion, increasing tourism, and the various developmental projects are directly contributing to declining avifaunal diversity in Zanskar Valley. The information about the avifauna is scanty and further study is needed to explore the avian species of the Valley. Therefore, it is the need of the hour to monitor the region systematically in the rapidly changing environment with a focused study on the conservation of the avifauna of the region.

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Image 2. 1—Himalayan Rubythroat | 2—Chukar Partridge | 3—Bluethroat | 4—White-winged Redstart | 5—White-throated Dipper | 6—Eurasian Magpie | 7—Tickell's Thrush | 8—Common Greenshank | 9—Europian Goldfinch | 10—Common Tern | 11—Common Rosefinch | 12—Grey Wagtail | 13—Wood Sandpiper | 14—White Wagtail | 15—Black Redstart.

Image 2 cont. 16—House Sparrow | 17—Great Rose Finch | 18—Monglian Finch | 19— Common Redstart | 20—Black-winged Stilt | 21—Desert Wheateater | 22—Critine Wagtail | 23—Ruddy Shelduck | 24—Robin Accentor | 25—Crested Lark | 26—Ibis-bill | 27—Eurasian Wigeon | 28—Lesser Grey Shrike | 29—Common Cuckoo | 30—Yellow-billed Chough.

Image 2 cont. 31—Eurasian Crag Martin | 32—Common Hoopoe | 33—Common Raven | 34—Rock Bunting | 35—Fire-fronted Serin | 36—Sulpher-billed Warbler | 37—Red-billed Chough | 38—Northern Pintail | 39—Blue-whistling Thrush | 40—Little Stint | 41—Horned Lark | 42— Northern Wheateater | 43—Common Redshank | 44—Oriental Turtle Dove | 45—Lesser Sand Plover.

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COMMUNICATION

Breeding tern colonies on the sandbars of Adam's Bridge, India: new records and significance

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Abstract: We conducted surveys on the Indian side of Adam's Bridge sandbars that separate Rameswaram Island of India and Sri Lanka, in collaboration with the forest department. We report new breeding colonies of five tern species: Greater Crested, Saunder's, Roseate, Little, and Bridled Terns. Preliminary surveys (2023) followed by rigorous surveys (2024) confirm these sandbars as critical breeding habitats.

Keywords: Breeding colony, Bridled Tern, central Asian flyway, Greater Crested Tern, habitat selection, Little Tern, marine, population estimate, Roseate Tern, Saunder's Tern, seabirds.

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Author contributions: BH—conceptualization, writing, editing and supervision; MH—writing, editing, data management and maps; RN—data curation; SR—editing and overall supervision; MDA—data curation

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INTRODUCTION

Seabirds are key indicators of marine ecosystem changes (Schreiber & Burger 2001; Gaston 2004) due to their long lifespans (Parsons et al. 2008) and dependence on terrestrial breeding habitats and marine food sources (Ballance 2007). Central to marine ecological research (Frederiksen et al. 2006; Zador et al. 2013), seabirds reflect anthropogenic and environmental impacts, including climate change (Barbraud et al. 2008), fisheries impact (Einoder 2009; Le Corre et al. 2012), and prey stock availability (Piatt et al. 2007; Lyday et al. 2015) supporting marine conservation efforts (Bibby et al. 2012).

Terns (family Sternidae) are a globally distributed seabird group comprising over 40 species (Gochfeld & Burger 1996); 19 are recorded within Indian borders (Praveen et al. 2016). Nine species breed along Indian coasts and sandbars (Mondreti et al. 2013) underscoring the ecological significance. Historical reports on seabird breeding including Roseate Tern *Sterna dougallii* (Abdulali 1942), Black-naped Tern *Sterna sumatrana* (Blyth 1846; Abdulali 1942, 1967), Bridled Tern *Onychoprion anaethetus*, Sooty Tern *Onychoprion fuscata*, Lesser Crested Tern *Thalasseus bengalensis* and Gull-billed Tern *Gelochelidon nilotica* (Abdulali 1942), primarily reported from the Andaman and Nicobar Islands, with Sooty Tern (Kurup & Zacharias 1994; Mathew et al. 1991) from Lakshadweep Island. Breeding of Little Terns (Balachandran et al. 2005; Li et al. 2009), Gull-billed Terns (Abdulali 1942; Balachandran et al. 2005; Li et al. 2009), and Whiskered Terns (Li et al. 2009) were recorded from Chilika Lake; Gull-billed Terns in Kolleru and Godavari (Li et al. 2009) and Sundarbans (Stanford 1937); Greater Crested Terns in Sundarbans (Li et al. 2009); and Whiskered Terns in Karavetti, Vettakudi and Thenpakkam (Li et al. 2009). In Sri Lanka, Saunders's, Little, Greater Crested and Bridled Terns breed in the Adam's Bridge (Panagoda et al. 2020).

On Rameswaram Island, earlier breeding records of Roseate Tern, Bridled Tern, Lesser Crested Tern, Little Tern (Abdulali 1942), and Greater Crested Tern (Stanford 1937) lacked detailed evidence. This study provides the first comprehensive documentation of breeding colonies of Bridled Tern, Saunder's Tern, Little Tern, Greater Crested Tern and Roseate Tern in the sandbars of Adam's Bridge, Gulf of Mannar (GoM), India.

METHODS

Study Area and Surveys

Raam Sethu, also known in some literature as Adam's Bridge, is a chain of sandbars connecting Rameswaram Island, Tamil Nadu, India, to Sri Lanka, and lies within the Gulf of Mannar Marine Biosphere Reserve. Approximately 8 km south-east of Arichalmunai, near the Sri Lankan maritime boundary, these sandbars (designated I to VII) remain largely isolated due to restricted access. The reserve supports regional endemic breeding species like Hanuman Plover *Charadrius seebohmi* (Byju et al. 2023; Niroshan et al. 2023), rare migratory species Arctic Skua *Stercorarius parasiticus* and Pomarine Skua *Stercorarius pomarinus* (Byju & Raveendran 2022a; Byju et al. 2024) and unusual vagrants like Light-mantled Albatross *Phoebetria palpebrata* (Byju & Raveendran 2022b). Sandbar VII is approximately 2.5 km in length and 1.5 km in width and consists of habitats like sand dunes, and shallow seawater pools. Sand bar III was smaller at 600 m long and 250 m wide (Image 1).

As part of a long-term coastal bird monitoring program, surveys were conducted using boats on all the sandbars except sandbar VII where surveys were conducted on foot due to extensive breeding activity. Surveys on Sandbar VII (9.116 N 79.510 E), from June to August 2024, focused on breeding Greater Crested Terns and other tern species. In total, five teams were formed that consisted of forest personnel and researchers and surveys were conducted simultaneously covering different sections from 0900 h to 1500 h. Breeding populations were estimated using total counts of active nests and direct observations of adult birds within colonies using Nikon binoculars (10 x 50) and Vanguard spotting scopes (14 x 70). The point counts were done in a radius of 100 m each, with each point observed for 15 minutes at randomly selected times as the breeding season coincided with tidal currents not engulfing the sandbar nesting areas on elevated dunes. Aerial (count of the number of birds rising into the air upon our approach) and territory counts (count of the number of nests/adults within colonies) were corroborated with photographs and video recordings to countercheck the estimation process (Surman & Nicholson 2009). The breeding adults did not leave the nests, other than for short periods while disturbed briefly for aerial and territory counts.

Data from Sandbar VII included active nest counts, qualitative description of the microhabitat, and observation of eggs and chicks. Disturbances, such as human activity or predation threats were noted. This

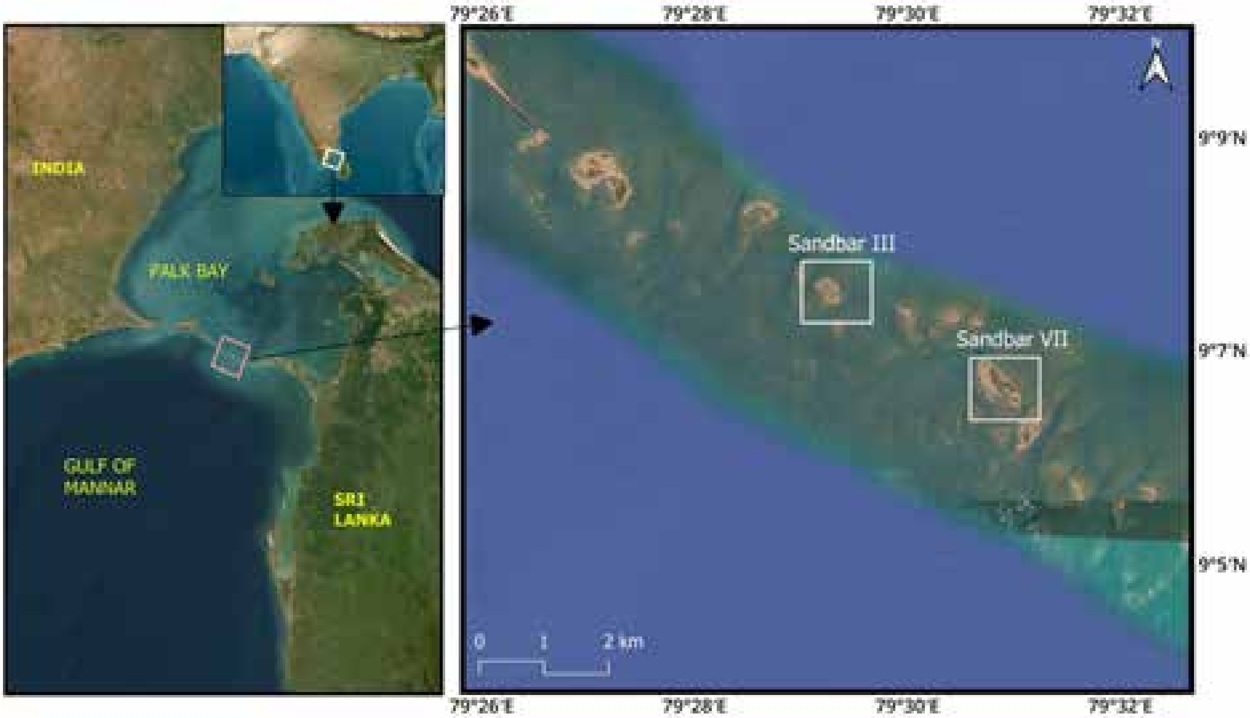

Image 1. Adam's Bridge showing sandbars III and VII as breeding sites.

methodology minimized disturbance while ensuring data collection, providing critical insights into tern breeding ecology in the GoM.

RESULTS AND DISCUSSION

Breeding was confined to sandbars III and VII (Image 1), with Sandbar VII hosting the largest colony of breeding terns. Possibly, the size, water currents and other human disturbances might be the possible reasons of terns avoiding other sandbars for breeding. A total of 16 species of waterbirds was recorded during our surveys (Appendix 1).

Observations from sandbar III and VII

Sandbar III

A colony of 250–300 nests of Greater Crested Tern were found. Little Terns, Brown Noddy (Image 11), and Lesser Noddy (image 12) were observed, even though no other nesting terns could be recorded.

Sandbar VII

Sandbar VII is characterized by sparse vegetation, including grasses (<0.15 m tall), *Sesuvium* and *Ipomea pes-caprae* that cover the sandy beaches where terns nest. Estimated adult tern populations included 12,000 Greater Crested Terns, 600 Bridled Terns, 400 Roseate Terns, 220 Saunder's Terns, and 80 Little Terns, supported by nest counts and photo and videographic evidence (Image 2A).

Greater Crested Tern: An estimated 2,500–3,200 nests were recorded in five different colonies (two major and three minor). Major colonies were approximately 500 m apart, while the minor colonies were separated approximately 200 m from the major colonies (Image 2B). Greater Crested Terns nested densely on elevated barren sand dunes with minimal vegetation (Image 3A) away from other species except for occasional Bridled Terns. Nests were simple depressions, rarely larger (~200 × 170 mm). Most contained one egg (Image 3B), occasionally two. By late July, hundreds of chicks were observed within the colony (Image 3C).

Bridled Tern: Approximately 200–210 nests were found within vegetation as reported earlier (Cramp et al. 1985; Hulsman & Langham 1985; Villard & Bretagnolle 2010), particularly under *Ipomea pes-caprae* and grasses (Image 4A). The vegetation provided shade and protection from predators and other unfavourable physical variables like wind, improving nesting success (Al-Fazari & Victor 2014). The species' nesting habits and habitats align with findings elsewhere (Higgins &

Image 2. A—Sandbar VII | B—Minor colony of Greater Crested Terns.

Image 3. Greater Crested Tern: A—Birds on elevated sand dunes and eggs in nest depressions | B—Egg | C—Chicks.

Davies 1996; Chatto 2001). Nests, typically concealed in the vegetation, contained a single egg (Image 4B), consistent with studies in Australia (Nicholson 2002) and New Caledonia (Villard & Bretagnolle 2010). Chicks were observed in late July (Image 4C).

Roseate Tern: Approximately 150–180 nests were found on the less elevated sand dunes (compared to the Greater Crested Terns) among *Sesuvium* plants with higher nest densities (Image 5A) than Bridled Terns. Nest sites ranged from scrapes with sparse vegetation to exposed concave depressions. Clutches contained 1–4 eggs (Image 5B), consistent with previous studies (Gochfeld et al. 1998). Hatching occurred in early July and the feeding of chicks was observed in late July (Image 5C).

Saunder's Tern: Approximately, 95–105 nests (Image 6A) were found among the *Sesuvium* plants consisting of unlined depressions on sandy ridges shaped by wind. Eggs were sandy in colour with brown blotches and lines (Image 6B). Roseate and Little Terns often nested near each other, with simple scrapes on sandy dunes surrounded by sparse vegetation or marine debris. Egg counts per nest varied between 1–2 and chicks were observed as early July (Image 6C). Nesting habitats, clutch sizes, and egg patterns align with previous studies (Panagoda et al. 2020).

Little Tern: Approximately, 30–35 nests were recorded (Image 7A), consisting of bare ground scrapes in sand. Clutch sizes ranged 2–3 eggs (Cheah & Ng 2008), with eggs showing olive-green or grey backgrounds and brown spotting (Image 7B) (Wait 1931; Baker 1935; Henry 1998). Chicks were observed in July (Image 7C).

Divergent nest-site selection and ecological requirements among closely related waterbird species breeding in mixed colonies likely serve as adaptive strategies to avoid interspecific competition (Burger & Gochfeld 1988; Chen et al. 2011) as the elevated sand dunes were used by Greater Crested Terns, and

Image 4. Bridled Tern: A—Nesting | B—Egg | C—Adult with the chick.

Image 5. Roseate Tern: A—Incubating adults in higher density | B—Egg and nest | C—Adult with chick.

Bridled Tern nested on the edges with vegetation. On our observations, the major colonies were separated at a farther distance than the minor colonies. For colonial breeders, inter-nest distance may reflect nest-site selection or an anti-predation strategy with larger terns breeding in denser colonies than smaller species as in the case of Greater Crested Terns and other breeding terns (Burger & Gochfeld 1988; Gochfeld & Burger 1996). Intensive nest surveys during peak breeding season revealed the presence of eggs and chicks, although hatching success and the count of chicks could not be determined due to logistical limitations. Sandbars III and VII support an estimated 4,000 breeding tern pairs likely representing the largest mixed breeding colonies in the southern peninsula of India. Their isolation from limited human disturbance makes them critical nesting habitats. However, climate change threatens food resources and population dynamics. For example, a local fisherman informed of the loss of vegetative cover (were in abundance in the past) largely after a major storm that hit a decade ago highlighting the need for long-term monitoring to assess these and several other impacts (Colwell 2010; Hu et al. 2010; Rashiba et al. 2022).

Image 6. Saunder's Tern: A—Adult | B—Egg and nest | C—Egg and nest and chick.

Image 7. Little Tern: A—Adults | B—Egg and nest | C—Chick.

Potential Threats and Conservation measures

We observed several dead bird carcasses from the colonies but could not confirm the reason of death (Images 8 A–C). While human interference is minimal, with rare boat visits to the sandbars by local fishermen, poaching of eggs and sometimes birds were recorded during the surveys. Fishermen or poachers from the Sri Lankan side transgress the Indian sandbar VII to collect eggs and birds using speed boats (Images 9 A&B). Local fishermen of Rameswaram Island also reported consuming tern eggs. Pollution is another threat with sand dunes in the area covered in fishing gear (including nests), plastic bottles, clothes, and household waste (Images 10 A&B). Labels on some of these waste

Image 8. Dead Terns: A—Greater Crested Tern | B—Chick of Roseate Tern | C—Chick of Greater Crested Tern.

Image 9. A—Greater Crested Tern eggs damaged by poachers | B—Poaching from across the border.

Image 10. A & B—Marine debris.

Image 11. Brown Noddy.

Image 12. Lesser Noddy.

materials indicate origins mostly from other parts of southern India, and Sri Lanka. Though hovercraft marks were visible on some sandbars, coast guard hovercraft did not directly threaten tern colonies, as interactions indicated awareness of the breeding areas.

The nesting habitats on Sandbar III and VII, hosting the southern peninsular India's largest colonies of Greater Crested Terns and other tern species, face significant threats from poaching and disturbance. Poachers from across the border and Indian fishermen consume tern eggs. Mitigation efforts should focus on raising awareness and fostering collaboration between the wildlife department and security agencies. Steps have been initiated with security agencies highlighting them with need of not overrunning the nesting populations during breeding time. Conservation measures must also consider the region's sensitivity as an international border, where disputes between the Sri Lankan Navy and Indian fishermen, underscore its importance for biodiversity.

The ecological importance of terns, as well as their sensitivity to environmental perturbations, highlights the need for comprehensive future studies to verify and monitor these breeding populations, particularly given their role as indicators of marine health. Such coastal biodiversity is crucial in maintaining and preserving the ecological integrity and balance within these regions.

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Appendix I. Complete list of seabirds and shorebirds observed around the nesting habitat on the sand bars in the Adam's Bridge.

Common name	Scientific name	IUCN Red List status
Greater Crested Tern	*Thalasseus bergii*	LC
Little Tern	*Sternula albifrons*	LC
Roseate Tern	*Sterna dougallii*	LC
Bridled Tern	*Onychoprion anaethetus*	LC
Lesser Crested Tern	*Thalasseus bengalensis*	LC
Saunder's Tern	*Sternula saundersi*	LC
Sooty Tern	*Onychoprion fuscatus*	LC
Caspian Tern	*Hydroprogne caspia*	LC
Lesser Noddy	*Anous tenuirostris*	LC
Brown Noddy	*Anous stolidus*	LC
Arctic Skua	*Stercorarius parasiticus*	LC
Brown Skua	*Stercorarius antarcticus*	LC
Slender-billed Gull	*Chroicocephalus genei*	LC
Heuglin's Gull	*Larus fuscus heuglini*	LC
Ruddy Turnstone	*Arenaria interpres*	NT
Greater Sand Plover	*Charadrius leschenaulti*	LC
Intermediate Egret	*Ardea intermedia*	LC
Grey Heron	*Ardea cinerea*	LC

LC—Least Concern | NT—Near Threatened.

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COMMUNICATION

Assessment of nest and nesting activities of White-bellied Heron *Ardea insignis* Hume, 1878 (Aves: Ardeidae) in the broad-leaved forests of northeastern India

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Abstract: The discovery of White-bellied Heron *Ardea insignis* nesting in India in 2014 was a significant record since it was the second nesting report in India after one reported in Bhutan 'dooars (= Terai)' below Darjeeling. White-bellied Herons are known to build their nests in the riverine forests between 300 m and 1,500 m. The majority of the nesting records are from Chir Pine *Pinus roxburghii* forests of Bhutan. This article highlights heron's nest site selection and nesting activities in the broadleaved forests in Arunachal Pradesh, India. During the study period (2013–2017) in Namdapha Tiger Reserve, two active nests of this species were recorded one in 2014 and another in 2015. Though both the nests failed without producing any offspring, the findings, shed crucial information, especially on how the herons select their nesting sites and nest trees and the risks involved in the process. These findings will help implement conservation actions especially while safeguarding the known nesting sites in India.

Keywords: Arunachal Pradesh, behavioural ecology, Critically Endangered, eastern Indian Almond, Hollock, Namdapha, nest material trips, nesting tree.

Bengali: ভারতবর্ষে, ২০১৪ সালে, সাদা-পেটের বক তথা *Ardea insignis*-এর বাসা বাঁধার ঘটনাটি ছিল একটি উল্লেখযোগ্য আবিষ্কার, কারণ এই ঘটনাটি, দার্জিলিংয়ের নীচে ভুটানের 'ডুয়ার্স (তরাই)'-এর পরে, ভারতে দ্বিতীয় বাসা বাঁধার ঘটনা হিসাবে বিবৃত হয়েছিল। সমুদ্রপৃষ্ঠ থেকে ৩০০-১,৫০০ মিটার উপরে নদী-তীরবর্তী বনে, সাদা-পেটের বক, বাসা তৈরি করে বলে জানা যায়। ভুটানের চির-পাইন বা *Pinus roxburghii* বন থেকে এই পাখিটির বেশিরভাগ বাসা বাঁধার বিবরণ পাওয়া গেছে। এই নিবন্ধটি ভারতবর্ষের অন্তর্গত অরুণাচল প্রদেশের বিস্তৃত-পাতাযুক্ত বনে (broad-leaved forest), এই বকদের বাসা নির্বাচন এবং তাদের বাসা বাঁধার ঘটনাবলী উল্লেখ করে। নামদাফা ব্যাঘ্র প্রকল্পে (Namdapha Tiger Reserve) গবেষণার সময়ে (২০১৩-২০১৭), এই প্রজাতির পাখিটির, দুটি সক্রিয় বাসা পাওয়া গিয়েছিল, একটি ২০১৪ সালে এবং আরেকটি ২০১৫ সালে। যদিও উভয় বাসাই খুব সম্ভবত কোনও সন্তান উৎপাদন না করে ব্যর্থ হয়েছিল, তবুও তৎকালীন অনুসন্ধানগুলি, গুরুত্বপূর্ণ তথ্য প্রকাশ করে, বিশেষ করে এই প্রজাতির বক কীভাবে তাদের বাসা বাঁধার স্থান এবং বাসা বাঁধার গাছ নির্বাচন করে এবং প্রক্রিয়াটির সাথে কি ধরনের ঝুঁকি সম্পর্কিত। এই আবিষ্কারগুলি, এই বিরল প্রজাতির বকের সংরক্ষণকে কার্যকর করতে, বিশেষত ভারতবর্ষে, তাদের পরিচিত বাসা বাঁধার স্থানগুলিকে সুরক্ষিত করার ক্ষেত্রে, উল্লেখযোগ্য ভূমিকা পালন করবে।

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INTRODUCTION

The White-bellied Heron (WBH hereafter) is the only heron classified as 'Critically Endangered' by the IUCN Red List of Threatened Species (Maheswaran et al. 2021a; BirdLife International 2024). It is a resident in Bhutan, northeastern India and Myanmar with merely about 60 reported individuals (Price & Goodman 2015 Maheswaran et al. 2021b). In India, it is mainly reported from Namdapha Tiger Reserve (Mondal & Maheswaran 2022), Kamlang National Park and reserve forests in Walong area of Anjaw District, Arunachal Pradesh (Reddy et al. 2021).

In Bhutan, the first nest of WBH was reported in 2003 (Acharja 2019; Khandu et al. 2020); with 27 active nests identified by 2017 (Khandu et al. 2020). In India, Hume & Oates (1890) reported the first nest of *Ardea insignis* as a platform of sticks placed on the top of a large tree in an inaccessible swampland southern of Darjeeling, in the Bhutan dooars (= terai). No photographic evidence was available as it only mentioned that a large stick nest was placed high upon a large tree in a swampy and inaccessible area. The breeding period mentioned was during July–August. the present study documents two nests of WBH from the Namdapha Tiger Reserve. This article will be the first of its kind that will assess the nesting of this rare heron species in India and aid in further research and future conservation action and management plans.

MATERIALS AND METHODS

During the study period (2013–2017), in Namdapha Tiger Reserve (27.392–27.661 °N & 96.251–96.976 °E) (NTR hereafter) (Image 1), all the activities of WBHs were monitored and recorded along with their nest building activities. The studies focused on understanding how nest site/s were selected and followed by the nest building activities.

Behavioural observation

Studies on nest-building activities of WBH were conducted over two years (06–18 March 2014 and from 24 February 2015 to 10 May 2015). Nesting activities were observed for a total of 39 days—eight days in 2014 and 31 days in 2015. The longest continuous stretch of observation was from 24 February to 4 April 2015. During this period, observations were made for 25 days with intervals of 1–2 days in between. The continuous scan sampling method (Martin & Bateson 2007) was used to record various nest-building activities of WBH from 0530 h to 1730 h. Various behavioural activities of WBH were observed during this period: courtship (making calls for its mate and greet their mates when they come back to the nest), nest-material trips (when one of the pair flew to bring nest material to the nest), foraging (catching fish at the river). Observations were made from a distance of 300 m with a pair of 8 x 40 binoculars (Nikon) and a spotting scope (Nikon) and photographed with Nikon D70S SLR camera and Sigma 500 mm telephoto lens. Hideouts constructed at a distance of 100 to 150 m from the nest tree to observe behavioural activities without disturbing the nesting. Locating the active nest of WBH is merely a chance and can be found by following the adult bird from their foraging sites to the roosting area, especially during breeding season. As soon as WBH was spotted at its nest, or seen building the nest, the observation on the individual/pair started and continued till the heron(s) disappeared from the sight or flew away towards the Noa-Dehing River for foraging or nest material collection. As WBHs do not have any distinctive sexual dimorphism, identifying individual birds remained difficult.

Evaluation of the nesting sites and nests

The tree species used for nesting by WBH was identified using Chowdhery et al. (1996). The height of the nesting tree and the height at which the herons built their nests were measured using conventional methods of measuring a smaller tree nearby, using rope and then extrapolating that with the nest tree to arrive at the actual height. The diameter of the fallen nest was measured with the help of a measuring tape. Coordinates and elevations of the respective locations were recorded using Garmin GPS. Using Google Earth, the aerial distance were measured between the nesting tree and the regular foraging sites and human tracks and villages.

Data analysis

Nesting: Time spent by WBH in nesting was calculated for each day. The entire observation period of a day was divided into three categories:

(i) Morning: 0530–0930 h.
(ii) Mid-day: 0930–1330 h.
(iii) Evening: 1330–1730 h.

The percentage time spent by the pair in nest-building activities was calculated for different times of the day.

$$\frac{\text{Hours spent on nesting on a specific category of time of the day X 100}}{\text{Total hours spent on nesting}}$$

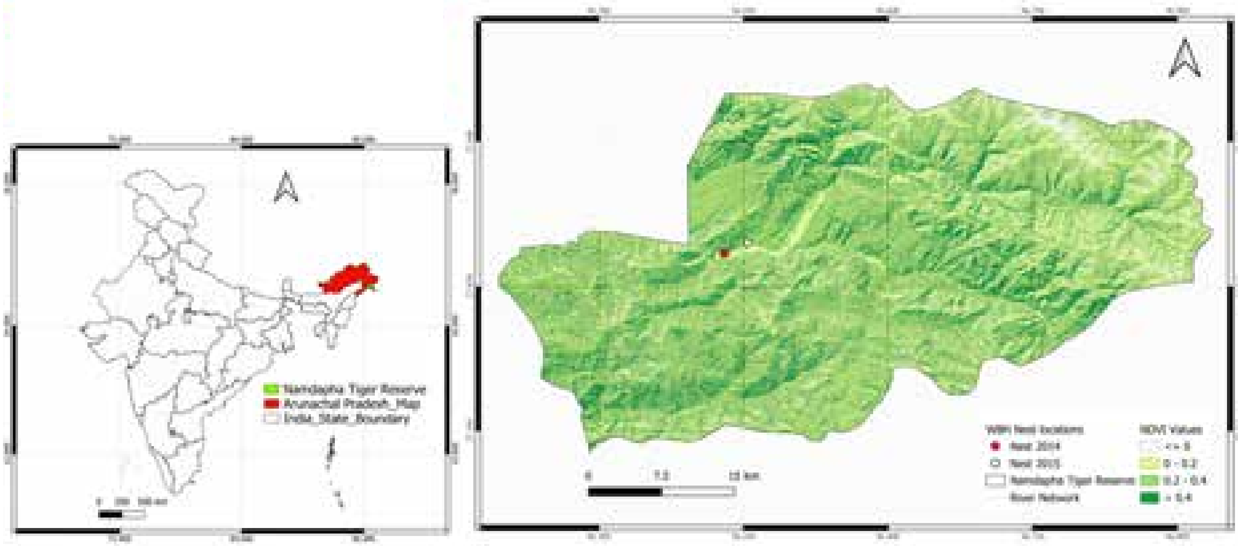

Image 1. Map of Namdapha Tiger Reserve indicating nests of White-bellied Heron.

Mean±SD of each of these categories were calculated to understand during which time of the day the species preferred to construct their nest.

Nest material trips

'Nest material trips' are the trips (flights) made by the adult nesting birds from their nesting tree to the nearby trees or land and return to their nest with sticks in their bills (Maheswaran & Rahmani 2005). These sticks or 'nest materials' are collected by the WBH, waiting in the nest. Whenever the herons returned to the nest with nest materials in their bills the time taken to make such trips was also recorded. At a time, WBHs were seen collecting only one piece of nest material. Percentage (%) of nest material trips and percentage (%) and Mean±SD value of time spent on such trips were calculated for each category during different times of the day and also for the years 2014 and 2015, separately.

RESULTS

Nesting sites: Two nests of WBH, one each in 2014 and 2015, were located in different tree species (Table 1) that were 2.69 km apart. Each year, one pair of WBH was spotted building the nest. It could not be confirmed whether the same pair of WBH constructed both nests. Certain features were common for both nesting sites.

Forest type: The forest type of this area is categorized as the northern tropical evergreen forest or Assam Valley tropical wet evergreen forest. Champion & Seth (1968) mentioned three types of forests in NTR: (a)—northern tropical evergreen forest or Assam Valley tropical wet evergreen forest (dominated by *Dipterocarpus*) | (b)—northern Indian tropical moist deciduous forest (dominated by *Terminalia*) | and (c)—miscellaneous forest (no single species dominance). In both years, WBHs were seen building their nests only in the nearby riverine or fringes of the forests but not much in the interiors.

Forest edge: The trees chosen to build the nest were at the forest edge, between the open riverbed and the interior dense forest. Distance of the nesting tree from their regular foraging site was 663 m and 201 m in 2014 and 2015, respectively.

North-sided forest: WBHs were seen almost regularly foraging in the Noa-Dehing River that flows in an east-west direction at the 27-mi area of NTR. Both nests were recorded at the north-sided forest of this area. Also, the north-sided forest is less anthropogenically disturbed than the south-sided forest.

Nest Azimuth: In both years WBHs were seen building their nest facing east that ensured better reception of sunlight throughout the nesting period.

Human trails: The nearest human track was on the other side of the Noa-Dehing River (near south sided forest), more than 800 m away from the nest. The nearest human settlement was far more interior in the forest (at least 1.5 km away from the nesting site) (Table 1).

Nesting tree height: WBH selected 22–33 m trees to build their nests although there were many tall trees in the vicinity.

Position of the nest in the tree: WBH did not construct nests at the top of the nesting tree but the nests were built at the middle, more specifically on the outer branches (Images 2, 3, & 4).

Nesting activities

In 2014 and 2015, in NTR, the courtship of WBH was observed starting from January onwards. In 2014, WBH already started building their nest by the time we noticed them on their nest for the first time (Image 2). On 24 February 2015, it was assumed that the WBH pair was seen to assess the trees to select the nesting tree as they were flying from one tree to the next and eventually settled for one, where they removed a few branches and leaves with their bill to create some vacant space to build their nest. From 26 February 2015 onwards, the pair started nest material trips that lasted up to 21 March 2015. The number of nest material trips gradually decreased towards the later phase of the nest-building period. During this time, WBHs were also seen spending a considerable amount of time on the nest without any nest material trips (Image 3). From 25 March 2015 onwards, at least one of the adult herons was seen in the nest throughout the observation period, indicating that the female had laid the egg(s). No drastic step like moving very close to the nest in the presence of the birds or climbing up the nesting tree were undertaken to observe the activities of adults and to look for eggs and chicks at any point in time ensuring zero disturbance in their habitation and activities.

Nesting activities of WBH were observed for a total of 93.74 h (17.67 h in 2014 and 76.07 h in 2015) in 34 days (8 days in 2014 and 31 days in 2015). During this period, WBHs were recorded completing 175 nest material trips (total duration – 17.8 h).

During the nesting period (mainly at the beginning), WBHs were spotted less frequently at their foraging site/s during morning hours as they were engaged in nest-building activities (Table 2 & 3). The majority (90.85%) of the nest material trips were also conducted in the morning (Table 3). These trips generally started from 0630 hr and were at their peak at 0700–0800 h. Each trip was 0.02 to 0.3 h long. The mean length of each nest material trip was 0.10±0.06 (Mean±SD) hr. On four occasions, the herons were seen returning to the nest without any nesting material (n = 1 in 2014 and n = 3 in 2015). Generally, the pair were seen to cease their nest-building activities around 0830 h and both of them flew (generally one after another) to their foraging site/s.

Fate of the identified Nests

2014: The breeding success of the 2014 nesting pair was not known because that study could not be continued from mid-March 2014 onwards due to excessive rainfall and heavy floods in the study area. The nest that WBH built in 2014, could be seen on the same tree but found abandoned in 2015 (Image 4).

Table 1. Details of the nesting trees of White-bellied Herons identified in Namdapha Tiger Reserve.

Particulars	First nesting tree (2014)	Second nesting tree (2015)
Common name	East Indian Almond *Terminalia myriocarpa* (Van Heurck & Müll. Arg.)	Hollong *Dipterocarpus macrocarpus* (Vesque)
Local name	Hollock	Hollong
Altitude	426 m	410 m
Height of the nesting tree	22–27 m	28–33 m
Height of the nest from the ground	18 m	25 m
Distance from nearest regular foraging site	663 m	201 m
Distance from human settlement or road	1.55 km (nearest village) 0.86 km (from the nearest regular dirt track used by villagers)	1.90 km (nearest village) 1.36 km (from the nearest regular dirt track used by villagers)

Table 2. Time spent by White-bellied Heron while nesting during different times of the day in Namdapha Tiger Reserve.

Observation	Times of the day (h)		
	Morning	Mid-day	Evening
2014	16.37	0.72	0.58
2015	45.08	16.40	14.58
Total	61.45	17.12	15.17
Percentage (%) Mean±SD	77.96±36.71	14.07±29.86	9.51±23.52

Table 3. Nest material trips by White-bellied Heron during different times of the day in Namdapha Tiger Reserve.

Times of the day	Number of nest material trips		Duration of nest material trips		
	n	%	hr		%
			Total	Mean±SD	
2014	54	30.86	6.48	0.12±0.06	36.42
2015	121	69.14	11.32	0.09±0.06	63.58
Morning	159	90.85	16.87	0.11±0.06	94.75
Mid-day	13	7.43	0.77	0.06±0.03	4.31
Evening	3	1.72	0.17	0.06±0.04	0.94
Total	**175**	**100**	**1068**	**6.10±3.68**	**100**

Image 2. Nest-building activities of White-bellied Herons *Ardea insignis* at 27 mi in 2014 (Mondal & Maheswaran 2014).

Image 3. Active nest of White-bellied Heron at 27 mi in 2015.

Image 4. Abandoned first nest (nest built in 2014) of White-bellied Heron at 27 mi in 2015.

Image 5. A part of the broken eggshell near the fallen nest of White-bellied Heron at 27 mi in 2015.

Image 6. Fallen nest of White-bellied Heron at 27 mi in 2015.

2015: On 13 May 2015, it was found that the WBH nest amidst the boulders (almost dried stream) (Image 6). The maximum diameter of that nest was 141.8 cm. The fallen nest consists of only dry branches or twigs of 50–110 cm in length (average length 83.46±15.60 cm; n = 24). One large portion of the broken eggshell (3.6 cm length) was also found at the same site (Image 5), 28.2 m away from the fallen nest. It was presumed that it was of WBH as we could not see any other nest nearby. The outer colour of the recovered eggshell was light blue with a white inner surface. No traces of yolk were present in the egg shells. As permission to collect samples were not granted, the egg shells and the twigs were left in place after being photographed. The reason why the nest had fallen remains unclear.

During the remaining study period (till January 2017) in the study area, we neither came across any other nests nor any juveniles of WBH in NTR.

DISCUSSION

Larger herons are generally known as colonial breeders (Kushlan & Hancock 2005; Stier et al. 2017; Byju et al. 2024) but WBH is a solitary breeder. In Bhutan, WBH were mainly known to nest in the Chir Pine *Pinus roxburghii* trees (Acharja 2019; RSPN 2024). The study discovered that WBHs also prefer broadleaved forests. In 2018, a similar record also from Bhutan (Nesting trees *Michelia champaca* and *Pterospermum acerifolium*; Khandu et al. 2020). In 2021, two WBHs with their active nest were spotted in Walong (1,123 m), Anjaw District, Arunachal Pradesh (Reddy et al. 2021), a habitat dominated by Chir Pine forests.

Nesting site selection is extremely essential for the continual survival and reproduction of the nesting bird species (Dyrcz et al. 1981; Nguyen et al. 2003). Forest fires at the Chir Pine forest nesting sites are quite frequent in Bhutan and Walong. Whereas, the nesting sites in the broad-leaved forest are less likely to suffer from forest fire (Khandu et al. 2020).

In NTR, WBHs selected 22–33 m trees to build their nests at the height of 18–25 m (Table 1), similar to the height of the nests (18.3±7.4 m) in the trees in Bhutan (Acharja 2019).

For the majority of the cases in Bhutan, WBH nests were at the top of the nesting tree (Acharja 2019). In NTR, WBH constructs their nests in the middle, more specifically on the outer branches. Such a position ensures easy entry and exit for a large bird-like WBH (wingspans approximately 2 m in flight), better visibility of their feeding sites and potential threats or disturbances nearby (Mondal & Maheswaran 2014).

The nearest human track and human settlement were on the other side of the Noa-Dehing River (near south-sided forest) (Table 1). Hence these nesting sites receive less anthropogenic disturbances. This is very important for a shy species like WBH (RSPN 2012; Acharja 2019) whose minimum tolerance distance to human presence was roughly estimated to be 150 m in Bhutan (Acharja 2019). In NTR, the herons are more shy and the tolerance distance to any human presence was around 200–300 m. WBH have been found to remain in their nests until any disturbance or threat from closer distance particularly during their initial phase of nesting.

From the information available on the WBH nesting sites in NTR, Bhutan (Acharja 2019) and Walong (Reddy et al. 2021), the following possible inferences can be drawn.

i) They nest at the riverine forest edges that are also close to their feeding grounds. Furthermore, the vast open river gave herons a clear view of any approaching threat.

ii) They prefer to nest in the north-sided forest maybe because it is less disturbed and they can build east-facing nests that can potentially aid in the incubation process by providing heat from direct exposure to the sun.

iii) They tend to abandon their older nests though this aspect needs to be studied further.

Both in India and Bhutan, nesting of WBH usually begins from late February to early March onwards. Herons generally build their nest during morning hours (Kushlan & Hancock 2005). The weather during morning hours seems less stressful to birds and morning fog in this area can soften the tree branches and make it easier for the WBH to break. Most likely it took almost a month for the pair to prepare their nest for laying eggs. After laying the eggs, they spent more time hatching or protecting the eggs/ chicks from danger.

The diameter of the fallen nest is similar to the nest diameter (1.5 m) of the large heron species, as suggested by Kushlan & Hancock (2005). In Bhutan, the diameter of the WBH nests was measured at around 87–120 cm (Acharja 2019). The larger diameter of the nest in NTR, can be attributed to the loosening of twigs when the nest fell from 25 m height.

Like Great Blue Heron, the broken egg shells found beneath the nesting tree might indicate the possible result of hatching (Cottrille & Cottrille 1958). No live or dead chicks were found near the spot in NTR. Acharja (2019) postulated that WBH nesting in the broad-leaved forest can result in breeding failure particularly because of predation. In Punatsangchhu, Bhutan, numerous droppings of small frugivorous mammals and monkeys were found near the unsuccessful nesting sites (Acharja 2019). No such droppings were found at the fallen nest site in NTR.

Though the observations on these two nests were anecdotal, their discovery in the riverine habitat of the broad-leaved forest indicates the importance of conserving this habitat not only to ensure future conservation of the breeding pairs within NTR but also ensure long-term survival of the species in NTR (Mondal & Maheswaran 2022), particularly when this area is infamous for illegal logging, hunting (Datta et al. 2008) and fishing (Maheswaran 2007).

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COMMUNICATION

Preliminary checklist of avifauna from All India Institute of Medical Sciences, Guwahati, Assam, India

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Abstract: Bird diversity in various types of habitats, including institutional campuses, underlines the importance of these green areas for preserving ecological integrity and providing necessary havens for avian species. The present study presents the first preliminary checklist of avifaunal species within the AIIMS Guwahati campus. A total of 75 bird species were recorded in this study from April 2024 to July 2024. Fifty species were observed in wetland habitat and 40 in built-up areas, with 15 species occurring in both habitats. About 73 species are classified as 'Least Concern', and two as 'Near Threatened', according to the IUCN Red List. The present study highlights the importance of natural habitats like wetlands, which are more favourable for bird foraging and nesting than built-up areas.

Keywords: AIIMS, birds, built-up land, campus, greenspace, habitat connectivity, Kamrup, Near Threatened, point count, wetland.

Assamese: পক্ষীবৈচিত্ৰতাই, বিভিন্ন প্ৰকাৰৰ বাসস্থানকে ধৰি প্ৰতিষ্ঠানিক চৌহদৰ ভিতৰত অৱস্থিত সেউজীয়া অঞ্চলসমূহে যে সিহঁতক প্ৰয়োজনীয় আশ্ৰয়স্থল প্ৰদান কৰাৰ উপৰিও পৰিৱেশগত অখণ্ডতা সংৰক্ষণ কৰাত বিশেষ গুৰুত্ব প্ৰদান কৰে, তাৰে এক নিদৰ্শন ডাঙি ধৰে | বৰ্তমানৰ অধ্যয়নৰ যোগেদি AIIMS গুৱাহাটীৰ চৌহদৰ ভিতৰত পৰিলক্ষিত হোৱা বিভিন্ন পক্ষী প্ৰজাতিসমূহৰ এখন প্ৰাৰম্ভিক তালিকা প্ৰস্তুত কৰা হৈছে , য' ত 2024 চনৰ এপ্ৰিল মাহৰ পৰা আৰম্ভ কৰি জুলাই মাহলৈকে সৰ্বমুঠ 75 টা প্ৰজাতিৰ পক্ষী তালিকাবদ্ধ কৰা হৈছে |তাৰে ভিতৰত মুঠ 50 টা প্ৰজাতি জলাশয় অঞ্চলত, 40 টা প্ৰজাতি নিৰ্মিত অঞ্চলত আৰু 15 টা প্ৰজাতি দুয়োটা অঞ্চলত পৰিলক্ষিত হৈছিল | IUCN ৰেড লিষ্ট অনুসৰি উক্ত তালিকাৰ 73 টা প্ৰজাতি " Least Concern " (অতি কম সংকটাপন্ন) আৰু 2 টা প্ৰজাতি " Near Threatened" (প্ৰায় সংকটাপন্ন) হিচাপে শ্ৰেণীবদ্ধ কৰা হৈছে | উক্ত অধ্যয়নৰ জৰিয়তে প্ৰাকৃতিক অঞ্চলসমূহ যেনে জলাশয় যে নিৰ্মিত অঞ্চলসমূহৰ তুলনাত পক্ষীবোৰৰ কাৰনে খাদ্য সংগ্ৰহ কৰিবলৈ আৰু বাঁহ সাজিবলৈ অধিক অনুকূল তাক দৃষ্টিগোচৰ কৰা হৈছে |

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Author contributions: NA and VC conceptualized the study and designed the methodology. NA, VC, and MB were involved in data collection and analysis, ensuring the accuracy and reliability of the results. All authors (NA, VC, PKS, and MB) participated in writing, reviewing, and editing the manuscript. All authors have read and approved the final version of the manuscript.

INTRODUCTION

Avian diversity on built-up land provides insights into the ecological health of the region (Latta et al. 2013; Bajagain et al. 2020). Avifaunal diversity observed within an institute's premises highlights the importance of maintaining suitable habitats for birds, as they fulfil numerous ecological functions, serve as bioindicators and contribute to migration and adaptation processes (Rajashekara & Venkatesha 2017). Their presence and diversity can be used to assess the environmental quality of the institute's surroundings.

Assam, a northeastern state of India, is known for its rich and diverse avifaunal population. The region's unique geographic location, encompassing the eastern Himalaya and the Brahmaputra River basin, provides a habitat for many birds. Assam is home to around 700 bird species in recognised Important Bird and Biodiversity Areas (IBAs), and also in urban and semi-urban settings including institutional campuses (Rahmani et al. 2016; Bhaduri & Rathod 2022; BirdLife International 2022). Research has shown that educational campuses host significant avian diversity, with surveys reporting an average of 66 to 88 bird species per campus, including some threatened species (Devi et al. 2012; Aggarwal et al. 2015; Chakdar et al. 2016; Liu et al. 2021; Guthula et al. 2022; Kumar et al. 2024; Singh et al. 2024). These campuses serve as significant habitats for birds due to their abundant greenery, food resources, and relatively low levels of disturbance (Bhaduri & Rathod 2022).

The All India Institute of Medical Sciences (AIIMS) in Guwahati, situated near significant birding sites like Deepor Beel Wildlife Sanctuary, Dighali Beel, and Jendia Beel, is a potential habitat for birds. This study is focused on documenting the avian diversity within the AIIMS Guwahati campus.

MATERIALS AND METHOD

Study area

Bird observations were conducted in and around the All India Institute of Medical Sciences (AIIMS), Guwahati. The institute is located at 26.253 °N and 91.696 °E in Changsari, a locality of Kamrup District, Assam, and spans 189.2 ac (Image 1). The campus features built-up land featuring the hospital, institute and residential campus with newly created green space. A significant portion of the campus includes a marshy wetland habitat that spans around 85 ac, while the built-up urban area is approximately 95 ac. The marsh areas are mainly composed of rooted vegetation such as *Nymphaea stellata*, *Pontederia hastata* and free-floating plants like *Eichhornia crassipes*. The nearest forest, Dirgheswari Reserve Forest, a moist deciduous hill forest, is about 1.5 km to the northeastern side of the campus.

Data collection

This study was carried out from April 2024 to July 2024. The point count method was used, which lasted 15 min per point count (Drapeau et al. 1999). As the primary goal of the study was to record the list of species, a point count with an unlimited radius was used (Bibby et al. 2000). All birds observed and heard were noted. Most observations were conducted in the morning between 0600 h and 0900 h, except a few in the evening (between 1500 h and 1700 h) to count some species that usually roost in marshy wetlands. Field surveys were undertaken twice a week from April to July. Birds encountered during other than census period were also considered during the study. Birds were observed using a pair of binoculars (Nikon 8 × 40), and field identification was done based on Grimmett et al. (2016). Taxonomy was followed as per Clements Checklist v2023 (Clements et al. 2023).

RESULTS

During the study period, 75 species belonging to 16 orders and 42 families of birds were observed (Table 1). Among the recorded species, 29 were passerine, while 44 were non-passerine. Among the 42 families, the highest species (6 species) belonged to the Ardeidae family. The point count surveys recorded an average of 7.5 ± 2.4 (mean ± SD) species per survey. According to the IUCN Red List, 73 species are listed as Least Concern, while two species, namely Lesser Adjutant *Leptoptilos javanicus*, and Oriental Darter *Anhinga melanogaster*, are classified as Near Threatened.

Among the two Near Threatened species observed, the Lesser Adjutant had the highest count, with a maximum of three individuals recorded in a single survey. This was followed by the Oriental Darter, with two individuals. Two winter migratory species, Dusky Warbler *Phylloscopus fuscatus* and Brown Shrike *Lanius cristatus* were also observed in the wetland habitat during the study. Higher numbers of species (n = 50) were observed in the wetland habitat relative to built-up land (n = 40), and 15 species were observed in both habitats (Figure 1).

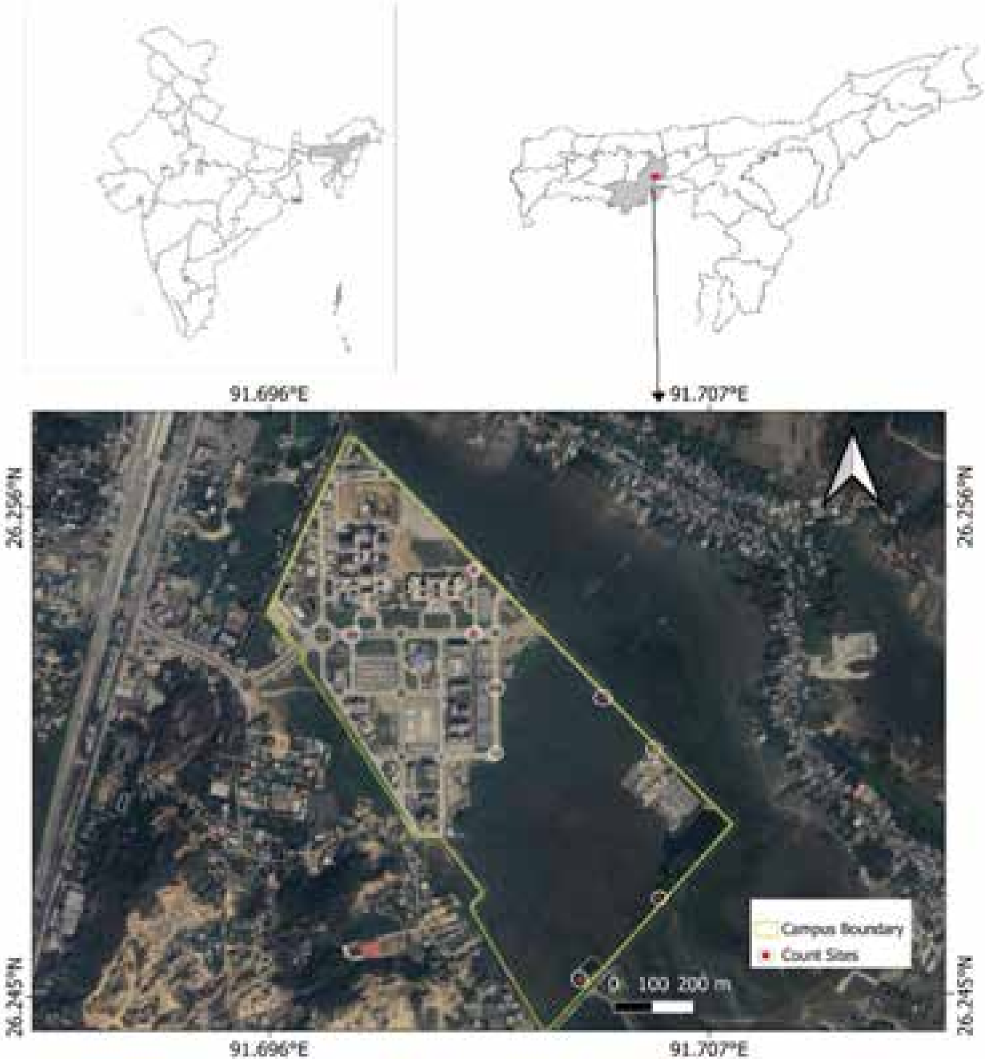

Image 1. Location of point count sites within the study area. Map data: Google, 2024 Airbus.

DISCUSSION

The wetland habitat on the AIIMS Guwahati campus supports a greater diversity of bird species compared to built-up areas, primarily due to its varied vegetation, including tall grasses (e.g., *Saccharum* sp.), free-floating plants like Water Hyacinth *Pontederia crassipes*, rooted aquatic species such as Lotus *Nelumbo nucifera*, and abundant food resources. This rich habitat attracts bird species, including the Chestnut Munia *Lonchura atricapilla*, Grey-headed Swamphen *Porphyrio poliocephalus,* and Bronze-winged Jacana *Metopidius indicus*, which use the area for nesting, foraging, and roosting. Numerous studies have highlighted the importance of wetlands in supporting high bird species richness (Zhu & Wang 2022; Cristaldi et al. 2023; Zhang et al. 2023). Also, wetlands, the transition between terrestrial and aquatic habitats, often host a wide array of resident and migratory bird species (Khatri et al. 2019). The presence of two near-threatened species of waterbirds in the campus wetlands is particularly noteworthy, as it highlights the biodiversity value of these habitats and the need for their conservation to safeguard the regional avifauna (Kumdet et al. 2021).

Low species number in the campus might be due to the newly-constructed built-up land, as they often lack tree cover, which results in the loss of vital nesting and foraging habitat for birds (Bajagain et al. 2020). Additionally, the short duration of the study, which did not cover the winter season, might have contributed to the observed lower species number, as some migratory bird species are present during specific times of the year. Similar results were also obtained on the campuses of the Indian Institute of Technology, Guwahati (Bhaduri

Table 1. List of avian species observed from AIIMS, Guwahati campus. B—Built-up land | W—Wetland | IUCN— International Union for Conservation of Nature | LC—Least Concern | NT—Near Threatened.

	Order / Family/ Scientific name	Common name	IUCN Red List status	Habitat
	Anseriformes			
	Anatidae			
1	*Dendrocygna javanica*	Lesser Whistling Duck	LC	W
	Columbiformes			
	Columbidae			
2	*Streptopelia chinensis*	Spotted Dove	LC	B
3	*Streptopelia tranquebarica*	Red Collared-Dove	LC	B
4	*Streptopelia decaocto*	Eurasian Collared-Dove	LC	B
5	*Columba livia*	Rock Pigeon	LC	B
	Cuculiformes			
	Cuculidae			
6	*Centropus bengalensis*	Lesser Coucal	LC	W
7	*Centropus sinensis*	Greater Coucal	LC	W
8	*Hierococcyx varius*	Common Hawk-Cuckoo	LC	W
9	*Eudynamys scolopaceus*	Asian Koel	LC	B, W
10	*Cacomantis merulinus*	Plaintive Cuckoo	LC	W
	Caprimulgiformes			
	Apodidae			
11	*Cypsiurus balasiensis*	Asian Palm-Swift	LC	B, W
	Gruiformes			
	Rallidae			
12	*Amaurornis phoenicurus*	White-breasted Waterhen	LC	W
13	*Gallinula chloropus*	Eurasian Moorhen	LC	W
14	*Porphyrio poliocephalus*	Grey-headed Swamphen	LC	W
	Charadriiformes			
	Charadriidae			
15	*Vanellus indicus*	Red-wattled Lapwing	LC	W
	Jacanidae			
16	*Metopidius indicus*	Bronze-winged Jacana	LC	W
17	*Hydrophasianus chirurgus*	Pheasant-tailed Jacana	LC	W
	Ciconiiformes			
	Ciconiidae			
18	*Anastomus oscitans*	Asian Openbill Stork	LC	W
19	*Leptoptilos javanicus*	Lesser Adjutant	NT	W
	Suliformes			
	Anhingidae			
20	*Anhinga melanogaster*	Oriental Darter	NT	W
	Phalacrocoracidae			
21	*Microcarbo niger*	Little Cormorant	LC	W
	Pelecaniformes			
	Ardeidae			
22	*Ardea purpurea*	Purple Heron	LC	W
23	*Ardea intermedia*	Medium Egret	LC	W
24	*Ardeola grayii*	Indian Pond Heron	LC	W
25	*Bubulcus ibis*	Cattle Egret	LC	B, W
26	*Nycticorax nycticorax*	Black-crowned Night-Heron	LC	W
27	*Ixobrychus cinnamomeus*	Cinnamon Bittern	LC	W
	Threskiornithidae			
28	*Threskiornis melanocephalus*	Black-headed Ibis	LC	W
29	*Plegadis falcinellus*	Glossy Ibis	LC	W
	Accipitriformes			
	Accipitridae			
30	*Elanus caeruleus*	Black-winged Kite	LC	B
31	*Milvus migrans*	Black Kite	LC	W
32	*Pernis ptilorhynchus*	Oriental Honey-buzzard	LC	W
33	*Spilornis cheela*	Crested Serpent-Eagle	LC	B, W
34	*Hieraaetus pennatus*	Booted Eagle	LC	B, W
	Strigiiformes			
	Strigidae			
35	*Athene brama*	Spotted Owlet	LC	B
	Bucerotiformes			
	Upupidae			
36	*Upupa epops*	Eurasian Hoopoe	LC	B
	Coraciiformes			
	Alcedinidae			
37	*Halcyon smyrnensis*	White-throated Kingfisher	LC	B, W
38	*Alcedo atthis*	Common Kingfisher	LC	W
	Meropidae			
39	*Merops leschenaulti*	Chestnut-headed Bee-eater	LC	B
40	*Merops orientalis*	Green Bee-eater	LC	B
	Coraciidae			
41	*Coracias affinis*	Indochinese Roller	LC	B
	Piciformes			
	Megalaimidae			
42	*Psilopogon asiaticus*	Blue-throated Barbet	LC	B
43	*Psilopogon lineatus*	Lineated Barbet	LC	B

	Order / Family/ Scientific name	Common name	IUCN Red List status	Habitat
	Picidae			
44	*Dendrocopos macei*	Fulvous-breasted Woodpecker	LC	B
	Psittaciformes			
	Psittaculidae			
45	*Psittacula krameri*	Rose-ringed Parakeet	LC	B
	Passeriformes			
	Oriolidae			
46	*Oriolus xanthornus*	Black-hooded Oriole	LC	B
	Artamidae			
47	*Artamus fuscus*	Ashy Wood Swallow	LC	B, W
	Aegithinidae			
48	*Aegithina tiphia*	Common Iora	LC	B, W
	Dicruridae			
49	*Dicrurus macrocercus*	Black Drongo	LC	B, W
	Laniidae			
50	*Lanius cristatus*	Brown Shrike	LC	W
51	*Lanius schach*	Long-tailed Shrike	LC	W
	Corvidae			
52	*Corvus splendens*	House Crow	LC	B
	Paridae			
53	*Parus cinereus*	Cinereous Tit	LC	B
	Alaudindae			
54	*Alauda gulgula*	Oriental Skylark	LC	B, W
55	*Mirafra assamica*	Bengal Bushlark	LC	W
	Cisticolidae			
56	*Orthotomus sutorius*	Common Tailorbird	LC	B
57	*Prinia inornata*	Plain Prinia	LC	W
	Hirundinidae			
58	*Hirundo rustica*	Barn Swallow	LC	W
	Pycnonotidae			
59	*Pycnonotus cafer*	Red-vented Bulbul	LC	B, W
	Phylloscopidae			
60	*Phylloscopus fuscatus*	Dusky Warbler	LC	W
	Timaliidae			
61	*Turdoides striata*	Jungle Babbler	LC	B
	Locustellidae			
62	*Megalurus palustris*	Striated Grassbird	LC	W
	Sturnidae			
63	*Gracupica contra*	Asian Pied Starling	LC	W
64	*Acridotheres tristis*	Common Myna	LC	B
65	*Acridotheres fuscus*	Jungle Myna	LC	B
66	*Acridotheres grandis*	Great Myna	LC	B, W
	Muscicapidae			
67	*Copsychus saularis*	Oriental Magpie Robin	LC	B
	Nectariniidae			
68	*Aethopyga siparaja*	Crimson Sunbird	LC	B
69	*Cinnyris asiaticus*	Purple Sunbird	LC	B, W
	Ploceidae			
70	*Ploceus philippinus*	Baya Weaver	LC	W
	Estrildidae			
71	*Lonchura punctulata*	Scaly-breasted Munia	LC	B, W
72	*Lonchura atricapilla*	Chestnut Munia	LC	B, W
	Passeridae			
73	*Passer domesticus*	House Sparrow	LC	B
74	*Passer montanus*	Eurasian Tree Sparrow	LC	B
	Motacillidae			
75	*Anthus rufulus*	Paddyfield Pipit	LC	W

& Rathod 2022) and Assam University (Chakdar et al. 2016). As the AIIMS campus was constructed on a wetland, many common urban bird species such as Rufous Treepie *Dendrocitta vagabunda*, Large-billed Crow *Corvus macrorhynchos* and Black-rumped Flameback *Dinopium benghalense* were missing during the study period. The ongoing green space landscaping might attract those species in future once there is sufficient tree cover to support them.

Studies have shown that institutional campuses with well-developed greenspaces can support a surprising diversity of avifauna, likely due to the availability of suitable habitat features such as vegetation cover, water

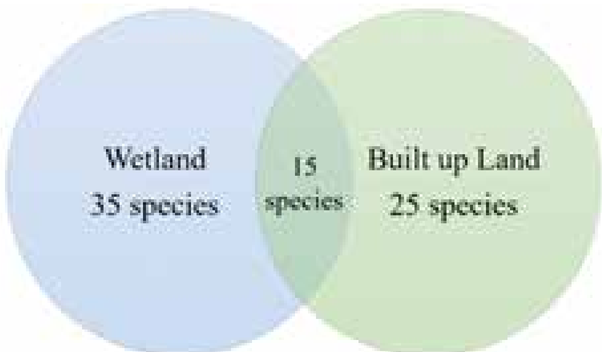

Figure 1. Species richness unique to each of the two habitats and the species shared between them.

sources, and reduced disturbance (Mardiastuti 2020). Understanding the factors that shape bird distribution in wetland and urban greenspace environments is crucial for informing effective conservation strategies. Habitat size, connectivity, and vegetation composition are identified as critical drivers of avian diversity in urban greenspaces (Aronson et al. 2014). The expansion of built-up areas can lead to a decline in bird diversity, as urbanisation often results in the fragmentation and loss of natural habitats that are essential for the survival and reproduction of many avian species. Newly created built-up land with planned green space can gradually attract more birds and support higher bird diversity over time, as seen in some institutional campuses, provided the green spaces are well-designed and maintained (Ibáñez-Álamo et al. 2020; Kumdet et al. 2021). Such landscapes play a vital role in supporting biodiversity in urban areas.

To conserve the existing wetland habitat on campus, it is essential to maintain water quality by controlling pollution and managing runoff from the built-up areas. Sustainable campus management practices, such as increasing green spaces and reducing impervious surfaces, which minimise environmental impact and support habitat conservation. Additionally, planting native trees including fig (Banyan and other Ficus species) can promote bird diversity by providing essential food sources and nesting habitats (Caughlin et al. 2012). Creating green corridors that link the marshland areas to the nearby Dirgheswari Reserve forest can promote biodiversity and enhance habitat connectivity for birds and smaller fauna.

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COMMUNICATION

Implementation strategy and performance analysis of a novel ground vibration-based elephant deterrent system

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Abstract: The establishment of human habitations, expansion of cultivation lands, and constant degradation of forest areas have intensified human-elephant negative interactions over the years in the Anaikatti area located at Coimbatore and Periyanaickenpalayam forest range in southern India. A few nature parks have been established in this interaction-prone area and are also affected by frequent elephant presence. To safeguard one such park, Nilgiri Biosphere Nature Park, from elephant and other wildlife intrusions, 13 units of a ground vibration-based 'elephant deterrent system' have been installed along its periphery. The system is a field-deployable version of our ground vibration-based 'elephant early warning system', designed to deter elephants using sound units upon detection. It analyzes the frequency of footstep vibrations to initially differentiate between elephant and non-elephant footsteps. The cumulative vibration data from sensors is then used to identify elephants more precisely. Furthermore, for certain system units, the system's algorithm has been adjusted via on-the-fly software updates to detect all animal footstep vibrations, activating deterrent sound effects tailored to the specific requirements of the current application. Insights from location surveys and discussions with local residents have contributed to the development of innovative implementation strategies and the careful selection of installation sites, which are detailed in this paper. The paper also outlines the system's installation layout, case-specific algorithms, and hardware architecture. Performance was monitored over an eight-month period, with the results analyzed alongside feedback from field observations. Notably, the system trial phase showed a reduction in elephant intrusions within the park. This report is the first detailed account of a trial field performance, making it a valuable reference for replicating similar solutions in other conflict locations.

Keywords: Human-elephant negative interaction, microcontroller, sensor string integration, signal conditioning unit, vibration sensor, warning system.

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Author contributions: SD—played a pivotal role in the development of hardware design, algorithm formulation, programming, and verification of field systems. RR—was responsible for conducting the field survey, overseeing the installation, and managing data collection. SKR—contributed significantly to the field installation process and the drafting of the manuscript.

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INTRODUCTION

Over the years, several technologies and systems have emerged for human-elephant negative interaction management, but they come with their advantages and limitations (Shaffer et al. 2019; Vogel et al. 2020; Tiller et al. 2021). If categorized broadly, the technologies come in two categories: first, the elephant early warning system, and second, the elephant deterrent system (Choudhury 2010; Rohini et al. 2016; Tripathy et al. 2021). Although there has been notable progress in the domain of early warning technologies, very few successful non-contact elephant deterrent systems have been reported so far. (Nayak & Swain 2020; Feuerbacher et al. 2021). The high intelligence and adaptive learning capability of the elephant have restricted technologists from designing a long-lasting elephant deterrent system (Locke et al. 2016; MoEF 2020). The few reported short-term successful systems also had a lack of range, element of surprise, and have terrain-specific limitations (MoEF 2020).

Considering those technological ambiguities and urgent needs, our ground vibration-based 'elephant early warning system' (EEWS) was reconfigured into an elephant deterrent system, with a re-engineered system design, operational algorithm, control circuit, and addition of a high-volume hooter/siren. The EEWS was designed over the years with national and international funding (Ramkumar & Deb 2021). The EEWS was tested through simulated experiments, as well as with field implementation at Sathyamangalam Tiger Reserve in 2020 (Ramkumar & Deb 2021). With the feedback data from field-installed EEWS units, the technology was refined. With all those added attributes, the EEWS was re-configured into a ground vibration-based 'elephant deterrent system' (EDS). Under this work, a total of 13 units were installed to cover the 3.5 km periphery of the Nilgiri Biosphere Nature Park (NBNP).

Location Survey

Anaikatti is a small township near Coimbatore, located in the Western Ghats at the Tamil Nadu-Kerala border in southern India. Human activities such as agriculture, urbanization, and tourism are disrupting the traditional migratory routes of elephants. Additionally, the depletion of forest resources has forced elephants to explore new migration paths, making Anaikatti a key interaction hotspot (Karthick et al. 2016; A Times of India Report 2019; Deivanayaki et al. 2019). The intensity of the conflict is so severe that the area frequently makes news headlines and has been the subject of several research articles (Ramkumar et al. 2013; Natarajan et al. 2024). Being situated in this area, the Nilgiri Biosphere Nature Park (NBNP) has elephants visiting the site over the years. The NBNP is a nature-based organization designed to introduce and educate young minds about the unique flora and fauna of the Western Ghats, boasting a large collection of these species. The availability of food and water, especially during summer, has made the park an attractive entry point for the elephants.

To assess the elephant visitation scenario at NBNP, a detailed field survey was carried out on foot to accurately map the elephant movement paths. Additionally, key terrain factors such as soil conditions, ground slope, sunlight availability, and other parameters relevant to system installation were also surveyed. On the northern side of the NBNP, a hillside is covered in forest. To the east of the park, there is open land extending for about 1.5 km. This area features small patches of forest, scattered agricultural fields, and a few houses, as illustrated in Figure 1. Meanwhile, the southern and western sides of the park are covered by cultivation land and human habitation. There is a narrow footpath covering the three sides of the park, except for the western side, which is covered by a motorable road. According to local reports, the narrow path is utilized by cattle grazers, wood collectors, and farmers during the day, while at night, it becomes a route for deer, pigs, leopards, and other wildlife, including elephants. We interviewed a group of 50 individuals in and around the park, local forest officials, including park workers, to understand the status of interactions, map the movement paths of elephants & other wildlife, and analyze the intentions behind these intrusions, their frequency, distribution across seasons, and times of day. The survey was conducted during the first two weeks of August 2022, and the results are presented in Table 1.

The information from the general survey, presented in Table 1, indicates that over the past three years, a sub-adult male resident elephant and a mature migrating bull have frequented the site. The survey also reveals that the bull enters the area from November to April each year. During the day, elephants settle on the eastern side of the hill forest and visit the park and nearby villages after sunset. Despite the entire park perimeter being secured by an electric fence, it has proven insufficient to prevent elephant intrusions over the years.

Implementation Strategy

All potential entry and exit paths of the elephants have been marked on the map by analyzing ground conditions, gathering residents' feedback, and reviewing

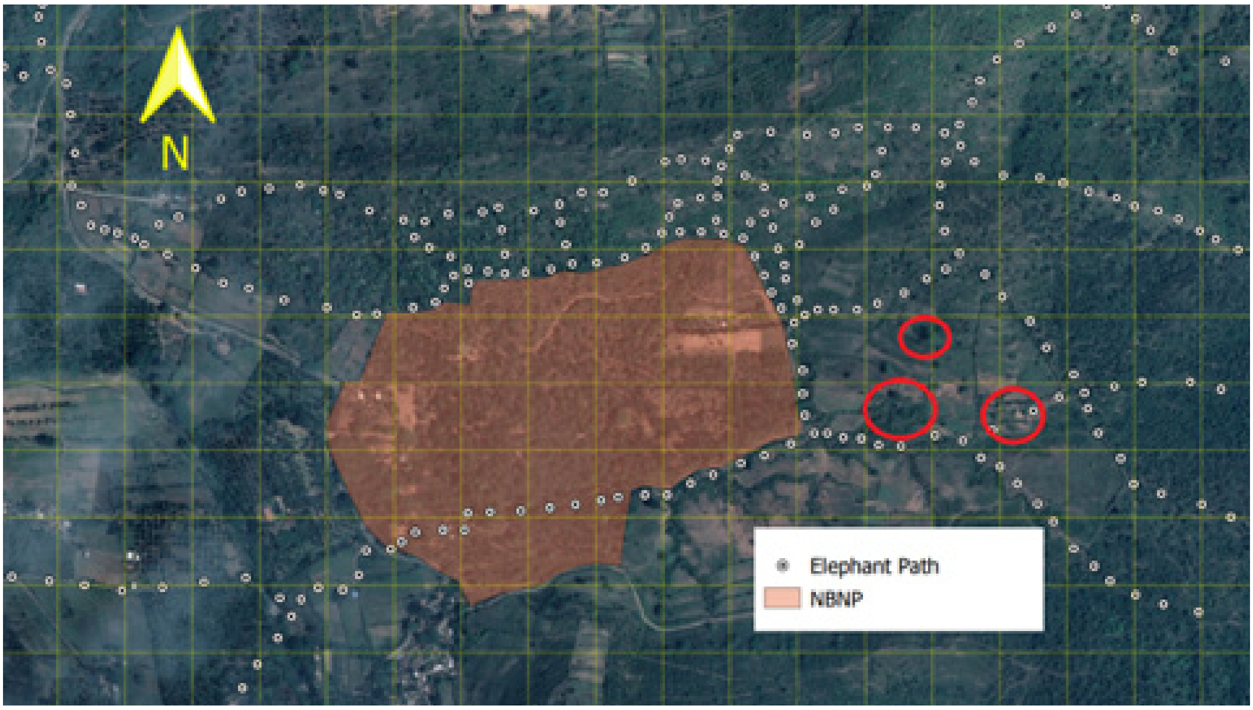

Figure 1. The satellite map of NBNP and the surrounding area, along with demarcated elephant paths and a few houses on the eastern side (marked with a red circle).

the survey report, as illustrated in Figure 1. It has been identified that most elephant paths from the northern and eastern sides of the park terminate at the boundary, which is secured by an electric fence. According to feedback from local residents and park workers during the field survey, once the elephants reach the fence, they walk along it in search of a weak point to breach the fence. Alternatively, they may continue their journey to reach the river and agricultural areas on the southern or western side. The survey also revealed that a narrow monsoon river runs through the southern section of the park, and during the dry months, this path is frequently used by elephants to access those destinations.

A comprehensive analysis of terrain conditions, vegetation, local infrastructure, animal species, the nature and direction of the visit, and other localized factors is crucial for designing and implementing an effective system to minimize visits. For instance, while we specialize in laser fence-based animal early warning systems, the steep slopes, dense vegetation, and the elephant movement paths along the park's electrical fence make such a solution impractical (Ramkumar & Deb 2022). Based on our survey and feedback from other project stakeholders, we have concluded that to effectively manage the human-elephant interactions in this area, it is essential to prevent elephant movement along the paths surrounding the park's perimeter. Therefore, we decided to install footstep vibration-based EDS units at the junctions where elephant paths intersect with the park's boundary. This solution is anticipated to be highly effective, as illustrated in Figure 2.

System Details

The EDS is a modified variant of EEWS with few added features, as described in the following sections with Figure 3.

System Hardware Architecture

The EDS is a two-sensor strings-based design, where one sensor string takes reference input from the other string to reject any common vibration. With two separate sensor strings, only one string captures footstep vibrations during a visit, while vibrations from rain, landslides, and vehicle movement are detected simultaneously by both strings. This allows the system to effectively distinguish and eliminate noise vibrations, responding only to footstep vibrations. The sensor string is designed with piezoelectric sensors in successive series and parallel combinations to optimize sensor string output in terms of both current and voltage. Two sensor strings are connected with the 'signal conditioning unit' (SCU), as shown in Figure 3. The signal conditioning unit is the combination of two identical 'pre-amplifier and filter sections' connected with each sensor data line

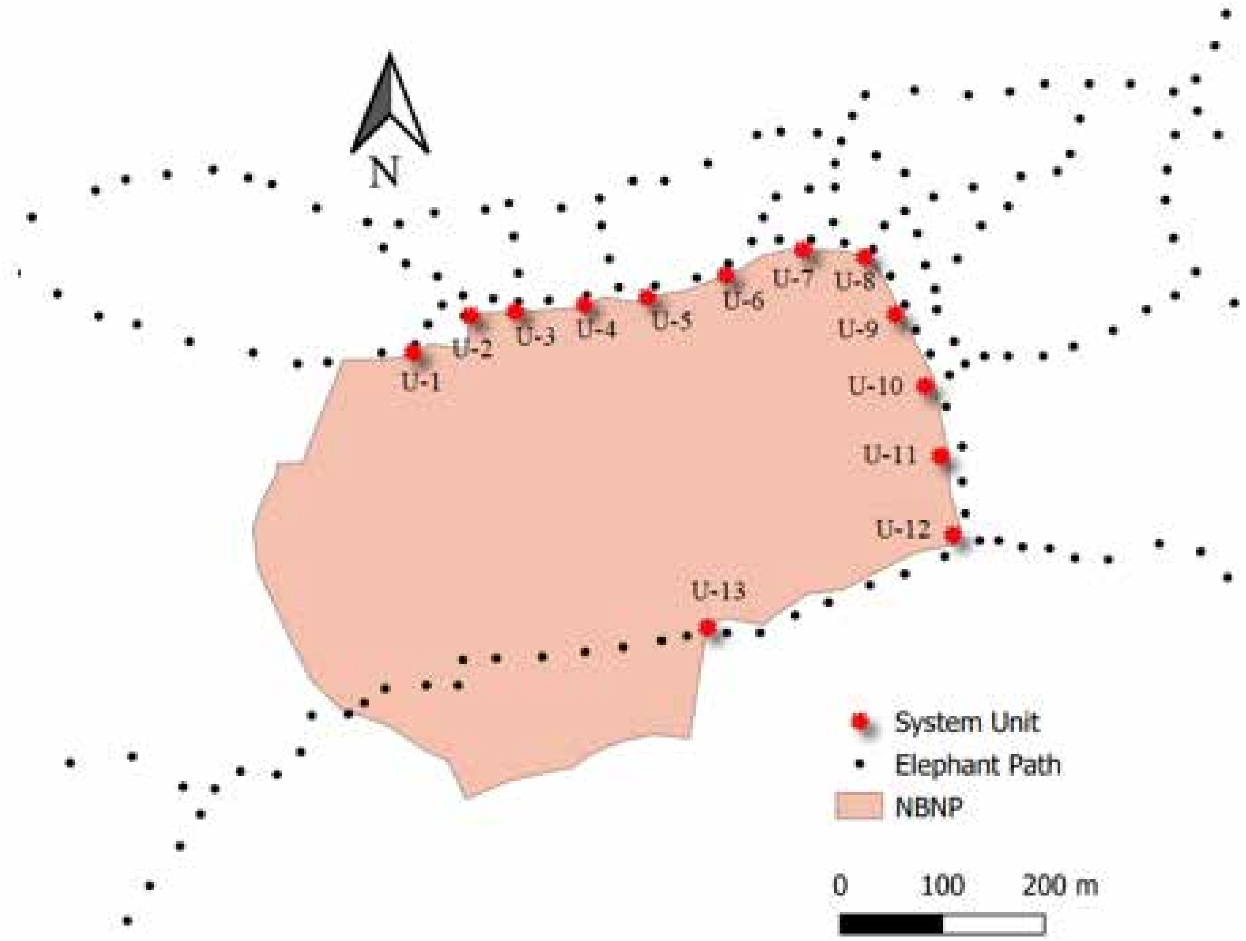

Figure 2. Elephant paths and placement of Elephant deterrent system units (U—1–U—13) along the park periphery.

Table 1. The conflict status survey. It involved a selected group of 50 individuals from NBNP Park and surrounding areas, including local villagers, park security, staff, and local forest officials. The sample was composed of 70% adult males, 20% children aged 7–13, and 10% females.

Questions	People Response
How many times has he/she seen an elephant in the past two years?	40% have not seen an elephant, 20% have seen one 1–2 times, 10% have seen it more than twice, and 30% have not seen it but felt its close presence.
What size was the elephant observed (adult, semi-adult, juvenile)?	70% reported seeing adults, 20% observed semi-adults, and 10% were unable to distinguish due to darkness.
During which season did he/she see the elephant?	80% of sightings occurred in summer, 5% in the monsoon, 10% in winter, and 5% could not recall the season.
At what time of day did he/she observe the elephant?	60% saw elephants during late evening, 30% in early morning, and 10% at midnight.
What was the likely path or track of the elephant's movement?	1. Did it bypass the park area and move toward the riverside? 40% of the time. 2. Did it go to the crop fields on the southern and western sides of the park? 25% of the time. 3. Did it intrude into the park area? 10% of the time. The remaining 25% were unsure.
What might be the cause of the elephant's intrusion?	1. Did it go to the river for water? 30% of respondents answered yes. 2. Did it raid crops in the agricultural land? 40% of respondents answered yes. 3. Did it go to the park area for food and water? 10% of respondents answered yes. The remaining 20% were unsure.

separately. The signal conditioning circuit of EDS is a design with few instantly configurable pot resistors, and thus its vibration sensitivity can be adjusted in real-time as per the terrain conditions and the target vibration. In a nutshell, the EDS can be configured into a highly sensitive mode to capture footstep vibration even from a house cat or extremely less sensitive, where it will sense the footstep vibration of large animals only. The authors have already analyzed the signal parameters for different animals footsteps and reported in (Ramkumar & Sanjoy 2021).

The control unit functions based on a microcontroller circuit. In this work, we utilized an Arduino-based microcontroller unit for decision-making, which is an open-source hardware and software component. The vibration patterns of various animals and humans are stored in the microcontroller. When the control unit receives processed signals from the SCU, it runs an identification algorithm and compares the input with pre-saved reference signal patterns. Upon detecting a match, the control unit activates the hooter to repel intruding animals. The basic identification algorithm has already been analyzed and documented by (Ramkumar & Sanjoy 2021), and the modified version used in the preset application is presented in detail in the following sections. The EDS operates on a 12-volt power supply and includes a stand-alone unit featuring solar panels (12V, 20W), charge controllers (12V, 6A), and batteries (12V, 2.5Ah). A daylight sensor is integrated into the system, allowing it to activate at dusk and automatically turn off at twilight.

System Implementation Design

In the current EDS design, each sensor string consists of four sensors, with each sensor spaced 1 m apart. The sensor string is buried at a depth of 20 cm and follows a zigzag pattern, providing a cumulative physical coverage area of 3 m² (calculated as 2 × 1.5 m²), as shown in Figure 4. However, once buried, each sensor has a vibration detection radius of approximately 2 m, making the effective sensing coverage area 2–3 times larger than the physical coverage area. When the sensor string is placed underground, it creates a detection field similar to an underground sensor carpet. The sensor string can be placed at a long distance from the hooter pole, providing a long detection range. The system is versatile and can be placed in various terrain conditions, except for waterlogged areas.

Placing the sensor string too deep can reduce its sensitivity but also help minimize background noise vibrations, so the depth must be optimized based on the terrain conditions and target species. The separation between two sensor strings (denoted as 'x' in Figure 4) must also be adjusted according to specific unit requirements. For this project, the maximum separation 'x' is 20 m for EDS Unit—10, while for EDS Unit—2, the separation between the two strings is 5 m.

In the current application, five types of 12-volt hooters are used across different system units in a random pattern, each producing a distinct sound to ensure sound diversity. The positioning of the hooter poles, the number of hooters, and their orientation are tailored to the specific requirements of each case.

System Algorithm

The system monitors three key parameters: 'signal frequency', 'signal amplitude', and the cumulative 'volume of vibration'. The EDS operates on a 10-second 'detection loop', controlled by a microcontroller (which aligns with the verified time an elephant typically takes to cross the sensor string). The flowchart shown in Figure 5 outlines the basic process for detecting and identifying elephants and other animals in the EDS. Previous simulated studies have indicated that elephant footsteps generate low-frequency vibrations, in contrast to animals with hooves, which produce higher-frequency vibrations above 100 Hz (Ramkumar & Deb 2021). This distinction is especially noticeable on rocky ground. After the signal is pre-amplified and filtered, the system algorithm checks the frequency input. If the frequency is identified as less than 100 Hz, it proceeds along the "elephant line".

Following frequency determination, the signal values are accumulated over a 10-second period, referred to as the "detection loop", and the resulting value is recorded as the 'cumulative vibration' (Vc). During each loop, the system checks for vibration peaks above a pre-set threshold. All amplitude values exceeding this threshold are accumulated within the loop to calculate the Vc. If the Vc is greater than or equal to the 'voltage elephant threshold' (Vte), the sound deterrent unit is activated to repel the elephant. This Vte has been determined from a previous simulated experiment with an elephant but also needs slight adjustment to counter the background noise of the implementing site. While humans and other soft-toed animals also generate low-frequency vibrations, previous observations show that their cumulative vibration values are significantly lower than the Vte, allowing them to be excluded when targeting elephants specifically.

This unique approach has been shown to achieve over 80% accuracy in detecting elephants through footstep vibrations, as confirmed by previous simulated

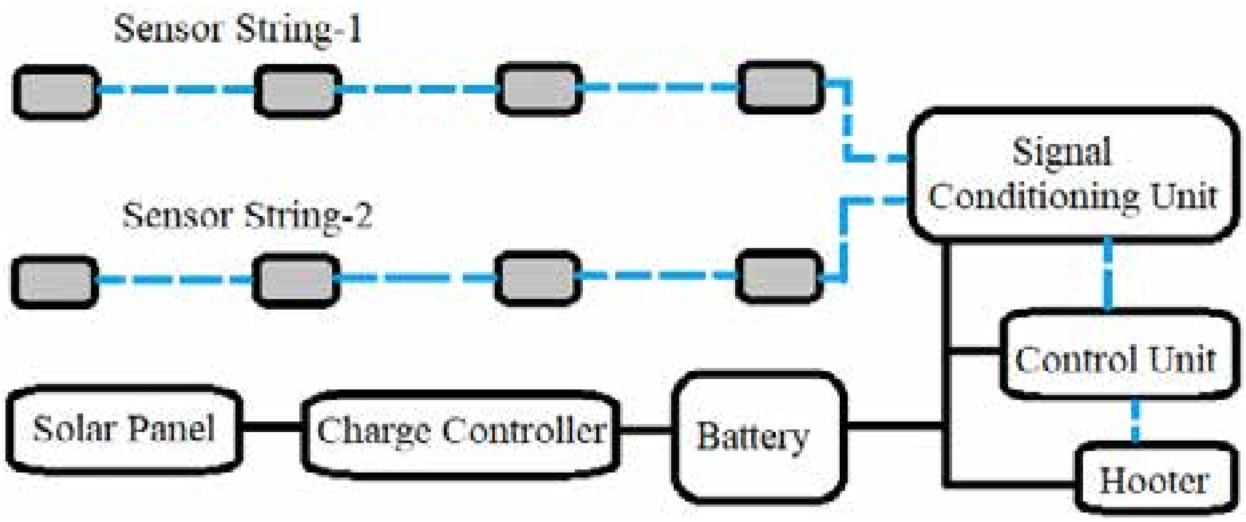

Figure 3. The internal hardware block design for Elephant deterrent system (dashed line are data lines and solid lines are power lines).

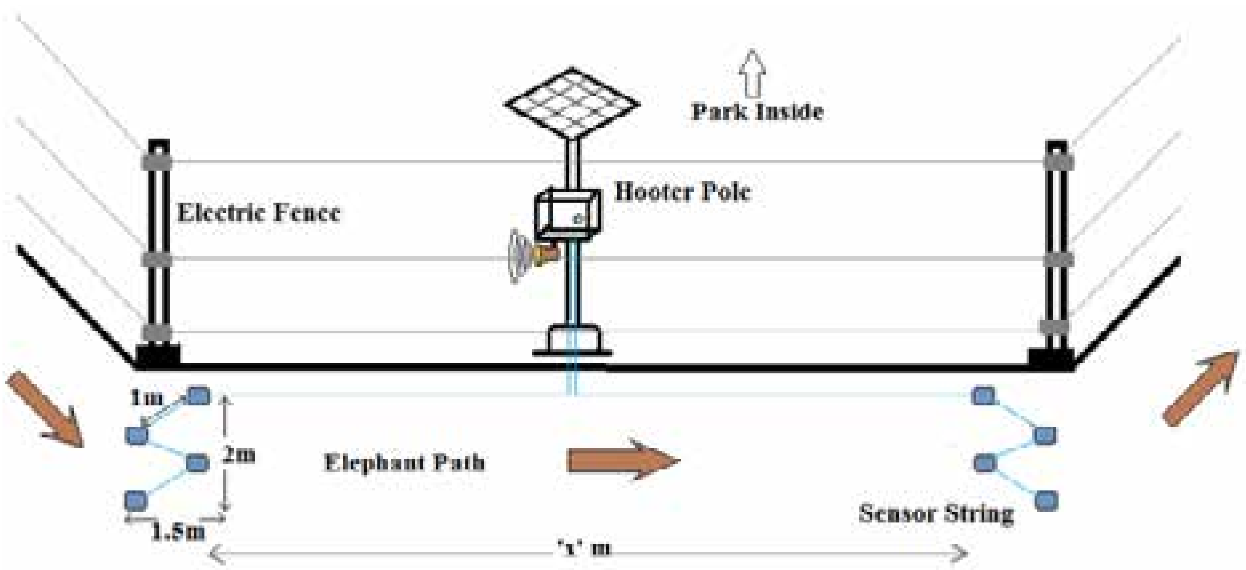

Figure 4. System field implementation architecture with hooter pole, sensor strings, elephant path, and existing electric fence.

experiments (Ramkumar & Deb 2021). The remaining 20% discrepancy in accuracy arises from system limitations in detecting elephants under certain conditions, such as muddy soil or loose sand, where sensor sensitivity is significantly reduced. In these situations, the system may incorrectly identify elephants and other animals. Additionally, high-volume vibrations from overlapping frequencies generated by a group of other animals crossing the sensor field could cause the system to misinterpret the detection as an elephant, leading to potential confusion.

To further distinguish elephant detections from those of other animals, the EDS employs distinct sound patterns. For example, when an elephant is detected, the hooter will sound continuously for five minutes to maximize the deterrent effect. This distinct sound pattern serves as an alert to park security personnel, prompting them to verify the potential elephant intrusion. In contrast, detections of other animals will trigger a one-minute sound with a five-second on-off pattern, ensuring different responses based on the type of detection. Considering our practical experience, the system algorithm is designed to trigger a maximum of 20 times per day, ensuring that contentious sound generation is avoided throughout the night, even in the event of a system malfunction.

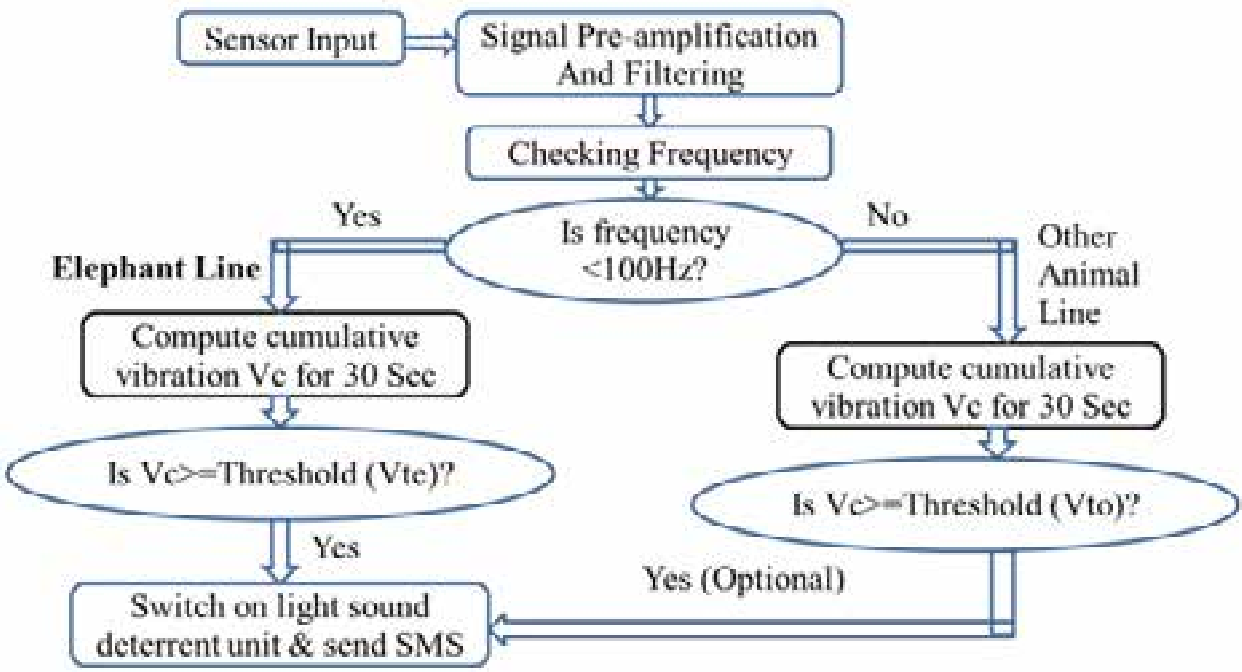

Figure 5. Elephant deterrent system algorithm flowchart.

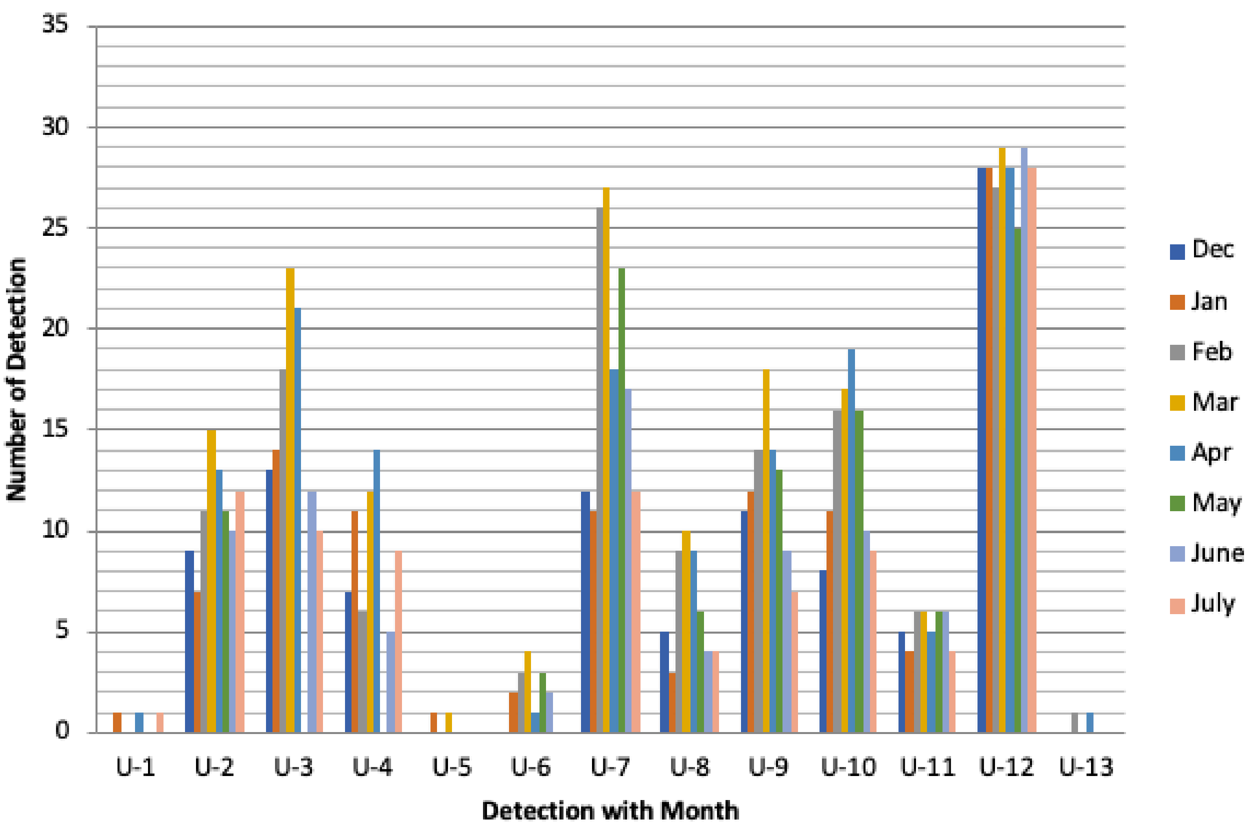

Figure 6. Elephant deterrent system unit-wise detection in months December 2022–July 2023.

System Performance Analysis

In October and November 2022, 13 EDS units were installed around the park perimeter. In addition to elephants, wild pigs, and spotted deer frequently visit the park, predating upon or uprooting plants including flower & vegetable gardens. Visitations are not limited to animals, as wood poachers have occasionally entered the park and poached valuable trees. To address these safety concerns, all units except Unit—1, Unit—5, and Unit—13 were configured in "all-animal detection" mode to reduce animal and human activity along the park's perimeter pathways at night.

As outlined in the algorithm flowchart, the EDS operates in two modes: 'elephant line', which detects and responds exclusively to elephant footsteps, and 'other animal line', which detects and responds to vibrations caused by various animals, including elephants. This enables the EDS to function either as an 'animal deterrent system' or an 'elephant deterrent system'. For trial purposes, Units 1, 5, and 13 were configured in elephant deterrent mode to evaluate their effectiveness, while the remaining units were set to animal deterrent mode to meet practical needs.

To create distinct sound effects, five types of horns and hooters were used with varying on-off patterns, ensuring unique sound signatures for each unit. Park security personnel monitored the system for eight months, recording unit-specific detections based on these unique sound patterns. During this period, the system was most frequently triggered by pigs, spotted deer, leopards, and humans, with elephants triggering the system only rarely.

The unit-wise EDS detection report for the eight-month period of December 2022–July 2023 is shown in Figure 6. According to our field observation report, based on input from local stakeholders, most detections were caused by wild animals and human activities, with only two instances involving elephants. Animal activity was found to vary seasonally; during peak summer, the scarcity of natural water and food sources attracted more animals to the park, where pump water holes are available at several locations. Consequently, most EDS units reported higher animal intrusions during late winter and peak summer.

A discrepancy was noted between the number of animal detections (total count of sound alarm) by the system and the actual number of animal intrusions into the park. This mismatch occurs because many animals bypass the park, using paths that lead to nearby villages instead. Notably, detections by Units 11 and 12 remained consistent throughout all months, later identified as being primarily due to human footsteps. To understand this pattern, time-wise detection data for all units was analyzed and is presented in Figure 7.

The survey revealed that most human outdoor activities around the park completely cease after 2000 h and resume after 0500 h. Except for three units, all other EDS units are configured to detect all animal modes. Thus, it can be inferred that detections occurring before 2000 h and after 0500 h are predominantly due to human activities. Most of the detections from units 11 and 12, located along human movement paths, occurred during these times, confirming them as human activity. Field investigations further revealed that several houses on the eastern side of the NBNP (marked with red circles in Figure 1) have residents who frequently use pathways near these units during those hours.

In contrast, other units primarily captured animal movements, which peaked before 2100 h, gradually decreased by 2300 h, increased again around 0300 h, and settled after 0500 h. This pattern may be due to animals moving towards nearby cultivation areas, villages, and rivers in search of food and water, especially as human activity is high in the evening and early morning. This aligns with the well-known pattern of animals raiding crops during late evening and early morning hours. Some units, like Unit 7, which are far from regular human pathways, recorded consistent animal activity during early evening, late night, and intermittently throughout the night.

The specially configured units (1, 5, and 13) did not detect any elephants during their runtime but did register a few false elephant alarms. The exact cause of these false alarms remains unclear, although no major technical malfunctions were identified. Elephant footsteps were detected on two occasions—at Unit 3 in January and Unit 8 in March. However, since these units were not configured in elephant detection mode, they produced sounds associated with other animals.

While no systematic statistical data exists on the exact number of elephant intrusions in the park over the years, discussions with staff and other relevant individuals indicate approximately nine visitations occurred in the three years prior to system installation. In contrast, following the system's installation, only one intrusion was recorded. This incident occurred during the peak north-east monsoon when many units were struggling with low battery issues, and the system failed to trigger an alarm.

According to park staff, elephants typically follow their habitual paths at night, testing the fence for weak points to enter. It is believed that the loud sounds triggered by

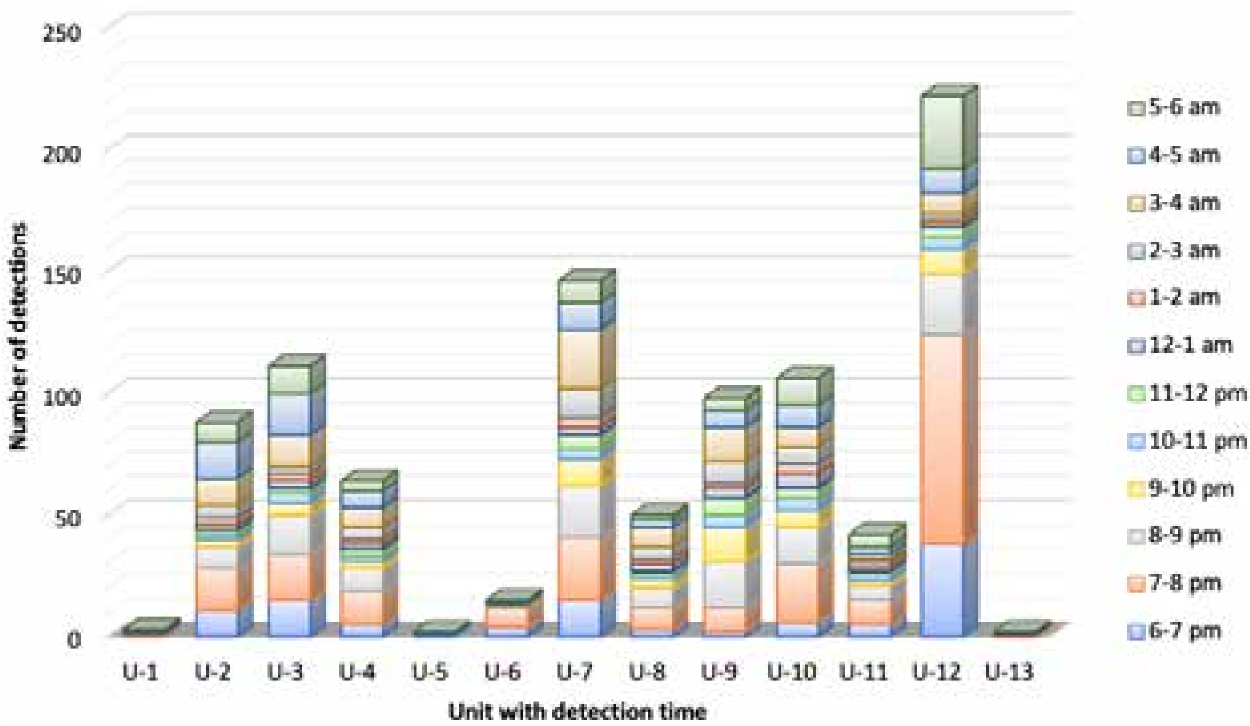

Figure 7. Elephant deterrent system unit-wise detection with different time phases during the night.

their footsteps, or the frequent sounds triggered by other animal movements, have discouraged them from using their regular paths along the park's periphery. Although the EDS has demonstrated a significant impact, its long-term effectiveness requires further validation, additional installations at other high-risk locations, and a detailed investigation into the underlying factors contributing to its success.

EDS Pictorial Representation

Figures 8–13 show some system-relevant pictures to help us better understand the EDS actual field architecture, infield performance, and other notable issues.

CONCLUSION

The ground vibration-based elephant deterrent system presented in this paper represents a pioneering approach and serves as the first trial report from India. This system is an advanced, field-implementable adaptation of the previously field-validated elephant early warning system technology. The paper provides a comprehensive description of the EDS hardware, field implementation strategy, and its innovative operational algorithm. This study documents the deployment of 13 EDS units in NBNP nature park and evaluates their performance over eight months. Additionally, it includes a field survey and subsequent analysis of conflict scenarios at the project site, accompanied by an accurate map of elephant movement paths. Such surveys and precise mapping are crucial for designing a strategic insulation plan, and the details shared in this paper offer valuable insights for similar projects. While the EDS is intended primarily to detect elephant footstep vibrations with precision, it has been optimized using a modified algorithm to enhance sensitivity, enabling the detection, and deterrence of other animals. This capability has been implemented and thoroughly reported in the current project. The system's performance analysis, which considers detection data across different times and seasonal variations, demonstrating that the EDS units effectively mitigate animal activities in the operational areas. By addressing the fundamental limitations of earlier animal-deterrent systems, the innovative EDS design has proven successful. The insights detailed in this paper provide a foundation for replicating this solution at other human-wildlife conflict hotspots, contributing significantly to the field once published.

Image 1. Interaction with locals during field survey.

Image 2. Preparing poles for installation.

Image 3. Installation of poles at selected locations.

Image 4. Digging the ground and placing the sensors.

Image 5. Field testing of system units.

Image 6. A fully functioning Elephant deterrent system unit with hooter.

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SHORT COMMUNICATION

Blackwellomyces pseudomilitaris (Hywel-Jones & Sivichai) Spatafora & Luangsa-ard, 2017 (Sordariomycetes: Hypocreales: Cordycipitaceae): first report from Western Ghats of India

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Abstract: A rare entomopathogenic fungus *Blackwellomyces pseudomilitaris* (Hywel-Jones & Sivichai) Spatafora & Luangsa-ard on lepidopteran larva is described for the first time from India. This fungus was formerly known as *Cordyceps pseudomilitaris* Hywel-Jones & Sivichai. Morphological, microscopic, and cultural characteristics with molecular identification has been discussed.

Keywords: Cordyceps, cultural studies, first record, fungal pigment, ITS sequencing, medicinal mushroom, phylogeny, taxonomy,

Cordyceps, a medicinal mushroom, is highly valuable in the market. There are two *Cordyceps* species in the market: *Ophiocordyceps sinensis* (Berk.) G.H.Sung, Hywel-Jones & Spatafora and *Cordyceps militaris* (L.) Link. Others include *Metacordyceps liangshanensis* (M.Zang, D.Liu & R.Hu) G.H.Sung, J.M.Sung, Hywel-Jones & Spatafora and *Ophiocordyceps nutans* (Pat.) G.H.Sung, Hywel-Jones & Spatafora. These formulations are available in the Chinese market and consumers are searching for more effective alternatives (Zha et al. 2018). *Cordyceps* species has gathered attention for its immunostimulatory properties. Numerous species exhibit biological actions such as anti-oxidant, anti-cancer, anti-hyperlipidemic, anti-diabetic, anti-fatigue, anti-aging, hypo-cholesterolemic, hypotensive, vasorelaxation, anti-depressant, aphrodisiac, and kidney protectant (Das et al. 2021). The first record of *C. pseudomilitaris* came from Thailand (Hywel-Jones 1994). Isaka et al. (1999) mentioned that *C. militaris* is known to produce several secondary metabolites including nucleosides antibiotic cordycepin, while from *C. pseudomilitaris* Cordyanhydrides A and B have been detected. Diversity of *Cordyceps* from Maharashtra is not well known, however Pande (2001) listed three species of *Cordyceps*, viz., *C. militaris, C. forquignoni*, and *C. unilateralis* from Maharashtra State. Fungi from India database (www.fungifromindia.com) shows no record of the genus *Blackwellomyces* from India till date.

Blackwellomyces was proposed as a new genus on the basis of ascospores which are irregularly septate, but do not separate into part-spores. In contrast, septation and disarticulation are frequent in other family members. Some species of *Cordyceps* due to irregular septation and no separation into part spores were transferred to the genus *Blackwellomyces*, viz., *B. pseudomilitaris* and *B. cardinalis* (Kepler et al. 2017). Genus *Blackwellomyces* is not recorded from India (Manoharachary et al. 2022).

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During the present study, mature fruiting bodies of *B. pseudomilitaris* were collected on lepidopteran larva from Pachal, Ratnagiri District, Maharashtra, India. Morphological and microscopic identification was carried out. Isolation of *B. pseudomilitaris* into pure cultures, ITS rDNA identification, and evaluation of the phylogenetic relationship have been completed.

Material and Methods

a) Collection and morphological analysis: The specimen was collected from Pachal, Ratnagiri District, Maharashtra, India on an unknown lepidopteran larva. Morphological studies and microscopic observations were conducted with a Lawrence and Mayo N-300M research microscope.

Status of the genus from India and the world: The genus *Blackwellomyces* has been recorded from different regions of the world – Brazil, Papua New Guinea, United States of America, Colombia, Thailand, Dominica, Cuba, Czechia, South Africa, Estonia, Ecuador, Puerto Rico, Japan, and Korea (GBIF.org 2024). There is no record of the genus *Blackwellomyces* from India until this study.

b) Isolation: Pure cultures were obtained on SDAY (Sabouraud Dextrose Agar with Yeast Extract), PDA, and PDA +chicken egg yolk. Before inoculation stromata were surface sterilized with 0.1% $HgCl_2$ (Table 1).

c) DNA extraction, PCR amplification, and sequencing: Pure cultures obtained were used for DNA extraction (Aamir et al. 2015); 30 mm colonies were crushed with liquid nitrogen and the powder was treated with 1 ml lysis buffer (100 mM Tris HCl [pH 8.0], 50 mM EDTA, 3% SDS). Shaking was done by inverting the tube and centrifuging at 10,000 rpm for 10 minutes. The supernatant was taken in a new Eppendorf tube and an equal volume of phenol: chloroform: isoamyl alcohol (25:24:1) (PCI) was added and centrifuged at 10,000 rpm for 10 minutes. The aqueous layer was separated in a new Eppendorf tube and an equal volume of Chloroform: Isoamyl alcohol (24:1) (CI) was added and centrifuged at 10,000 rpm for 10 minutes. The upper aqueous layer was separated in a new Eppendorf tube and an equal volume of 100% ethanol was added. It was kept at -20 ˚C for 20 minutes and centrifuged at 10,000 rpm for 10 minutes at 4 ˚C. The pellet was washed with 500 µL 70% ethanol and centrifuged at 10,000 rpm for 5 minutes at 4 ˚C. The pellet was dissolved in an elution buffer. 2 µl DNA was subjected to 0.6% agarose gel electrophoresis. It was observed under a gel documentation system and quantity was measured by nano-300 micro-spectrophotometer. For PCR and sequencing of DNA, the samples were sent to PEON laboratories, Kolhapur, India. Sequence was edited by BioEdit 7.2 software and Phylogram was obtained with MEGA 11 software.

Results and Discussion

Stromata 25–65 mm long and up to 1–5 mm wide, solitary, unbranched or branched arising directly from the head of the Lepidopteran larva. Stipe 10–35 mm long & 1–3 mm wide fleshy, brittle, flexible, solid, yellow to orange towards apex; whitish-cream towards the base. Stroma 12–25 mm long and 1–3 mm wide, cylindrical, often flattened, with blunt apex, yellow to orange, often bright orange towards apex. Perithecia superficial, immersed in the base, apex prominent, elongated-ellipsoid or elongate-ovoid, 289–574 x 122–241 µm with hyaline walls. Unitunicate ascus with ascus cap; asci 210–395 × 5–6 µm; eight ascospores not breaking into part-spores (Image 1a–f).

Collection examined: India, Maharashtra, District Ratnagiri, Tehsil Rajapur, Pachal (16.7038 ^{0}N, 73.7211 ^{0}E), on larvae buried in soil, 11 August 2022; Snehal Biranje & Yogesh Patil.

Remarks

Blackwellomyces pseudomilitaris was collected on Lepidopteran larva covered by hyphae around the dead diseased larvae that gathered into a loose network of rhizomorph like structures. *C. pseudomilitaris* was discovered from in the deciduous monsoon forest of Sam Lan National Park, Thailand. The species looked similar to *C. militaris* but on the basis of some distinguishing morphological characters, it was described as *C.*

Table 1. Isolation of *Blackwellomyces pseudomilitaris* on different media.

Name of medium	Granulated PDA	Dextrose	Peptone	Agar type I	Yeast extract	Magnesium sulphate	Egg yolk (Chicken)
SDAY	-	20 g/L	5 g/L	15 g/L	5 g/L	0.3 g/L	-
PDA	39 g/L	-	-	-	-	0.3 g/L	-
PDA + egg yolk	39 g/L	-	-	-	-	0.3 g/L	25 ml

SDAY—Sabouraud dextrose agar with yeast extract | PDA—Potato dextrose agar | PDA + egg yolk—Potato dextrose agar + egg yolk.

pseudomilitaris. The ground-dwelling host lepidopteran larvae were often found 2–5 cm below the soil surface. The hyphae around the dead, diseased larvae gathered into a loose network of rhizomorph-like structures that encircled the caterpillar. These structures developed independently throughout the soil, periodically coming together and then splitting apart once more, until combining to create the stroma at the surface (Hywel-Jones 1994), stromata 12–25 mm long, rhizomorphs present, ascospores do not split into part-spores and asci 210–395 × 5–6 µm (Catania et al. 2018). The collections from the present specimen shows similarities to it with respect to morphological characteristics. *C. militaris* has been more frequently found on pupae of lepidopterans than the larvae. However, some researchers noted that *C. pseudomilitaris* was found only on the larvae (Mains 1958; Hywel-Jones 1994). *C. militaris* is usually found on pupae of many distinct families of moths. Contemporary molecular data also argues that *C. pseudomilitaris* distinct from *Cordyceps militaris* (Artjariyasripong et al. 2001). The microscopic characteristics of the non-disarticulating ascospore and host preference for lepidopteran larva of *C. pseudomilitaris* contrasts with the characteristics of *C. militaris* but resemble *C. cardinalis* (Sung & Spatafora 2004). The distinctive characteristics such as ascospores with irregularly spaced septa and non-disarticulating part-spores are used to identify *Blackwellomyces.* Two combinations are made in the genus *Blackwellomyces* i.e., *B. cardinalis* and *B. pseudomilitaris* (Kepler et al. 2017).

Cultural characteristics

The pure colonies isolated on PDA and SDAY are circular, white, umbonate with irregular margin and formed within two days of inoculation and achieving 20–30 mm diameter, release red pigmentation in the medium similar growth observed on PDA + egg but faster than PDA and SDAY (Image 1: g–l).

Previously some workers isolated *B. pseudomilitaris* into pure culture on PDA and MCM (Mushroom complete medium) which produced red pigments in two conditions, shaking and static (Sutthisa & Sanoamuang 2014). The production of reddish pigments diffusing in the agar medium and it can be used to identify species such as *B. aurantiacus*, *B. roseostromatus,* and *B. cardinalis*. *B. calendulinus*, *B. minutus*, and *B. pseudomilitaris* do not produce reddish pigments in agar medium (Mongkolsamrit et al. 2020). In the present study, there is secretion of red pigment by *B. pseudomilitaris* into the medium.

Phylogenetic analysis

Morphologically the present specimen shows similarities to *Cordyceps militaris* with some minor differences. The cultures released a red pigment in the medium. The 564 bp sequence obtained was deposited in the GenBank at the National Center for Biotechnology Information (NCBI) with Accession no. OR259389. GenBank BLAST search sequence showed 98.57% similarity with *Blackwellomyces pseudomilitaris* (MT000700) and 98.55 % similarity with *Cordyceps*

Figure 1. Collections of the genus *Blackwellomyces* from around the world (© GBIF | Global Biodiversity Information Facility).

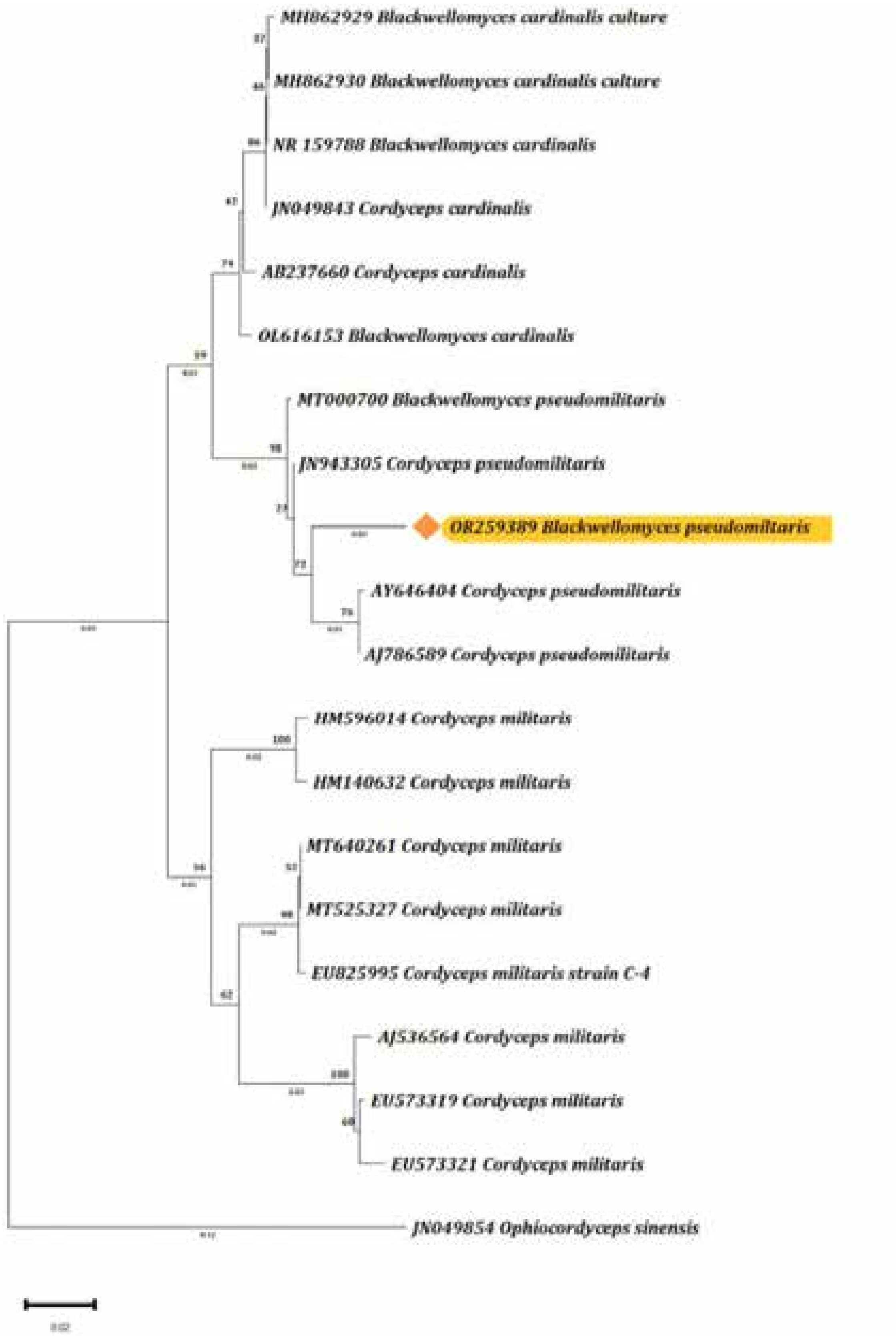

Figure 2. Phylogenetic tree of *Blackwellomyces pseudomilitaris* and other *Cordyceps* species based on rDNA internal transcribed spacer (ITS) sequences with neighbor-joining method with Kimura 2-parameter model with rapid bootstrapping algorithm of 100 replicate and *Ophiocordyceps sinensis* used as an outgroup.

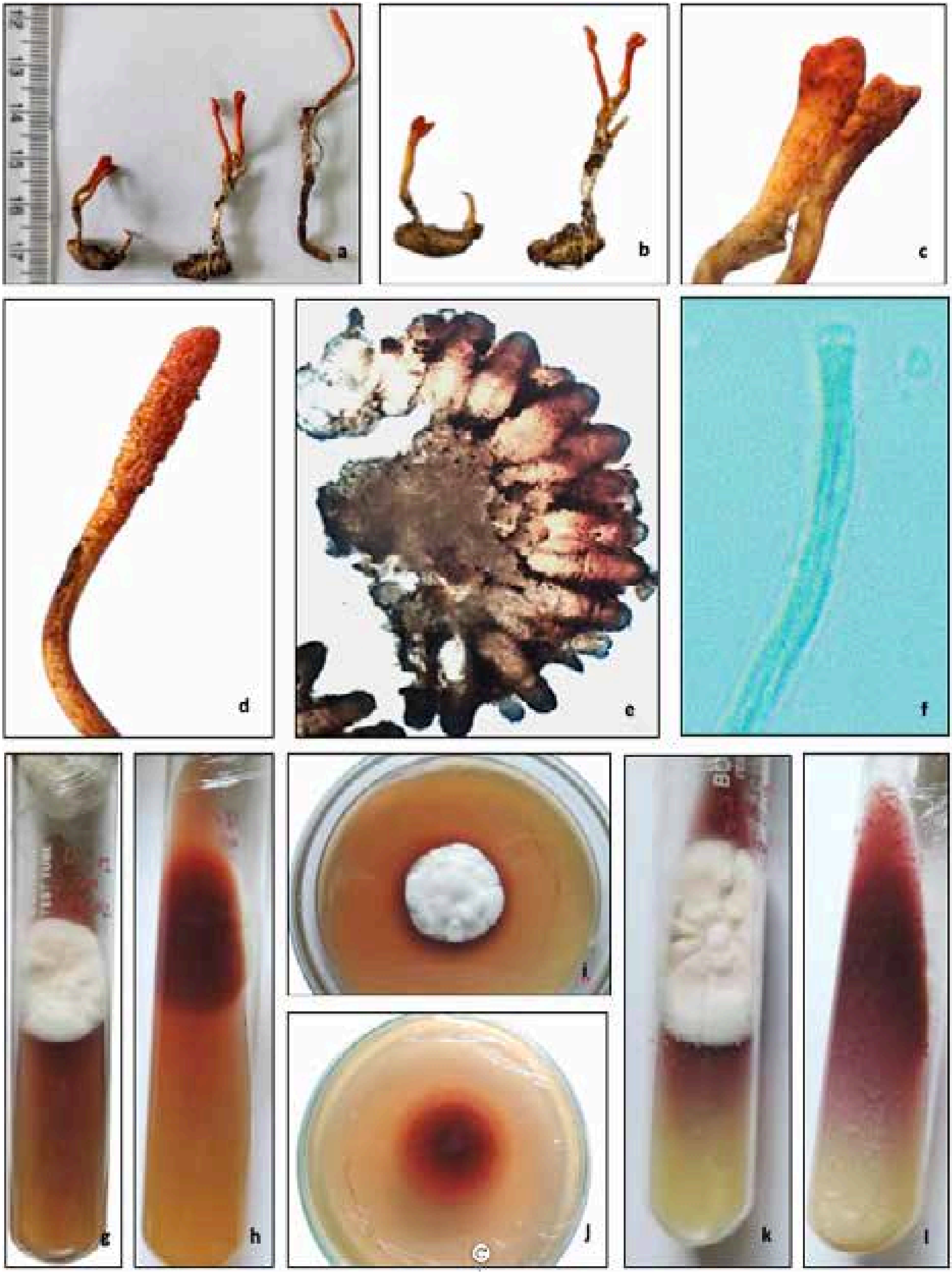

Image 1. ***Blackwellomyces pseudomilitaris*** **(Hywel-Jones & Sivichai) Spatafora & Luangsa-ard: a–b—Habit | c–d—Stromata with semi superficial perithecia | e—Perithecia 10X | f—Ascus 100X | g–h—Pure cultures growing on PDA | i–j—Pure cultures growing on SDAY | k–l—Pure cultures growing on PDA+ egg. © Snehal Biranje.**

pseudomilitaris (JN943305). For phylogenetic analysis, all available ITS rDNA sequences of reference such as *B. pseudomilitaris, B. cardinalis*, and *Cordyceps militaris* were retrieved from GenBank. *B. pseudomilitaris* (MT000700) and *C. pseudomilitaris* (JN943305) show maximum match which indicates that the isolated strain is *Blackwellomyces pseudomilitaris.* All retrieved sequences were aligned using the MEGA11 program. Phylogenetic tree was constructed using the neighbor-joining method with Kimura 2-parameter model in MEGA11 software. Bootstrap analysis was performed with 100 replications to determine and support the match (Figure 2).

Microscopic, cultural, and molecular data clearly indicate that *C. militaris* and *B. pseudomilitaris* are phylogenetically separate species. The present collection shows affinity towards *B. pseudomilitaris*. Thus, this makes a new record to the fungi of India. As it shares a close relation to *Cordyceps militaris* which is one of the important medicinal fungus, further studies will result in exploring the medicinal potential of the present specimen.

Conclusion and future prospective

B. pseudomilitaris is recorded for the first time from India. This species has been only reported from Thailand. It clearly indicates that, it is an extremely rare species. Morphology, microscopy, cultural studies, and ITS rDNA sequencing confirms the identity of the species.

Even though *C. militaris* and *C. cardinalis* show morphological similarity the molecular sequence shows the highest similarity with *B. pseudomilitaris*. Further biochemical characterization of cultures will lead to knowledge about its biological potential.

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OPEN ACCESS

SHORT COMMUNICATION

Calvatia craniiformis (Schwein.) Fr. ex De Toni (Agaricomycetes: Lycoperdaceae): a new puffball mushroom record from eastern India

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Abstract: The present study reports the occurrence of *Calvatia craniiformis*, collected during early monsoon, from the forest floor of Ajodhya Hills, near Teliabhasa village in the Baghmundi Block of Purulia District, West Bengal. The identity of the taxon was revealed through macro- and micro-morphological characterization, followed by nrITS based phylogenetic analyses, representing a first report from eastern India. A detailed description, scanning electron microscopy micrographs and molecular phylogeny are provided.

Keywords: Agaricales, brain puffball, micro-morphology, nrITS phylogeny, SEM, taxonomy.

Calvatia Fr. is a gasteroid fungus belonging to the family Lycoperdaceae F.Bercht. & J.Presl., commonly known as puffball mushrooms. The genus was established in 1859 by Fries and is typified by *Calvatia craniiformis* (originally described as *Bovista craniiformis* Schwein.). It represents a group that includes some of the largest-sized puffballs. The name *Calvatia* is derived from the Latin word 'calvus' meaning 'bald' (Hedavoo 2020). The specific epithet *craniiformis* is derived from two Latin words: *cranion* meaning 'skull' and *forma* meaning 'form', referring to the resemblance of the puffball to a human brain. Consequently, it is also commonly called Skull Puffball or Brain Puffball (Marshall 2003; Hard 2009; Hawkeswood 2019; Gogoi & Kumar 2020). The genus *Calvatia* is characterized by a soft, pyriform to globose, turbinate, and epigeous basidiome; cottony to pulverulent gleba; simple and well-developed subgleba, dehiscence by irregular rupturing of peridium rather than by an apical pore; *Calvatia*-type capillitium, and basidiospores smooth to ornamented (verrucose and echinate) (Krüger et al. 2001; Coetzee & Wyk 2009).

At present, 47 species of *Calvatia* are accepted. *C. craniiformis* has been reported from various countries, including Australia, China, Indonesia, Japan, Malayasia, South Korea, Thailand, and the United States (Jung 1995; Bates et al. 2009; Hosaka & Uno 2012; Hawkeswood 2019; Gogoi & Kumar 2020; Yuwa-Amornpitak & Yeunyaw 2020; Patel & Rajput 2024). In India, approximately 25 species of *Calvatia* have been reported from different regions. Based on their current taxonomic status, only 15 species are accepted, while several have been synonymised with other genera or species (Patel & Rajput 2024). Few reports on *C. craniiformis* from India have been achieved from southern India (Abrar et al. 2008), northeastern India (Gogoi & Kumar 2020), and northern part of Western Ghats (Kshirsagar et al. 2020). Earlier,

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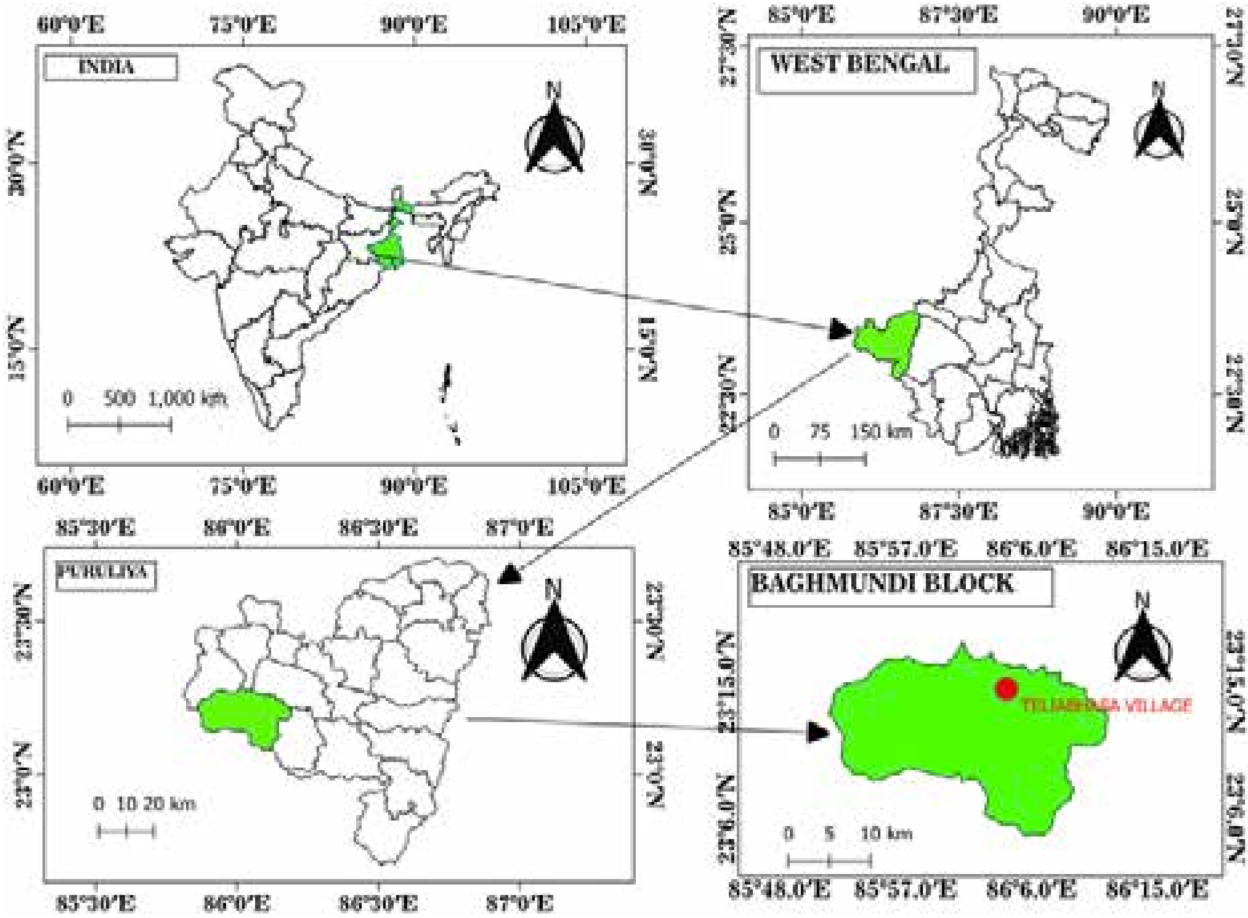

Figure 1. Location of study site on map.

the species has been found growing in humus-rich soil with leaf litter (Hawkeswood 2019), as well as in open ground and meadows (Abrar et al. 2008). Additionally, *C. craniiformis* is recognized as an important source of food and traditional medicine, with reported antifungal properties (Gogoi & Kumar 2020).

In the present investigation, the isolated fungal strain was identified as *Calvatia craniiformis* through combined approach of morpho-taxonomy and molecular phylogenetic characterization and revealed as first report from eastern India.

Materials And Methods

Collection site

The specimen was collected from the dry deciduous, humus-rich forest floor of a sacred groove, 'Jaherthan', near Teliabhasa Village in the Ajodhya Hills, Purulia, West Bengal at an altitude of 647 m (Figure 1). The specimens were found growing either in clusters or scattered during June 2023. Fresh fruiting bodies were sampled, dried and preserved for further studies.

Morpho-anatomical analysis

Macro-morphological and substrate details of fresh, young to mature basidiomata were recorded in the field or at the respective basecamps, including colour, odour, texture, substratum, and size of the basidiomata. Images of the basidiomata were captured by Realme 8, 64MP AI quad-camera. The collected specimens were dried overnight in a hot air oven at 60°C and preserved in sealed plastic bags with silica gel. An herbarium record of the collected specimens was deposited in the Department of Botany, Sidho-Kanho-Birsha University, Purulia. Colour code followed the Methuen Handbook of Colour (Kornerup & Wanscher 1967). Micromorphological characters were observed by preparing free hand sections of dried samples, mounted in a mixture of 3% KOH, 2% Congo Red and observed under the microscope (Leica DM 3000 LED). Images were captured using a digital camera (Leica MC 190 HD). SEM analyses were done to study the ornamentation of basidiospores using the model JEOL JCM-6000 Plus Benchtop. Basidiospores were collected from dried gleba, placed in a water droplet, and mixed gently. The mixture was immediately pipetted onto a cover glass, dried, placed on a stub and coated with the gold (Hansen et al. 1999).

Molecular characterization and phylogenetic tree analysis

Genomic DNA of *C. craniiformis* was extracted from a dried powder sample of basidiomata following Aamir et al. (2015) and amplified using ITS1 and ITS4 as forward and reverse primers, following White et al. (1990). PCR products were purified using the QIAGEN QIA quick PCR Purification Kit and sequenced using the Sanger sequencing method (Kshirsagar et al. 2020). The size of PCR product was estimated by comparing the migration distance of SRAM-220626 to the loaded DNA ladder and confirmed using NEBcutter V1.0 (Vincze et al. 2003). The nBlast program of NCBI (National Centre for Biotechnology Information) database was used to analyze the obtained raw sequences and compare them with available fungal sequences in the database. The dataset was prepared using partial 18S rRNA gene sequence of SRAM-220626 obtained in this study, along with other retrieved sequences from the GenBank database, with *Termitomyces heimii* Natarajan as an outgroup. Sequences were aligned using the ClustalW program in MEGA11 (Tamura et al. 2021). Molecular phylogeny was determined using the RAxML-HPC2 Workflow on XSEDE programme of RAxML v.8.2.10 with a bootstrap value of 1000 (Kantharaja & Krishnappa 2022) and visualized with FigTree software v 1.4.4 (Rambaut 2018). The newly generated sequence has been submitted to GenBank.

Results

Taxonomy

Calvatia craniiformis (Schwein.)
Fr. ex De Toni, Syll. Fung. 7: 106 (1888)
(Image 1 A–D)

GenBank accession number OR185460

Basidiomata gasteroid, 50–80 mm high and 40–70

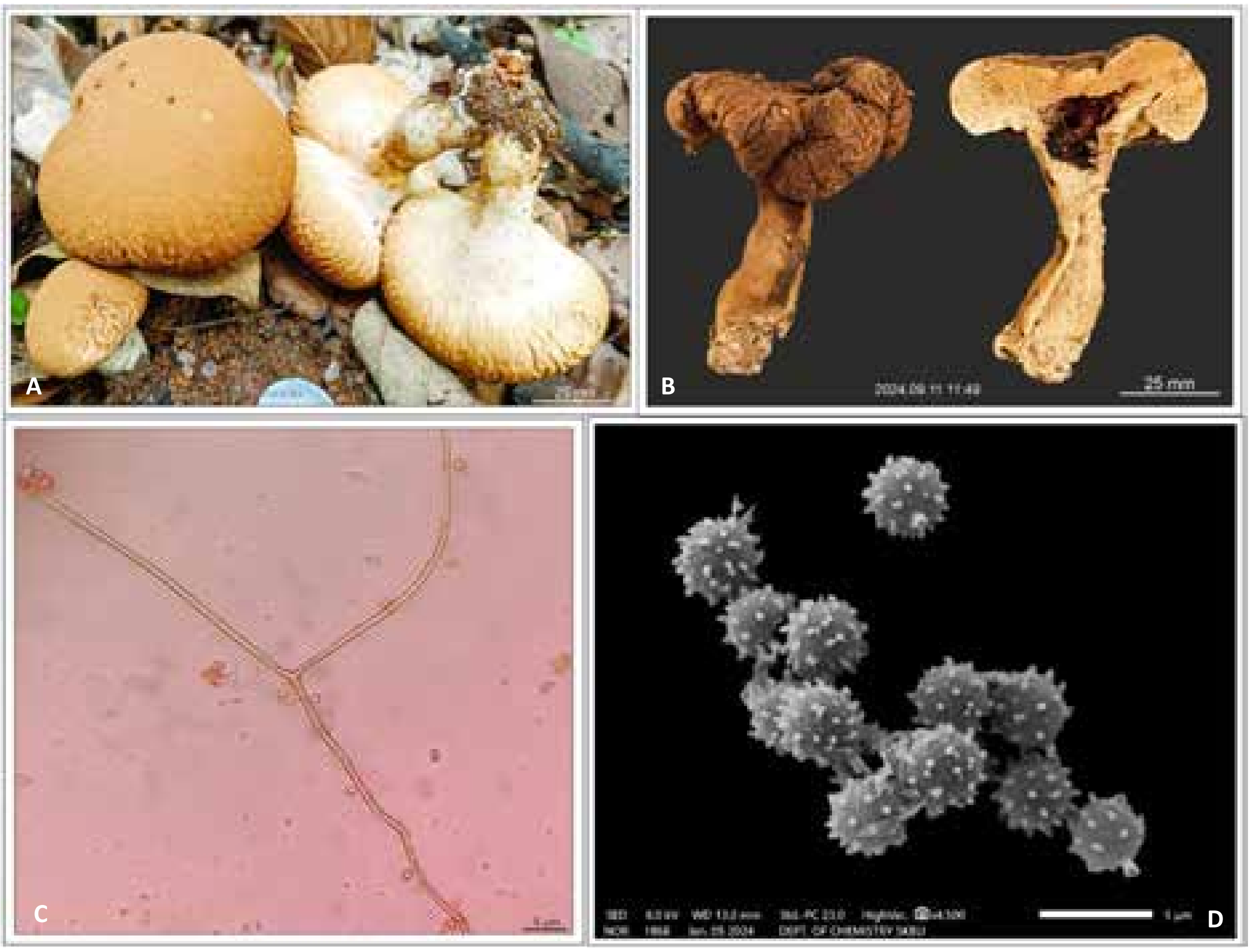

Image 1. Basidiomata, capillitial hyphae and spores of *Calvatia craniiformis*: A—Basidiomata of *Calvatia craniiformis* | B—Gleba of dry fruit body | C—Capillitial thread | D—SEM of spores. © Asit Mahato.

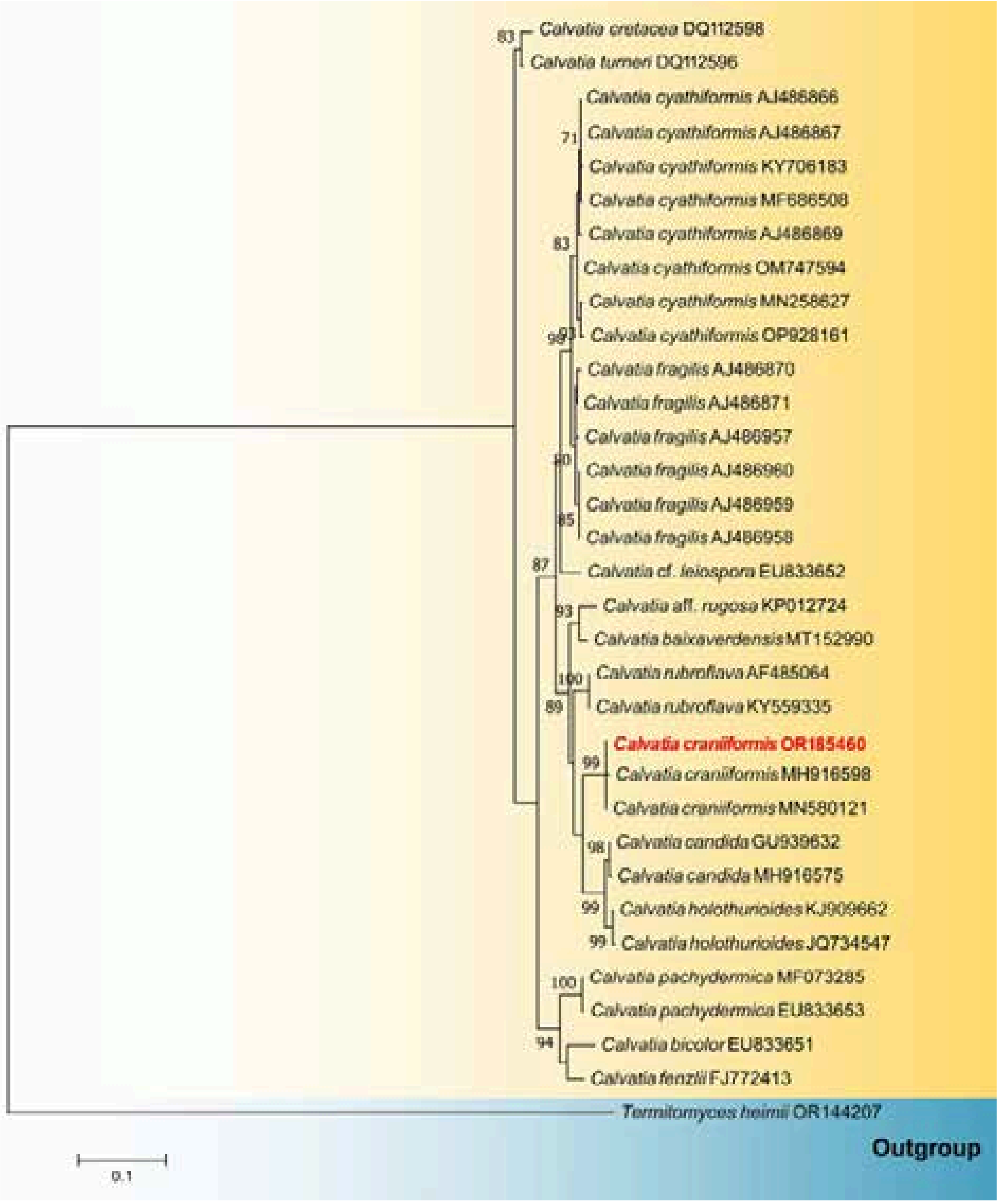

Figure 2. Phylogenetic tree based on 18S rRNA sequence analysis showing genetic relationship among different *Calvatia* species, including isolate *Calvatia craniiformis* SRAM-220626 (OR185460) and *Termitomyces heimii* used as outgroup. The tree was inferred by RAxml programme with 1,000 bootstrap value.

mm broad, epigeous, medium to large-sized, globose to turbinate, dry, low hygrophanous, wrinkled, splitted, lacinate, rivulose, brownish-yellow (5C7) to yellowish-brown (5D8), with an anise-like to unpleasant odor, and a mild taste. Two or more separate fruit bodies arise from a single basal position; ostiole absent. Stipe central, subclavate, glandular-dotted, arid, with moderate basal tomentum, white to brownish, unbranched or branched.

Peridium smooth to wrinkled, folded, and pulverulent. Exoperidium thin, granulose, yellowish-brown, and darker than the endoperidium. Endoperidium papery, white to brownish-white.

Gleba yellowish-white (4A2) to light brown (5D7), solid when young, becoming spongy and cottony at maturity. Capillitia *Calvatia*-type, occasionally branched, light brown, septate 2–4 µm, straight to undulate. Basidia not observed.

Basidiospores (2.3) 2.5–3.5 (3.8) × (2) 2.2–3.1 (3.3), 3.1 ± 0.43 × 2.6 ± 0.73 µm, globose to subglobose, echinulate with spinulose to spinose ornamented under SEM, spines measuring 0.65–0.75 µm in length; pedicellate, with hyaline pedicels.

ITS Sequences and Phylogeny analysis

NEBcutter V1.0 indicated that the length and GC content of the generated sequence are approximately 600 bp and 44.2%, respectively. The BLAST program of NCBI inferred that the strain, SRAM-220626, is closely clustered with *C. craniiformis* CMIS (MN580121) from Thailand and *C. craniiformis* C2 (MH916598) from India. Phylogenetic tree analysis based on nrITS sequences of 52 different *Calvatia* species, along with the Indian isolate of *C. craniiformis*, was conducted using *Termitomyces heimii* as an outgroup (Figure 2). The analysis revealed that *C. craniiformis* CMIS, *C. craniiformis* SRAM-220626 and *C. craniiformis* C2 cluster together in the same clade with a strong ML bootstrap support (MLbs = 99%).

Discussion

Based on a combined approach of macro- and micro-morphological characterization, along with molecular phylogenetic analyses, the Indian collection was confirmed as *Calvatia craniiformis*. The present collection also shows similarities with other Asian collections of *C. craniiformis* from different regions of India, as reported by Abrar et al. (2008), Gogoi & Kumar (2020), Kshirsagar et al. (2020), and mentioned the size of the mature basidiomata as: 50–150 × 60–120 mm, 70–200 × 70–180 mm, and 30–35 × 20–30 mm, respectively. Notably, the size of the mature basidiomata in the present study is relatively smaller than the specimens examined by Gogoi & Kumar (2020) and Abrar et al. (2008) but significantly larger than the collections described by Kshirsagar et al. (2020), while the basidiospores are comparatively smaller than those described by Kshirsagar et al. (2020). This investigation represents the first report of *Calvatia craniiformis* from West Bengal and eastern India, contributing to regional mycological knowledge and expanding the distributional range of the species in the Indian subcontinent.

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OPEN ACCESS

SHORT COMMUNICATION

Rediscovery of the gypsy moth *Lymantria kanara* Collenette, 1951 (Insecta: Lepidoptera: Erebidae) from Kerala, India, after 73 years and its taxonomic redescription

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Abstract: The species, *Lymantria kanara* Collenette, 1951, belonging to the family Erebidae, subfamily Lymantriinae, is a rare taxon considered to be endemic to southern India. Here, we provide information on the recently rediscovered *L. kanara* from Kerala, India, after a 73-year hiatus. Prior to this study, all published research on this taxon was based on catalogues or the type specimens housed in museums with scanty descriptions. Hence, this study provides a detailed taxonomic description of an adult male and its genitalia, to easily identify the species.

Keywords: Agricultural crops, bipectinate antenna, broad sacculus, light trap, Lymantriinae, Lymantriini, male genitalia, Palakkad, rare species, Singappara forest, southern India.

Lymantriinae is one of the enigmatic subfamilies of the family Erebidae due to various reasons such as sexual dimorphism, interspecific variations, and geographical variations. Another important reason for the complexity of the subfamily is that many species are insufficiently illustrated with only a small number of specimens in museum collections. This is a species-rich subfamily in spite of a smaller number of genera (Schintlmeister 2004). Many species of this subfamily are predators of various agricultural crops (Swafvan & Sureshan 2022). This group of moths was earlier placed in the family Lymantriidae, which was then relegated to the subfamily status by Zahiri et al. (2012) based on a molecular and phylogenetic study. Hübner (1819) established the genus *Lymantria*, using *Phalaena monacha* Linnaeus as the type species. It is believed to be distributed in Asia, North America, Africa, and the Indo-Australian tropics, with a higher concentration of species from the Indo-Australian tropics (Holloway 1999). Hampson listed 18 *Lymantria* species from British India including Ceylon and Burma (Hampson [1893]). This genus is currently a member of the subfamily Lymantriinae and tribe Lymantriini. Globally, there are about 167 species grouped into 12 subgenera, i.e., *Porthetria*, *Papuatria*, *Lymantria*, *Beatria*, *Nyctria*, *Syntria*, *Pantria*, *Collentria*, *Spinotria*, *Sarantria*, *Griveaudtria*, and *Pyramocera*. Four species, i.e., *Lymantria nussi* Schintlmeister, *L. vinacea* Moore, *L. todara* Moore, and *L. kanara* Collenette, are listed as endemic to southern India (Schintlmeister 2004). The lectotype of *L. todara*, designated by Gupta (1984), was collected from southern India. Later, reports of *L. todara* from Maharashtra and Goa have been recorded based on the Moths of India website (Sondhi et al. 2024). *Lymantria nussi*, described by Schintlmeister (2004), was distributed in three states: Kerala, Tamil Nadu, and Karnataka. The holotype of the species *L. vinacea* was designated from southern India. However,

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further studies on this species are not available. The species, *L. kanara,* was first described by Collenette (1951) from Kanara, southern India (Kanara was referred to for the western coastal plains of present-day Uttara Kannada and Dakshina Kannada at the time of British India). There is no record of the species after the original description by Collenette (1951).

Schintlmeister (2004), while reviewing the genus *Lymantria*, examined the type repositories and based on the genitalia study, placed numerous *Lymantria* species under a new subgenus, *Collentria*, with *Lymantria grisea* as the type species. This subgenus includes only seven species, viz., *L. grisea* Moore, 1879; *L. cryptochloea* Collenette, 1932; *L. barlowi* Schintlmeister, 1994; *L. caliginosa* Collenette, 1933; *L. fumida* Butler, 1877; *L. fergusoni* Schintlmeister, 2004 and *L. kanara* Collenette, 1951. The species, *L. kanara* has been rediscovered after 73 years in Kerala, India. Hence, a detailed taxonomic redescription of the adult male, along with male genitalia characters is also provided in this paper. This study represents the only record of the species apart from the holotype designated by Collenette (1951).

Figure 1. Collection site of *Lymantria kanara* in Kerala, India.

Materials and Methods

The adult male specimen was collected from the Singappara forest range (Collection permit no. KFDHQ-3342/2023-CWW/WL10), Palakkad District, Kerala on the 29 February 2024 (10.975 ^{0}N, 76.642 ^{0}E) (Figure 1). The collection was done using the light sheet trap method. The collected specimen was pinned, dried, labeled, and deposited in the insect collection of Entomo Taxonomy Lab (ETL), Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala. Genitalia preparation follows the method of Robinson (1976). The genitalia was examined under the Labomed Luxeo 4D stereozoom microscope and identified based on the original description by Schintlmeister (2004). The ArcGIS software version 10.8. was used to generate the specimen collection locality map. The terminology followed for morphological description is based on Hampson ([1893]), Holloway (1999), and Schintlmeister (2004).

Results

Systematic status
Superfamily: Noctuoidea Latreille
Family: Erebidae Leach, 1815
Subfamily: Lymantriinae Hampson, 1893
Tribe: Lymantriini Hampson, 1893
Genus: *Lymantria* Hübner, 1819
Subgenus: *Collentria* Schintlmeister, 2004
Type Species: *Lymantria kanara* Collenette, 1951

Lymantria kanara Collenette, 1951

Holotype: Southern India, Kanara, in British Museum of Natural History, London

Lymantria kanara Collenette, 1951. Some new species of Lymantriidae in the British Museum (Natural History) Ann. Mag. Nat. Hist. (12) 4 (46).

Material examined: 1 Male, India, Kerala, Singappara, Palakkad District, 10.975 ^{0}N, 76.642 ^{0}E; 960 m; 29-ii-2024; Adarsh P.K., CZR1000.

Redescription of Male (Image 1): Wing expanse 3.5 cm. Forewing length 1.6 cm. Head small, ochreous brown, frons and vertex, dark brown; ridge between vertex and collar white; collar dark brown; tegula with white and grey hairs; eyes smooth and black; palpi stout, clothed with brown and grey hairs, palpi dark brown near to compound eyes; third segment of palpi upright and comparatively large; proboscis well developed; antennae brown with long and thick bipectinations with pinkish hairs at base; abdomen covered with pale pinkish hairs and without lateral black-brown spots; fore legs and mid legs densely covered with light brown hairs except tarsus; hind leg with two pairs of

Image 1. Habitus of male *Lymantria kanara* (CZR1000). © ET Lab, Zoology Department, Christ College.

tibial spurs and comparatively with less hairs; forewing short and broad, apex rounded, outer margin (termen) elongated, inner margin (dorsum) short; ground colour brownish with two distinct black spots on tornus and discal area; costa with eight distinct black patches, 4th medial and 5th antemedial black patches comparatively large and prominent; area between medial costal marking, antemedial costal marking and the discal spot relatively dense with black scales; an obscure basal and sub-basal wavy blackish band present, subterminal and terminal wavy blackish bands well defined; termen with alternative clusters of black and greyish hairs from apex to tornus area; hindwing ground color pale grey with black shade towards terminal area, anal margin densely haired with pinkish tinge, cilia whitish-grey. Underside without bands, markings on costa and outer margin intact, base of costal margin with few pinkish hairs; forewing vein Cu1, M3 and M2 arising close to lower angle of cell and M1 from below upper angle, radial veins (R1, R2, R3 and R4) stalked; hindwing Cu1, M3 and M2 arising close to lower angle of cell, M2 and R from upper angle.

Male genitalia (Image 2): Small and stout structure. Uncus well sclerotized and pointed at tip, minute hairs present on lateral side; tegumen with a spine-like process pointing towards valvae ventrally; valvae coalesced, basal part (sacullus) moderately sclerotized and broad with two major dorsal and ventral processes distally; dorsal digitiform process with pointed end relatively longer than the spine-like processes on tegumen; ventral process broad at the base, distally tapering towards one side with a hooked tip; small lateral ridge near the base of valvae possess longer hairs pointing posteriorly; vinculum elongated; saccus 'v' shaped; aedeagus short, stout and slightly curved without spines.

Discussion

Lymantria kanara can be easily distinguished from other congeners by the presence of long and dense brown bipectinate antennae. The presence of distinct black spots on the tornus and discal area is another striking, distinctive character. Broad and strong sacculus is the unique male genitalia character of *L. kanara*. *Lymantria kanara* can be easily differentiated from other endemic species by the following features: a) an extensive black area is present in the post-basal and post-medial region of costa in *L. nussi* which is absent in *L. canara*; b) forewing of *L. todara* is pure white with prominent black markings and with yellowish-white abdomen; in *L. kanara* forewing is not pure white with black markings and abdomen is covered with pale pinkish hairs. Based on the data available, the known distribution of *L. kanara* can be more precisely stated as Karnataka and Tamil Nadu (Schintlmeister 2004). Through this study, Kerala is added as a new distribution record for this rare species.

Image 2. Male genitalia of *Lymantria kanara*. © ET Lab, Zoology Department, Christ College.

Conclusion

After 73 years, the species *L. kanara* has been rediscovered, and recorded for the first time in the state of Kerala, India. All published information on this species before this study was based on Collenette's original research or type specimens deposited in museums with minimal annotations. Therefore, this work presents a thorough taxonomic redescription of the adult male along with characteristics of its genitalia. This study is the sole known account of the species outside of the type designated by Collenette in 1951.

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SHORT COMMUNICATION

Nest predation by *Vespa tropica* (Linnaeus, 1758): observational insights into polistine wasp defense and hornet feeding behavior

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Abstract: *Vespa tropica* (Linnaeus, 1758) is a known predator of polistine wasps, actively hunting them to provision its larvae. This study reports two separate instances of *Vespa tropica* Greater Banded Hornet predation on the nests of two polistine wasp species, the Arabian Paper Wasp *Polistes* (*Gyrostoma*) *wattii* Cameron, 1900 and *Ropalidia brevita* Das & Gupta, 1989, in Uttarakhand, India. While the predatory behavior of *Vespa tropica* on different species of *Polistes* and *Ropalidia* has been well-documented in previous studies, this is the first photographic record of nest predation attempts on *Polistes wattii* and *Ropalidia brevita*. Additionally, the study documents the first known successful defensive counterattack by a prey species *Polistes wattii*, providing novel insight into the defensive capabilities of prey species against hornet predation.

Keywords: Brood raiding, cocoon, exoskeleton, Greater Banded Hornet, *Polistes*, paper wasp, predator-prey dynamics, prepupae, *Ropalidia*.

Vespa tropica (Linnaeus, 1758) (Hymenoptera: Vespidae), known as the Greater Banded Hornet, is widespread across southeastern Asia (Archer 1991; Carpenter & Kojima 1997). Historically, this species was confused with *Vespa affinis* Linnaeus 1764, both of which were initially recorded under *Vespa cincta* Fabricius 1775. Bequaert (1936) clarified their distinction, recognizing eight different color forms. More recently, *Vespa tropica* has been categorized into three species, collectively forming the *Vespa tropica* superspecies group (Archer 1991). The Indian subcontinent houses the subspecies *Vespa tropica haematodes*, which is the subject of this study.

Matsuura & Yamane (1984) conducted extensive research on vespine wasps, primarily focusing on temperate subspecies from Japan. Due to its broad geographic distribution, *Vespa tropica* exhibits notable morphological and behavioral differences between its tropical and temperate subspecies (Matsuura & Yamane 1984). While the ecology of *V. tropica* has been studied by many people, significant knowledge gaps persist regarding its populations in the Indian subcontinent.

Vespine wasps are highly predatory, consuming two primary food sources: carbohydrates (tree sap, nectar) and solid protein-based food (flesh pellets), which are exclusively fed to larvae (Matsuura & Yamane 1984). Among the vespine species, *Vespa tropica* is notably specialized, preying mainly on the larvae and pupae of polistine social wasps (Matsuura & Yamane 1984). Documented prey includes *Ropalidia* spp. Including *Ropalidia fasciata* (Fabricius, 1804); *Parischnogaster mellyi* (de Saussure, 1852); *Stenogaster* spp.; *Polistes stigma* (Fabricius, 1793); *Polistes snelleni* (de Saussure, 1862); *Polistes japonicus* de Saussure, 1858; *Polistes mandarinus* de Saussure, 1853; *Polistes jadwigae*

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Dalla Torre, 1904; *Polistes rothneyi* Cameron, 1900; *Polistes chinensis* (Fabricius, 1793); *Polistes hebraeus* Fabricius, 1787 (syn. *Polistes (Gyrostoma) olivaceus* De Geer, 1773); *Polistes jokohamae* Radoszkowski, 1887; *Parapolybia varia* (Fabricius, 1787); and *Parapolybia indica* de Saussure, 1854. There are also instances of *Vespa tropica* preying on the pupae of other *Vespa* species, such as *Vespa simillima* Smith, 1868 (van der Vecht 1957; Matsuura & Yamane 1984; Chakrovorty et al. 2023). On one occasion, this species was observed attempting to break open the mud chambers of a mud dauber wasp *Sceliphron javanum* Lepeletier, 1845 (van der Vecht 1957). Though specialized in wasp predation, *V. tropica* also preys on other insects like Skipper Butterflies (Hesperiidae), pyralid and arctiid moths, and caterpillars of *Tarsolepis sommeri* (Hübner, 1821) (van der Vecht 1957; Matsuura & Yamane 1984). Given the predatory nature of *Vespa* species on bees (Singh 1962) *Vespa tropica* is likely to prey on various bee species in regions where their habitats overlap. While some reports suggest its predation on bees, well-documented scientific studies on this interaction remain limited. Additionally, *V. tropica* feeds on tree sap, fruits, sugary substances, and carrion (van der Vecht 1957). Little is known about the foraging behavior of the Indian subspecies *V. tropica haematodes*, though it has been recorded attacking skipper butterflies, as well as *Polistes hebraceus*, *P. stigma*, and *P. olivaceus* nests in India (Bequaert 1936; van der Vecht 1957; Chakravorty et al. 2023).

Results and Discussion

A combative interaction between a solitary *Vespa tropica* and a *Polistes wattii* was observed on 21 September 2024, around 1030 h. *Polistes wattii* species was identified based on its all yellow body with no black even on the medial part of dorsal sulcus of clypeus as described by Tan et al. (2014) (Supplementary image 1). The hornet, known for its predatory behavior on *Polistes* species, was seen engaging in an intense encounter with the wasp, eventually emerging victorious (Image 1, Video 1). This occurred under an active *P. wattii* nest on the Hemvati Nandan Bahuguna Garhwal Central University, Chauras campus in Uttarakhand (30.228°N, 78.804°E). Based on observations over the next two days, it was inferred that while the hornet managed to subdue multiple adult wasps and larvae, the paper wasps eventually succeeded in neutralizing the hornet by day two.

The interaction between *V. tropica* and *P. wattii* lasted around 10 min, after which the hornet started consuming the thoracic region of the wasp, chewing it into softer pellet (Image 3). Interestingly, unlike prior reports (van der Vecht 1957), the hornet did not sever the wings or transport the wasp, indicating that the hornet was not primarily targeting adults for consumption but

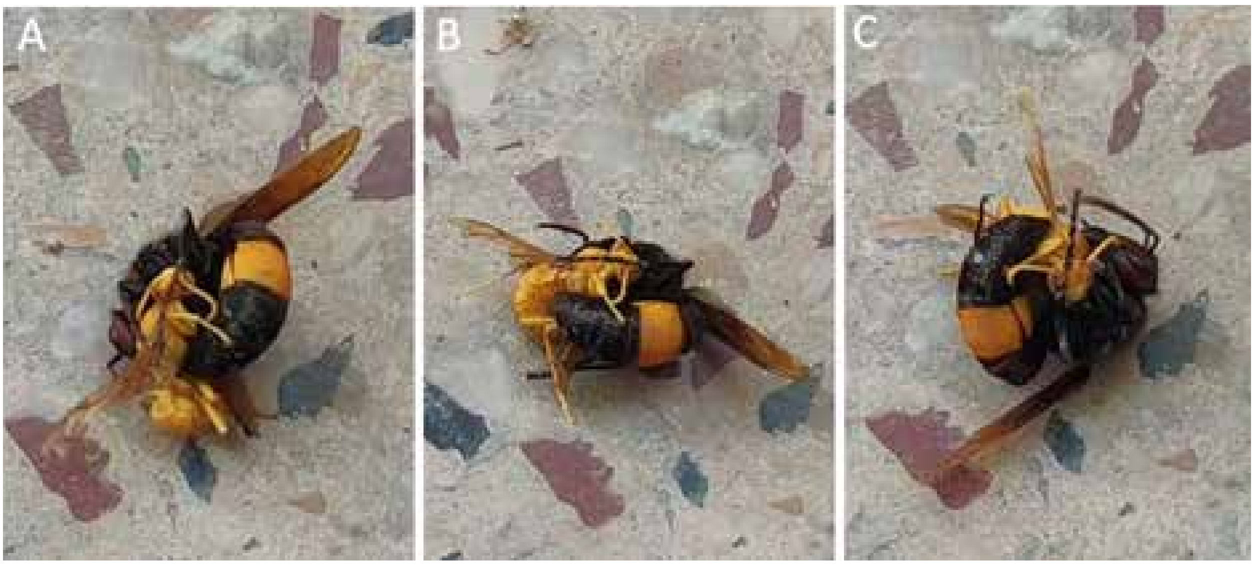

Image 1. Violent interaction of *Vespa tropica* and *Polistes wattii*: A—the *Vespa tropica* can be seen engaging in a physical confrontation with *Polistes wattii*, using its robust mandibles and forelegs to secure the wasp while simultaneously seeking a vulnerable area for stinging | B—despite being overpowered, the *Polistes wattii* maintains a firm grip on one of the hornet's front appendages and attempts to deliver a sting in defense | C—the hornet successfully subdues the wasp, delivering a sting between the sternites, and proceeds to consume the thoracic region by chewing through it. © Vartika Negi.

was rather involved only in the counterattack by the wasp. Additional evidence of resistance was supported by the discovery of four other dead *P. wattii* wasps near the nest. This suggests some level of defensive action on behalf of the wasps during the raid.

The observation revealed that the hornet revisited the nest multiple times over two days, twice on day one and thrice on the second day, seizing larvae every time with minimal resistance from the adult wasps. On the first day, after its initial successful attack, the hornet returned at approximately 1240 h. The wasps displayed panic but did not resist; they vacated the nest (Image 2), allowing the hornet to feed without hindrance, which is consistent with the behavior described by Matsuura & Yamane (1984). The next day we saw the hornet return at 1110 h with the same intent and with the same results repeating its charge two more times taking home five pupae or larvae during the observation period (Image 2). On the third day, the hornet was found dead near the nest, with no visible bite marks. It is hypothesize that

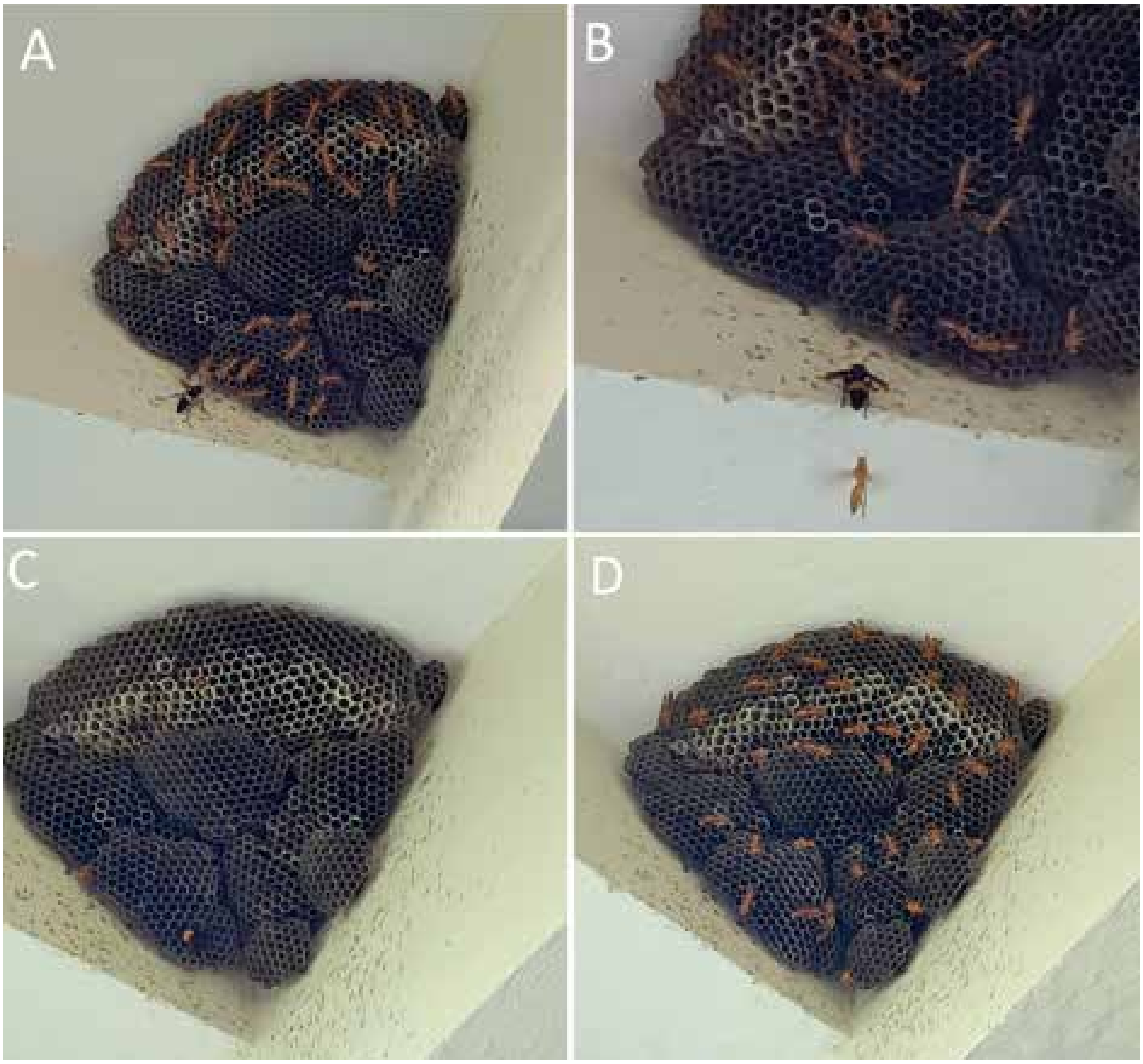

Image 2. Nest predation by Vespa tropica on a huge nest of Polistes wattii: A—the hornet approaches the large Polistes wattii nest cautiously, causing the adult wasps to become highly alert to the impending threat | B—during a subsequent visit, the hornet causes renewed agitation among the adult wasps, which exhibit defensive behavior but do not engage directly | C—the wasps vacate the nest as soon as the hornet starts ripping through the pupae, upon the hornet initiating its attack, tearing open pupal chambers, the adult wasps vacate the nest in an apparent escape response | D—once the hornet has consumed its prey and departs, the wasps gradually return to their nest, resuming normal activities. © Vartika Negi.

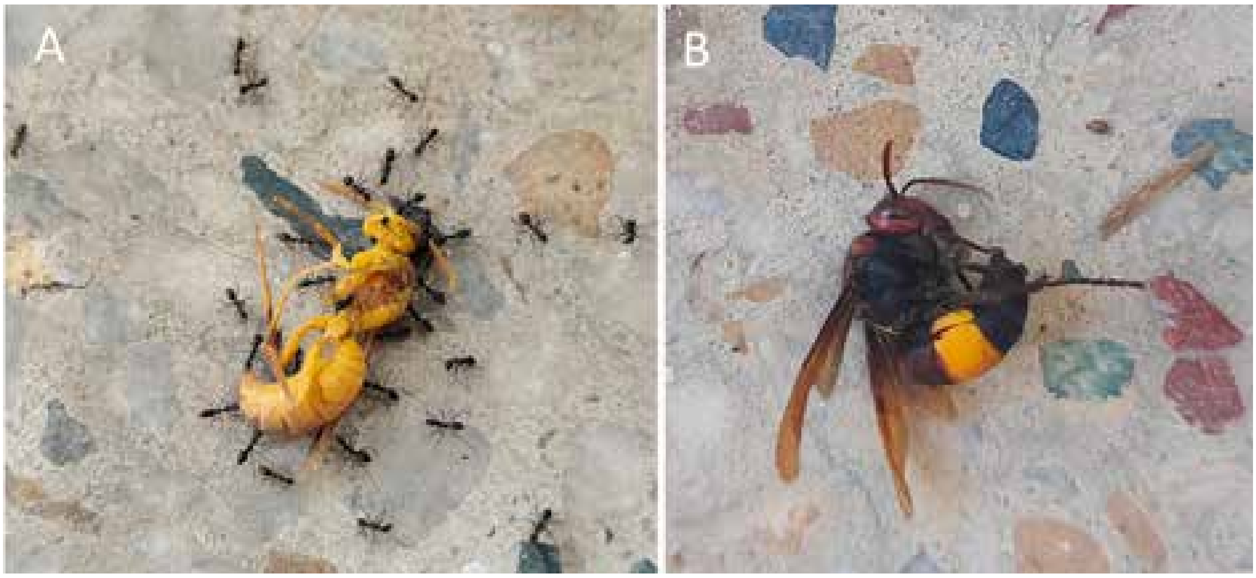

Image 3. The dead bodies of both species during the 3-day tussle: A—the deceased body of a *Polistes wattii* wasp that engaged in a fight with the *Vespa tropica* hornet. Note the damage to the thoracic region, which has been partially consumed by the hornet. Also, it was carried away by *Paratrechina longicornis* ants within minutes after its death. B—the remains of the *Vespa tropica* hornet, presumably killed by the *Polistes* wasps during a counterattack. No external bite marks were visible, suggesting death by stinging. © Vartika Negi.

Image 4. Nest predation by *Vespa tropica* on a huge nest of *Ropalidia brevita*: A—the *Ropalidia brevita* nest a week before the hornet attack, showing a healthy, undisturbed colony | B—the large *Vespa tropica* hornet positioned directly over the sealed brood chambers, displaying indifference to the presence of the smaller *Ropalidia* wasps. Notably, the paper wasps remain in close proximity to the hornet without showing any resistance or vacating the nest | C—the hornet using its mandibles and front legs to consume the soft pre-pupa, efficiently breaking down the tissue for ingestion | D—the nest after hornet's departure, note that nest exhibits multiple torn seals on several pupal chambers, clearly illustrating the extent of the damage caused by the predation event. © Vartika Negi.

the hornet may have been fatally stung by a paper wasp, capable of penetrating through its tough exoskeleton, thus successfully defending the colony. Following this event, the nest was repopulated by the paper wasp individuals, and no further hornet incursions were observed for the day.

In another event on 8 October 2023, a *Vespa tropica* was observed raiding the nest of a *Ropalidia brevita*, identified by its proportionally wider first metasomal tergum as described by Kojima et al. (2007) in Chandrabani area of Dehradun, Uttarakhand India (30.278° N, 77.971° E) (Image 4, Video 2). The *Ropalidia* wasps offered no significant resistance, allowing the hornet to repeatedly raid their brood and successfully consume larvae over several visits. As described by Matsuura & Yamane (1984), the hornet appears to assess the developmental stage of the pupae inside the cocoons using its antennae it was also observed that the hornets preferred the prepupae more than the already developed ones, it was tearing open the cocoon covers to extract the prepupae chewing it into a liquid form, and leaving behind a hollow husk, which fell beneath the nest. Throughout this process, the hornet remained suspended by its two pairs of hind legs, while using its forelegs and mandibles to extract the pupae. Similarly, the hornet made several raids to the nest uninterrupted and consumed the entire young lot until the whole nest was empty in a few days. This predation event ultimately led to the abandonment of the nest by the remaining paper wasps.

Conclusion

Vespa tropica predation on polistine species, particularly targeting pre-pupae, larvae, and pupae, is well-documented. While studies by Matsuura & Yamane (1984) suggests that *V. tropica* typically avoids adult wasps, the study observed the hornet engaging in combat with adult *Polistes wattii*, this inclines well with the observations mentioned by Van der Vecht (1957), in this case the hornet didn't fly away with the wasp and instead both fell from the nest during combat, which offered notable resistance and eventually killed the hornet—an unprecedented event. In contrast, *Ropalidia* wasps showed minimal defense.

These interactions add new prey records for *V. tropica* as predation on *P. wattii* and *R. brevita* is not mentioned in prior studies. Moreover, the observation of *V. tropica* feeding on an adult *P. wattii* is an unprecedented addition to the species' known predatory behavior. Although this behavior might have resulted as a response to the counterattack rather than an intentional predation on adult wasps, it adds a new dimension to the understanding of this hornet's diet. Furthermore, the successful counterattack by *P. wattii* represents a significant and novel observation, indicating that prey species may possess more advanced defensive strategies than previously recognized. This underscores the need for a more detailed study of *Vespa tropica-Polistes* interactions, particularly in the Indian subcontinent, where ecological variations may influence predator-prey dynamics.

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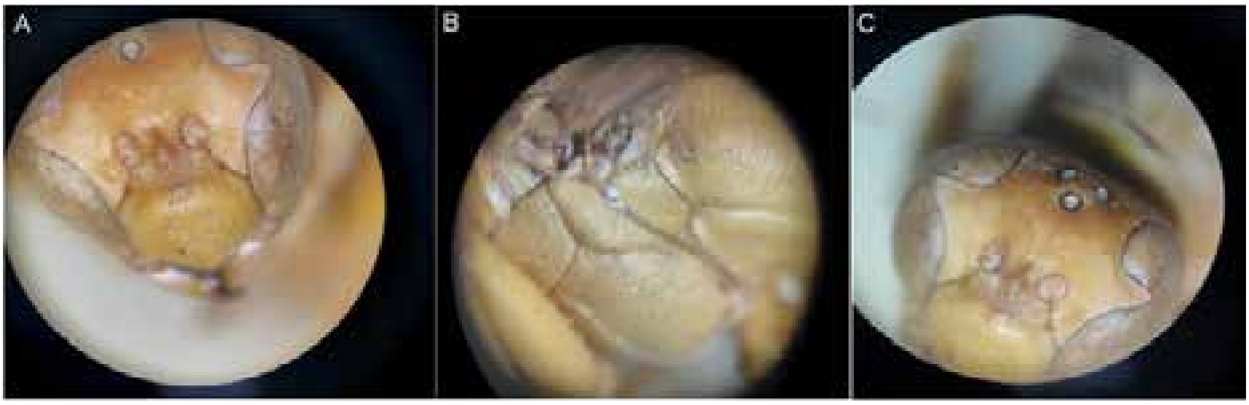

Supplementary Image S1. *Polistes wattii* Cameron, 1900: A–C—No black pattern in the dorsal sulcus of the clypeus | B—The mesopleuron weakly and sparsely punctate medially with no black pattern. © Vartika Negi.

Video 1. Violent interaction between *Vespa tropica* and *Polistes wattii*. © Vartika Negi.

Video 2. Nest predation by *Vespa tropica* on a huge nest of *Ropalidia brevita* © Vartika Negi.

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SHORT COMMUNICATION

The discovery of a male Malay Crestless Fireback *Lophura erythrophthalma* (Raffles, 1822) (Aves: Galliformes: Phasianidae) at Ulu Sat Forest Reserve, Machang, Kelantan, Peninsular Malaysia

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Abstract: A study was conducted in the Ulu Sat Forest Reserve, Machang to record the presence of terrestrial vertebrate animals by using the camera trapping method from April 2023 until May 2023, and seven camera trap units (Reconyx Hyperfire) were used. During the study, a male Malay Crestless Fireback *Lophura erythrophthalma* was recorded. This discovery is considered something important and needs to be documented because this species has been classified as 'Critically Endangered' by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. We believe that the record of this species can increase efforts in the management and conservation of the area.

Keywords: Avian conservation, biodiversity assessment, camera trapping survey, critically endangered species, forest reserve management, ground-living birds, habitat restoration, terrestrial fauna.

Lophura erythrophthalma is a galliform, endemic to Peninsular Malaysia and Sumatra, Indonesia (del Hoyo et al. 1994; Johnsgard 1999). There are few records from Borneo, where it appears to be rare and localized, especially in the southwestern side (Holmes 1989; Wilkinson et al. 1991a,b). Additionally, there are several records from Sumatra, namely from the Riau and Jambi regions (van Marle & Voous 1988; Danielsen & Heegaard 1995; eBird 2021). It is not a widespread species and appears to be localized, indicating a moderately small population size.

This species was once recorded to have a relatively high density of six individuals/km^2 in Peninsular

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Malaysia (Davison & Scriven 1987; Johnsgard 1999). It is unclear whether current pressures such as hunting and fragmentation allow such densities to persist anywhere. A recent three-month camera trap study in Peninsular Malaysia (August–October 2019) in a supposedly suitable habitat recorded only captures from 12 locations (totaling the equivalent of 542 days of survey effort) (Hamirul et al. 2021). Establishing robust population estimates for this species should be considered a priority, as well as clearly identifying patches of forest that still exist.

According to Wells (1999) and Eaton et al. (2016), *L. erythrophthalma* prefers lowland, primary, and well-regenerated, closed canopy and evergreen forests, below 300 m. This species has been found to tolerate lightly logged forests or selective logging (Danielsen & Heegaard 1995; Johnsgard 1999; Hamirul et al. 2021). Precise details about this species' habitat preferences and ecological interactions with another similar species, *L. rufa*, are lacking. According to Wells (1999), when *L. rufa* is present, *L. erythrophthalma* appears to avoid valley-bottom habitats. The population of *L. rufa* was found to increase especially in slope areas where *L. erythrophthalma* looks to be excluded and these two species look to have habitat ranges that do not overlap with each other (Johnsgard 1999; Wells 1999).

In 2000, the population of this species appears to have fallen drastically from a suspected 10,000–19,999 mature individuals, even though there are no reliable estimates (BirdLife International 2024). The main threats to this species are habitat loss, degradation, and fragmentation due to large-scale clearing for oil palm plantations and to a lesser extent, rubber and timber.

In this article, the presence of a male *L. erythrophthalma* inhabiting the isolated Ulu Sat Forest Reserve in Machang District, Kelantan, Peninsular Malaysia was reported. It was recorded by a camera trap used for the initial observation of terrestrial vertebrate animals at the location. This discovery is expected to encourage the conservation efforts of *L. erythrophthalma* and the forest reserve area.

Study area

The study focused on the collection of terrestrial vertebrate animal data in the Ulu Sat Forest Reserve from April 2023 to May 2023. This forest is a protected area located in Machang District, Kelantan in Peninsular Malaysia (Image 1). The type of forest in the Ulu Sat Forest Reserve area is a thick tropical rainforest consisting of dipterocarp hills and lowlands. This site is an ecologically important forest habitat for the watershed in Kelantan. It also plays an important role in ecotourism because it receives visitors for recreational activities throughout the year (Hazizi et al. 2020). In addition, it is also connected to the Greater Taman Negara Complex on the east side. The size of the Ulu Sat Forest Reserve is about 148 km^2. This forest is also famous for its rich biological diversity which has been proven as a result of the Ulu Sat Scientific Expedition carried out on 11–15 August 2018 (Radhi et al. 2020). Preserving the integrity of the Ulu Sat Forest Reserve is essential to safeguarding its unique biodiversity and supporting a sustainable ecosystem in the area.

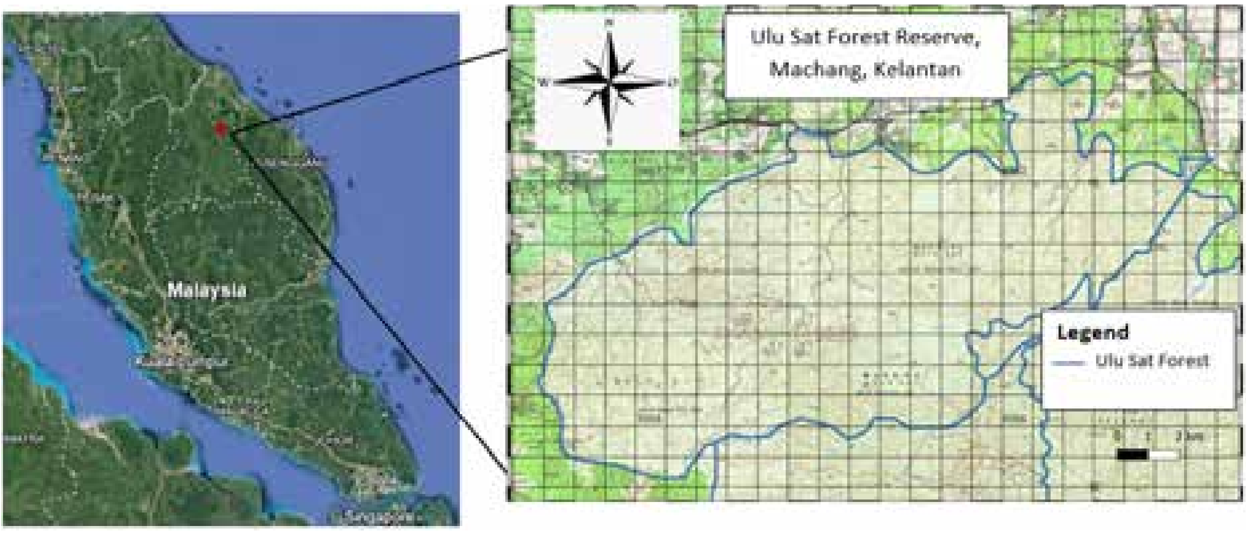

Image 1. Study area

Material and Methods

In this study, seven camera trap units (Reconyx Hyperfire) were installed at a spacing of 2 km in Ulu Sat. The distribution of camera traps is on the east side of Ulu Sat. A total of two camera traps have been placed in the valley area, four camera traps in the slope area, and one more camera trap at the peak. Camera traps were placed on trees bordering animal paths at a height of approximately 0.5 m above the ground to permit the detection of medium and large-sized mammals (Jansen et al. 2014). The camera traps were programmed at a one second interval between three series of image and equipped with 16GB SD capacity cards. The location of each camera was recorded with a Global Positioning System (Garmin GPSMAP 64s).

Results

The camera traps installed in the study area recorded 41 images of terrestrial vertebrates from the period starting from April 2023 until May 2023 (48 days). On 17 May 2023, four consecutive images show a male *Lophura erythrophthalma*. Out of the four consecutive images, the best one was selected at 0943 h (Image 2). Around the capture location is composed of plants such as *Artocarpus elasticus*, *Endospermum diadenum* and *Xylopia ferruginea*. The presence of some types of these plants were found to support the presence of other vertebrates species. Among other vertebrates species that have also been photo-captured at the same trap location were Common Barking Deer *Muntiacus muntjac*, Wild Boar *Sus scrofa* and White-thighed Surili *Presbytis siamensis*, showing the use of sympatric habitats.

Discussion

A photo of an adult male Malay Crestless Fireback *Lophura erythrophthalma* in the lowland forest was recorded on 17 May 2023 at 0943.31 h, flat land with medium to large trees separated from each other (less dense) and dim because they are protected by the tree canopy. This study supports the findings of Wells (1999) and Eaton et al. (2016) who stated that *L. erythrophthalma* likes to inhabit lowland and closed canopy areas and evergreen forests. The photo is not very full, but adequate to allow identification. For male *L. erythrophthalma*, it has fine vermiculation on the wings, orange (flame) back, purple back, and pale orange tail (Image 3) (eBird 2021).

The discovery of this species is felt to be very important and needs to be documented because *L. erythrophthalma* has been categorized as Critically Endangered after being re-evaluated on 21 September 2021 by the IUCN Red List of Threatened Species (BirdLife International 2022). This is because the habitat loss factor in the range of this species is rapid and as a species that is completely dependent on ground-level forests. Apart from that, the fragmented forest has also

Image 2. A male Malay Crestless Fireback *Lophura erythrophthalma* photographed at Ulu Sat Forest Reserve, Machang, Kelantan.

Image 3. Full picture of a male Malay Crestless Fireback *Lophura erythrophthalma* by Neoh Hor Kee: Image provided by eBird (www.ebird.org) and created [01 August 2022]. © Neoh Hor Kee.

opened up access to smaller patches of forest for hunting activities. Combining all these threats, the population of *L. erythrophthalma* is showing a faster decline pattern and if it is not contained and restored early it may be at great risk of extinction (BirdLife International 2022).

According to Savini et al. (2021), the Thai-Malay Peninsular's plains are losing forest at a very fast rate, and this loss is accompanied by fragmentation effects that raise the risk of extinction and hunting activities. This species is suspected to have suffered a severe decline in recent times due to habitat loss and hunting, to the extent that the population size is now considered much lower (no firm estimates can be made). Finding robust population estimates for this species needs to be considered important and prioritized, as well as clearly defining patches of forest that still exist for management and conservation efforts.

Of the 41 independent images recorded throughout the study, only one independent image (2.44%) of *L. erythrophthalma* (as part of four image sequences) indicated that the *L. erythrophthalma* species is relatively rare in the forest reserve. Dedicated work on this species' ecology is required to ascertain its true status.

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NOTE

New distribution record of *Korthalsia rogersii* Becc, a threatened endemic climbing palm of Andaman archipelago

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Sunda shelf holds a large number of palm species, also embraces a significant diversity of climbing palms (rattans) of the subfamily Calamoideae, which comprise eight genera (Baker et al. 2000; Vorontsova et al. 2016). Among these, the unique and conspicuous genus *Korthalsia* Blume (Arecaceae: Calamoideae: Calameae) has diversified with 28 species in the perhumid areas of Andaman & Nicobar Islands to New Guinea (Dransfield 1981). The Andaman archipelago harbors only two species of *Korthalsia*, the widespread *K. laciniosa* and the endemic species *K. rogersii* (Figure 1). The rest of the species are distributed across the Malesia region (Manohara et al. 2010; Shahimi 2018). Beccari (1918) used the type specimens of *K. rogersii* collected by C.G. Rogers from the South Andaman Islands in 1904 to describe the species; based on this specimen, Brandis (1906) also indicated the presence of the species in Andaman Island (Dransfield 1981; Mathew et al. 2007). Initially, the species was thought to be a miniature form of *K. laciniosa*. However, unique morphological characteristics of the species such as unarmed leaf sheath, ocera, slender & tementos rachilla and comparatively larger fruit size make the species morphologically more distinct from *K. laciniosa* and closer to *K. concolor,* a native species in Sabah, northern Borneo (Dransfield 1981). However, identification of the specimen of *K. rogersii* used for the study is provisional, the species has been found closer to *K. lanceolata* in the recent molecular systematics & evolutionary analysis (Shahimi 2018). A century after its initial collection, the species was again reported from Chidiyatapu, South Andaman in 1993 as part of the Flora India project. Further, living specimens of the species were relocated to the Jawaharlal Nehru Tropical Botanic Garden and Research Institute (JNTBGRI) and Kerala Forest Research Institute, Kerala, India, from its original location. Even though the species description was provided by Beccari (1918), Basu (1992); and Renuka & Vijayakumar (1995), it was based on the infertile specimen including rachilla. Renuka & Vijayakumar (1995) also reported that the species is differentiated from *K. laciniosa*. A description on the floral characteristics of the

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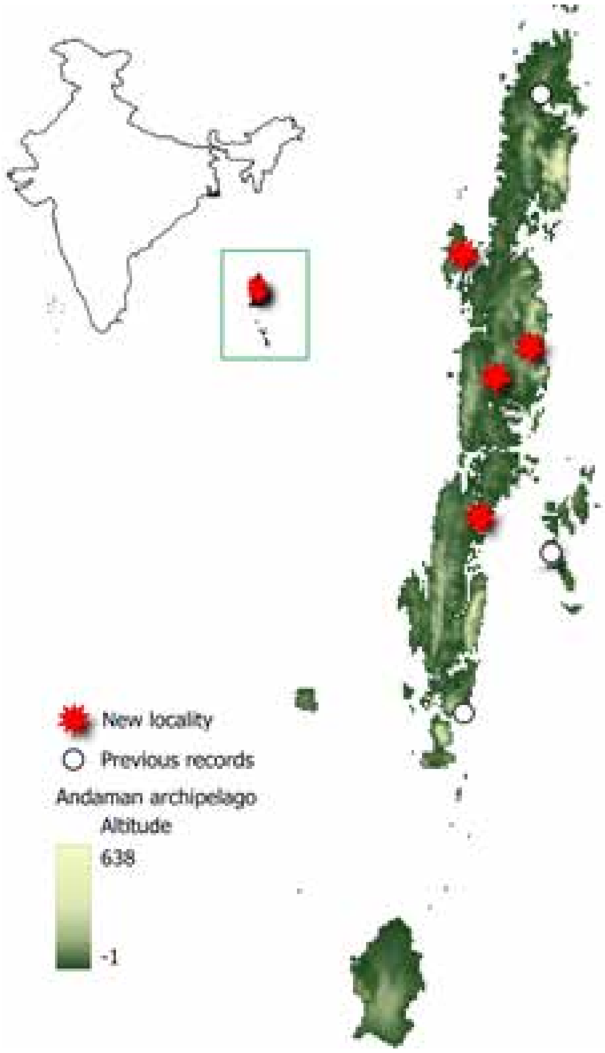

Figure 1. Map of Andaman Archipelago showing the distribution points of *Korthalsia rogersii*.

Image 1. *Korthalsia rogersii* from Interview Island. © Sarath P.

Image 2. Seedling recruitment of *Korthalsia rogersii* from Interview Island. © Sarath P.

Image 3. Seedling recruitment of *Korthalsia rogersii* observed from Chidiya Tapu. © Sarath P.

relocated living specimen flowered at JNTBGRI originally collected from Burmanallah, South Andaman were given by Mathew et al. (2007). Initially, the species was thought to be confined to Diglipur population, North Andaman, Havelock and Burmanallah/Chidiya Tapu, South Andaman population (Renuka & Vijayakumar 1995; Mathew et al. 2007; Manohara et al. 2010). However, the present study revealed four newly explored populations of the species spanning from North Andaman to South Andaman based on an expedition carried out across the Andaman Islands during 2022 (Figure 1).

The field survey was carried out across seven forest divisions covering the five major islands of Andaman and Ritchie's archipelago. The populations of *K. rogersii* were identified from seven locations including the previously known locality (Table 1, Figure 1). The identity of the species is confirmed by following the general characteristics of the species (Box 1) and taxonomic key reported to differentiate the rattan species in Andaman & Nicobar Islands (Renuka & Vijayakumar 1995). The individuals encountered during the survey were restricted to fewer than 25 individuals in the majority of the populations. However, the populations

Table 1. Locality records of *Korthalsia rogersii* from the Andaman archipelago.

Forest division	Island & Location	GPS	No. individuals
Diglipur	Radhanagar, North Andaman	13.3796 N, 92.9476 E	<20
Mayabunder	Interview Island	12.8969 N, 92.7130 E	>35
Middle Andaman	Beetapur	12.6169 N, 92.9161 E	<20
	Bakultala	12.5249 N, 92.8114 E	
Baratang	Baratang Island	12.1028 N, 92.7641 E	<25
Havelock	Havelock Island, Ritchie's Archipelago	12.0111 N, 92.9578 E	<30
South Andaman	Chidiya Tapu	11.51643 N, 92.7154 E	>40

at Chidiya Tapu and Interview Island were exceptions, where more than 30 individuals were recorded (Image 1). Most populations are distributed in evergreen and riparian habitats, with the species co-occurring alongside *K. laciniosa,* occupying a similar niche, except for the populations at Chidiya Tapu and Interview Island.

Consequently, we extended our survey to other areas where *K. laciniosa* is distributed (Saddle Peak, North Andaman; Prembukbay, Middle Andaman; Mount Harriet, Wandoor & Rutland Island, South Andaman; Little Andaman; Sir William Peel Island & Henry Lawrence Island, Ritchie's archipelago), but we were unable to find *K. rogersii* in these areas. Though a population of the species has been located on Havelock Island in the Ritchie's archipelago, we could not find the species in the nearby larger islands (Sir William Peel and Henry Lawrence Islands) of the archipelago. During our field visit in the months of April–May, we did not encounter any flowering/seed-bearing individuals, however, seedling recruitment was observed solely in Chidiya Tapu and Interview Islands (Images 2 & 3). It is noteworthy that despite the co-occurrence of *K. rogersii* and *K. laciniosa* in most populations, increased population size & seedling recruitment were evident in Chidiya Tapu and Interview Island populations, where *K. laciniosa* is notably absent. Furthermore, it would be intriguing to explore the impact of fragmented distribution of the species, along with its restricted population size and barriers to dispersal induced by the insular habitat, on gene flow and genetic structure of populations. This investigation holds significant implications for conservation of the species, which is further threatened by the extraction of canes.

Box 1. General description of the species based on Odoardo Beccari (1918); Basu et al. (1992); Renuka & Vijayakumar (1995) and Mathew et al. (2007).

Climbing aerially branching rattan with clustered, slender stem (0.7 cm in diameter), hapaxanthic, and hermaphroditic flowers. Pinnate leaves up to 1 m long with light green unarmed leaf sheath. Lower stem diameter & leaf size and absence of knee in the nodes. Ocrea is tightly sheathed without domatia. 15 cm long petiole armed below with 2 rows of recurved spins and with short cirrus. 13 x 6.5 cm cuneate-rhomboid, unevenly serrated, equidistant leaflets. Inflorescence 0.5 m long, with truncated secondary sheath and a tubular unarmed primary sheath. Inflorescence contains up to 3–5 cm long five rachillae. Flowers gamosepalous, broadly oval, and have a cup-shaped calyx with three (2 x 1) light brown sepals, and three fleshy boat-shaped petals (5 x 1 mm). Stamens 6, 3 + 3 dehisced abaxially and slightly inflexed toward the center. Tricarpellary with a pyramidal stigma and short style. Oblong fruits with a persistent calyx and stigma. Flowering time in September–November and fruiting in March–August

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NOTE

Clarifying the nomenclature of Roxburgh's pivotal name *Holigarna racemosa* Roxb. (Anacardiaceae)

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Drimycarpus Hook.f. (Anacardiaceae) is a southeastern Asian genus comprising four species (Murugan et al. 2015). It can be differentiated from other members of the tribe *Semecarpeae* by its imbricate petals, single style, and inferior ovary. In India, the genus is represented by only one species *D. racemosus* (Roxb.) Hook.f. ex Marchand (basionym: *Holigarna racemosa*), which is the type species of the genus *Drimycarpus*. It is distributed in northeastern states and Andaman & Nicobar Islands (Mukherjee & Chandra 1983, 2000). It is an economically important tree being widely used as a source of timber and the leaves as well as bark are used for treating skin diseases (De 2016; Sarkar & Devi 2017).

During the ongoing work on the systematics of Indian *Semecarpeae*, it has been found that the name *Holigarna racemosa* was erroneously typified. The relevant literature (including protologues) was analyzed in detail and herbarium specimens (original and non-original materials) were critically examined. Reasons for considering the earlier typification to be incorrect are discussed in detail and lectotype is designated. In addition to this, epitype has also been designated. All the specimens were scrutinized following the description in the protologue and comparison of the voucher details.

Taxonomic treatment

Drimycarpus racemosus (Roxb.) Hook.f. ex March and, Rév. Anacardiac. 172. 1869. *Holigarna racemosa* Roxb., Fl. Ind. (Roxburgh) 2: 82. 1832.

Type: Roxburgh's Icon 7: t. 2213 (Lecto, CAL; https://archive.bsi.gov.in/botanical-details?link=631A7335B59546KL, image!, designated here). Epitype (designated here): Bangladesh, Sylhet, N. Wallich 1006 (K001110590, http://specimens.kew.org/herbarium/K001110590).

Notes: William Roxburgh (1751–1815) was a British botanist and physician, who worked as Superintendent at the Calcutta Botanical Garden from 1793 to 1813. He catalogued the plants growing in the East India Company's Botanical Garden at Calcutta and it included several new taxa. One significant plant named by Roxburgh in this publication, the *Hortus bengalensis* (1814) was *Holigarna racemosa*. This was based on the specimens given to him by Mathew Richard Smith

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दिल्ली विश्वविद्यालय University of Delhi INSTITUTION OF EMINENCE प्रतिष्ठित संस्थान

in 1812 from Sylhet (either from Khasia Hills, Assam, or Bangladesh).

Roxburgh's *Holigarna racemosa* like most of the names in the 'Hortus Bengalensis' was a nomen nudum being published neither with a description nor with a reference to any earlier description and hence, not validly published as per Art. 38.1, ICN (Turland et al. 2018). Hooker (1862) transferred this invalid name to the genus *Drimycarpus*, however, this did not constitute a new combination as Hooker failed to associate the final epithet with the generic name as *D. racemosus* and hence this name also became invalid following Art. 35.2, ICN (Turland et al. 2018).

William Caregy (1761–1834) published manuscripts left by Roxburgh (1832) in 'The Flora Indica' wherein he validated Roxburgh's *Holigarna racemosa.* This included a description of the plant *H. racemosa* with a reference to the collection site as Sylhet but no further information about the collector or the collection date. We tried to locate Roxburgh's collection of *H. racemosa* from Sylhet or Smith's collections at CAL and K but no specimen was found.

Erroneous Lectotypification of *Holigarna racemosa* Roxb.

Mukherjee & Chandra (1988) revised the Indian Anacardiaceae and designated Wallich's specimens at K as lectotype of *Holigarna racemosa*. This was probably due to Hooker's inclusion of Wallich's specimen (Catalogue No. 1006) under *H. racemosa* in the 'Flora of British India' (1988). This specimen of Wallich was collected from the type locality as mentioned in the protologue, i.e., from Sylhet but the collector was H. Bruce and not Roxburgh or Smith. Since Roxburgh died in 1815, he could not see the herbarium specimens distributed by Wallich during 1829–1847. Further, Roxburgh did not keep herbarium specimens in his personal herbarium. Some of Roxburgh's specimens were also given to Wallich and due to this, the Wallich specimen might have been considered as the original material for *H. racemosa*. However, Wallich noted in his Catalogue about the specimens received from Roxburgh but no such information was mentioned against the collection number 1006. Also, in the Wallich Catalogue, Roxburgh's entries were after the number 2158 which was far ahead of the specimen considered

Image 1. *Holigarna racemosa*: A—Lectotype (https://archive.bsi.gov.in/botanical-details?link=631A7335B59546KL) (© Botanical Survey of India, Government of India) | B—Epitype (http://specimens.kew.org/herbarium/K001110590) (© Board of Trustees of the Royal Botanic Gardens, Kew).

the original material for *H. racemosa* (Forman 1997). Thus, Wallich's collection cannot be the original material for *H. racemosa,* and designating it as the lectotype is incorrect.

Another problem with the lectotype designated by Mukherjee & Chandra is that they designated Wallich's specimen no. 1006 at K as the lectotype but there are five specimens at K (barcodes K001110589, K001110590, K001110591, K001110592 and K001110593). This indicates that if the specimens collected by Wallich or Bruce had been the original material, a second-step lectotype was required to stabilize the application of the name. However, as it is not an original gathering, this possibility is already ruled out.

Lectotypification of *Holigarna racemosa* Roxb.

Considering that no specimen can be equivocally linked to Roxburgh's name, we searched for Roxburgh's drawings. Roxburgh used to have life-size drawings while describing the plants indicating the direct relevance of these drawings in establishing the identity of Roxburgh's names (Sealy 1956). A detailed drawing of *H. racemosa* was also traced at CAL that bears Roxburgh's number 2213 (Figure 1A) and hence designated here as the lectotype following Article 9.17 of ICN (Turland et al. 2018).

Epitypification of *Holigarna racemosa* Roxb.

Additionally, as the specimens collected by Wallich are from the same locality and match the description in the protologue, we designate here the specimen with barcode K001110590 (Figure 1B) as the epitype for *H. racemosa.*

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NOTE

First confirmed breeding of Brown Noddy *Anous stolidus* in southeastern India: a new record from Adam's Bridge

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The genus *Anous*, belonging to the family Laridae, includes three noddy species—Brown Noddy *Anous stolidus*, Black Noddy *Anous minutus*, and Lesser Noddy *Anous tenuirostris*—which form a significant group of tropical and subtropical seabirds worldwide (Mondreti et al. 2013). Among these, Brown and Lesser Noddies are breeding residents in the Indian Ocean (Gochfeld & Burger 1996; Rasmussen & Anderton 2012). Brown Noddy, the largest one of the three species, is categorized as 'Least Concern' by the IUCN Red List due to its widespread distribution and stable global population. It exhibits darker chocolate-brown plumage and contrasting pale forehead & crown, black lores that contrast with its pale grey forehead, and a relatively shorter bill which make the Brown Noddy easily identifiable (Harrison 1985; Gochfeld & Burger 1996; Rasmussen & Anderton 2012).

Brown Noddies were previously considered as rare visitors to Sri Lanka (De Silva 1979; Rasmussen & Anderton 2012; Warakagoda et al. 2012). However, recent studies have established them as breeding residents (Seneviratne et al. 2015). In India, their closest known breeding colonies are found on Cherbaniani and Pitti islands of Lakshadweep (Pande et al. 2007), as well as in the Maldives, the nearest country (Rasmussen & Anderton 2012). We documented the first confirmed nesting of the Brown Noddy along the southeastern coast of India, near Rameswaram Island.

Adam's Bridge, or Ram Setu, is a chain of sandbanks linking Rameswaram Island, Tamil Nadu, India, to Sri Lanka, within the Gulf of Mannar Marine Biosphere Reserve. Recent studies have recorded rare migratory birds such as Arctic Skua *Stercorarius parasiticus* (Byju & Raveendran 2022a) and vagrants like Light-mantled Albatross *Phoebetria palpebrata* (Byju & Raveendran 2022b). The sandbars (I–VII) remain largely undisturbed by human activity due to restricted access. Breeding behaviour of Brown Noddy was observed on sandbank VII (9.116° N, 79.5109° E) (Image 1), located about 8 km south-east of Arichalmunai point, Rameswaram. This sandbar spans approximately 2.5 km in length and up to 1.5 km at its widest point.

During observations on Sandbar VII in early July

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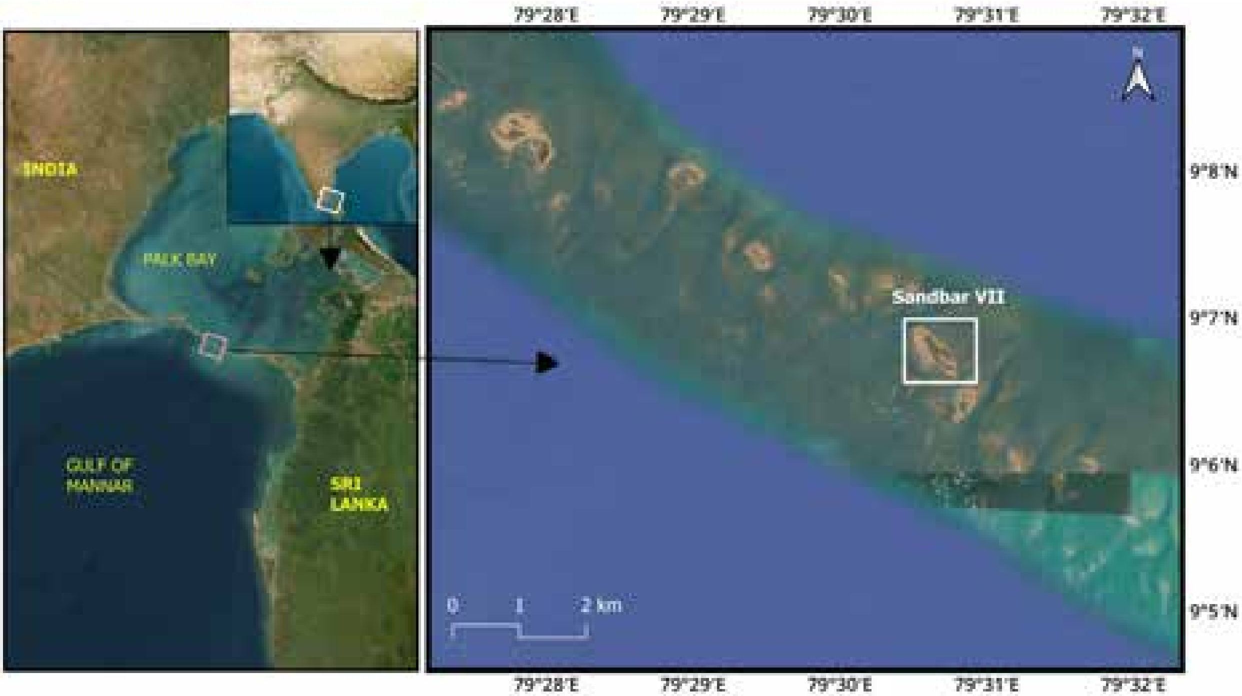

Image 1. Breeding location of Brown Noddy *Anous stolidus* on the sandbar VII of Indian side of Adam's Bridge

Image 2. Brown Noddy roosting with other tern species at sandbar VII of Adam's Bridge.

Image 3. Incubating Brown Noddy adults in Sandbar VII of Adam's Bridge.

Image 4. Brown Noddy egg in the nest at Sandbar VII of Adam's Bridge.

2024, 18–21 Brown Noddies were recorded roosting on vegetation like *Ipomea pescaprae* and *Sesuvium* sp. (Image 2). Courtship behaviour like low-flight displays and aerial chases with no conclusive evidence of breeding were noted. However, on 27 July, active breeding was confirmed, with individuals incubating eggs (Image 3). Six nests were identified with individuals incubating eggs, and some additional pairs were observed in courtship activities. The nests were located on the sand-dune slopes covered with *Ipomea pescaprae* and *Sesuvium* sp. amidst small grasses, forming a loose cluster with inter-nest distances of 1–5 m. The nests co-occurred with a few Bridled Terns *Onychoprion anaethetus* and thousands of Greater Crested Terns *Thalasseus bergii* breeding on the sandbar.

The nests of Brown Noddy were observed as shallow ground depressions created by clearing debris. Across its broader distribution, the species is known to nest on the ground, cliffs, trees, and shrubs (Gochfeld & Burger 1996). Each nest contained a single egg (Image 4). The eggs were slightly elliptical, predominantly white, and marked with blotches in various shades of brown. We found few adults incubating the eggs.

This study presents the first confirmed record of Brown Noddy breeding from the southeastern coast of India, apart from the record of Sri Lanka (Seneviratne et al. 2015) on the other side of Indian Mannar. Hence these sandbars connecting India and Sri Lanka (Adam's Bridge) requires high priority conservation measures as numerous important pelagic birds are breeding in this region.

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NOTE

First record of Painted Stork *Mycteria leucocephala* in Indonesia

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Storks are among the large "wading' birds, species that characteristically feed while walking about in shallow wetlands (Hancock et al. 1992) which are with long necks, bills, and legs; and they thus represent the most distinctive families (Elliott 1992). Twenty species are recognized, although there is still dispute over the taxonomic status of a few (del Hoyo & Collar 2014). Painted Stork *Mycteria leucocephala* is one of the most abundant Asian storks, ranging from Pakistan, Nepal, India, Sri Lanka, Bangladesh, China, and southeastern Asian countries (Elliott 1992; Hancock et al. 1992; BirdLife International 2023). This stork is recently listed as 'Least Concern' because it is thought to be a wide range that extends from southern Asia through to southeastern Asia, with a population trend that seems to be rising (BirdLife International 2023). *M. leucocephala* has been regularly recorded from Peninsular Malaysia and Singapore (Jeyarajasingam & Pearson 2012; Puan et al. 2020), but it has not been reported from the Indonesian archipelago (MacKinnon & Phillipps 1993; Eaton et al. 2021). Here, we report an observation of *M. leucocephala* from northern Sumatra, the country's first record for Indonesia.

On the afternoon (approximately 1600 h) of 19 January 2022, while observing waterbirds in the coastal zone of North Sumatra province, three of us (HA, FS, FAH) observed an individual Painted Stork. The site where this species was found is mangrove forest and mudflat habitat in Pematang Lalang village (3.7161 ^{0}N, 98.8122 ^{0}E), Percut Sei Tuan subdistrict, Deli Serdang district, North Sumatra province, Indonesia (Figure 1), along with 11 Milky Storks *Mycteria cinerea*. The bird is very similar to *M. cinerea* by size, behaviour, and morphological characteristics (white large stork with black-and-white markings on wings). Both *M. leucocephala* and *M. cinerea* share a very large size of waterbird, with white plumage, black wing markings, a long bill with slightly decurved, whitish neck & mantle, facial red skin, a bill bright yellow, and long legs (Image 1). We followed appropriate field guides (Sonobe & Usui

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Figure 1. Map of the area of observation of *Mycteria leucocephala* in Sumatra. Black triangle is record in 2022, and yellow triangle is recent record in 2025.

1993; Robson 2011; Puan et al. 2020) for identification. *M. leucocephala* has black colour markings in wing coverts; and pink flush colour in scapulars, secondaries andwing coverts. These characters are not present in *M. cinerea*, which have entirely white wing coverts.

In addition, three Painted Storks were documented on 31 January 2025 in Percut, northern Sumatra (eBird 2025). The site is very close to the previous observation of *M. leucocephala* in 2022. This recent record suggests *M. leucocephala* is a recently regular visitor in northern Sumatra.

The coastal zone of North Sumatra province is an Important Bird and Biodiversity Area (IBA) (Holmes & Rombang 2001; Birdlife International 2022). The nearest areas where *M. leucocephala* is found are Peninsular Malaysia and Singapore (Jeyarajasingam & Pearson 2012; Puan et al. 2020). In Peninsular Malaysia, *M. leucocephala* has been known as a migrant in low numbers to Perlis and Kedah (including Pulau Langkawi), vagrant to Kuala Lumpur, recently feral and locally common resident with free-flying populations successfully bred at National Zoo in Selangor, free-flying regularly disperses to feed in wetlands out of the zoo and frequent at the Kuala Lumpur and Putra Jaya wetlands where a satellite breeding colony has formed (Wells 1999; Jeyarajasingam & Pearson 2012). In Singapore, the birds are most likely from the Mandai Zoo which was introduced in 1987, free fly to Johor Bahru of Malaysia to feed in the wetlands (Jeyarajasingam & Pearson 2012). The distance between Pematang Lalang village of northern Sumatra and with Painted Stork found in the Malay Peninsula and Singapore is about 250–500 km. The Pematang Lalang village of North Sumatra province is about c. 250 km to Kuala Lumpur, c. 500 km to Johor Bahru, and c. 500 km to

Image 1. A *Mycteria leucocephala* perching on the mangrove tree in Pematang Lalang Village, Percut Sei Tuan Subdistrict, North Sumatra Province, Indonesia, 19 January 2022. © Hasri Abdillah.

Singapore. Considering the *M. leucocephala* in northern Sumatra from the Malay Peninsula or Singapore, it may be likely that the species also occurs in other suitable wetlands nearby in Sumatra for foraging.

Our record of *M. leucocephala* in northern Sumatra is part of a spate of new distribution records of vagrant migrant waterbirds in Sumatra. This appears most likely to relate to rapidly rising interest in waterbirds among local researchers and amateurs on the island in the last decade, as well as easier access to cameras with tele lenses for documentation (Abdillah & Iqbal 2012; Imansyah & Iqbal 2015; Putra et al. 2018). Due to its similarity with *M. cinerea*, it is possible this species was overlooked earlier in Sumatra in the past by birdwatchers or researchers. Based on this record, *M. leucocephala* needs special attention from birdwatchers in the future, particularly when a hybrid of this species with Milky Stork has been reported, both in the wild and the zoo (Baveja et al. 2019).

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NOTE

New sighting and conservation implications of the endemic Sulu Boobook *Ninox reyi* Oustalet, 1880 at Bolobok Rock Shelter, a key archaeological site in the Sulu Archipelago, southern Philippines

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The Sulu Hawk-owl *Ninox reyi*, also known as the Sulu Boobook, a member of the Strigidae family, is endemic to the Sulu Archipelago in the southern Philippines. Formerly classified as a subspecies of the Philippine Hawk-owl, it was reclassified as a distinct species in 2012 based on distinctive vocalizations and other evidence (Rasmussen et al. 2012). Kennedy et al. (2000) describes the Sulu Boobook as a modestly-sized owl, standing 20 cm tall, which places it between the larger Philippine Hawk-owl complex species and the smaller Luzon & Mindanao Boobooks in terms of size. Its plumage is characterized by brown stripes on the upper body, a warmer orange-brown hue on the underside, and noticeable white spots on the wings. A white throat mark and pale yellow eyes are its distinguishing traits. Unlike its congeners, the Sulu Boobook's call is a distinctive rattling sequence, not the usual hoots associated with Philippine owls.

Scientific research on Philippine Hawk-owls is generally scarce. Available studies indicate that they typically inhabit tropical moist lowland primary and secondary forests up to 700 m, and can also be found along forest edges, in glades, and on plantations. For the Sulu Boobook in Tawi-Tawi, its presence have been recorded in mature mangroves and large trees near villages (Rasmussen et al. 2012). It has also been documented in various places within Tawi-Tawi, such as Sibutu municipality, Bongao & Sanga-Sanga islands in Bongao municipality, and Tarawakan, Balimbing, & Batu-Batu in Panglima Sugala municipality (Allen 2001; Rasmussen et al. 2012; BirdLife International 2016) (Figure 1).

Although initially documented in the late 19th century, scientific data on the Sulu Boobook remain limited (Allen 2001; van de Ven et al. 2019). The most

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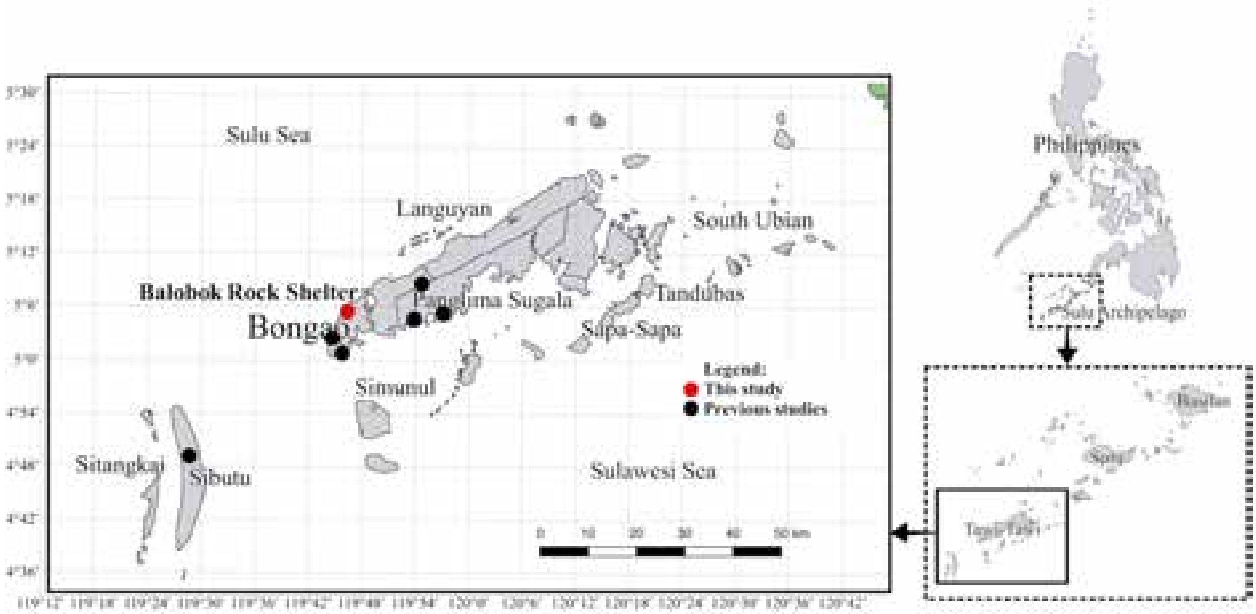

Figure 1. Map of the Philippines showing the location of Bolobok Rock Shelter and other locations of previous sightings of Sulu Boobook from others studies.

Image 1. Sulu Boobook *Ninox reyi* perched on a bare, slender vine at the Bolobok Rock Shelter.

recent comprehensive surveys in Tawi-Tawi, which documented the Sulu Boobook in its natural habitat, were carried out by Allen in the late 1990s. In 2016, Birdlife International classified the Sulu Boobook as Vulnerable, citing its declining population, estimated at fewer than 1,000 individuals, and threats from deforestation, and other anthropogenic disturbances. In 2019, the Department of Environment and Natural Resources (DENR) Administrative Order No. 2019-09 also listed the species as Vulnerable, highlighting the critical need for updated field observations.

This article reports a new sighting of the Sulu Bobook

Image 2. Varied landscapes, flora and fauna at Bolobok Rock Shelter, showcasing karst formations and potential habitats within the ecological niche of the Sulu Boobook *Ninox reyi*.

at the Bolobok Rock Shelter, an unrecorded location for this species situated along the coast overlooking the Sulu Sea in Barangay Lakit-Lakit, Bongao, Tawi-Tawi (Figure 1). An individual was observed at noon on 10 July 2023, perched quietly but alertly on the limestone ceiling at the entrance of Bolobok Rock Shelter at an elevation of 13.41 m (Image 1).

The immediate environment was characterized by a karstic limestone formation with an irregular and rugged surface (Image 2). The texture of the rock behind the owl was rough and pitted with erosion features, which are common in limestone that has been subjected to dissolution by acidic rainwater over time. Vegetation around the perch was sparse. The owl was perched on a bare, slender vine. The surrounding rock served as a microhabitat that likely supported various forms of wildlife, including this owl, which seemed well adapted to blend into the grayish-brown palette of the rock face. The crevices and fissures in the rocks could have provided shelter and nesting spots for the owl and other avian species. The shaded location of the rock shelter, coupled with its humid and quiet ambiance, are conditions that are often preferred by owls for roosting (Rebollo et al. 2023).

The owl exhibited a sense of undisturbed tranquility in the presence of observers, providing an opportunity to document and confirm its identification. It was confirmed as a Sulu Boobook based on key morphological features: prominent uniformly barred on crown and breast, distinctive mustard-yellow eyes, prominent white "X" markings around the bill, and a noticeable white patch on its throat, which match the characteristics of the species as described in Kennedy et al. (2000) and Rasmussen et al. (2012).

Bolobok Rock Shelter, located in Barangay Lakit-Lakit, Bongao, Tawi-Tawi—the southernmost province of the Sulu Archipelago—is an Important Cultural Property (National Museum Declaration No. 24-2016). It holds significant prehistoric artifacts, including polished shell adzes from *Tridacna gigas*, showcasing early tool-making (Faylona 2010; Bautista 2022; Muallil et al. 2024). Radiocarbon dating places these artifacts between 6810–3190 BCE (8,760–5,140 years ago), making Bolobok one of the Philippines' earliest known human settlements.

On the other hand, Lakit-Lakit is a remote barangay in Bongao, located along the Sibutu Passage in the northern part of the municipality. It has a population of about 1,500 and a coastal length of 2.72 km. The majority of its residents rely on farming, making Lakit-Lakit a primary source of agricultural produce in Bongao, which is the capital and commercial center in the province of Tawi-Tawi. Lakit-Lakit was once densely forested but suffered severe deforestation due to extensive logging and farming expansion, particularly in the 1990s (Sansawi et al. 2020). The local residents identified the species as 'lukluk' in Tausug and 'mongkok' in Sinama. They reported hearing the calls of the bird early in the evening and sometimes spotting the birds in trees near residential areas.

The discovery of the Sulu Boobook at Bolobok Rock Shelter not only provides a new locality record for Lakit-Lakit but also underscores the species' adaptability to varied microhabitats, suggesting that the Sulu Boobook may have a wider range than previously documented. A single sighting of the species in a new locality does not necessarily confirm a resident population, as its high mobility suggests it may be transient. To establish a sustained population at Bolobok Rock Shelter, multiple sightings over time, evidence of breeding pairs, or juveniles are necessary (Pradel & Sanz-Aguilar 2012). Nevertheless, this finding underlines the urgency for comprehensive field surveys and conservation efforts to ensure the survival of this vulnerable owl. Additionally, our research highlights the critical need to protect the Bolobok Rock Shelter, not only as a cornerstone of cultural heritage but also as an essential habitat for this species.

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NOTE

The occurrence of Glossy Ibis *Plegadis falcinellus* Linnaeus, 1766 (Pelecaniformes: Threskiornithidae) in southern Sumatra, Indonesia

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Ibises are medium-sized to large wading birds (ranging in length from just under 50 cm in the smallest species to 110 cm in the Giant Ibis) that have notable differences in bill morphology by having a narrow downcurved bill with a flattened tip (Hancock et al. 1992; Matheu & del Hoyo 1992). They are found in a variety of wetlands in all regions, except the Antarctic, with the greatest species diversity in the tropics (del Hoyo & Collar 2014). Currently, 24 species of ibises are recognized, and the Glossy Ibis *Plegadis falcinellus* is the only cosmopolitan member of the family Threskiornithidae (Ibises and Spoonbills) (Matheu & del Hoyo 1992). The *P. falcinellus* is distributed across Europe, Africa, Asia, and Australia (Hancock et al. 1992; Birdlife International 2022). Although the population trend appears to be decreasing, this species has a large range and population size (Birdlife International 2022). The *P. falcinellus*, a vagrant, is scarce in the Indonesian archipelago, except in Java, where they are locally common residents (MacKinnon & Phillipps 1993; Eaton et al. 2021). This study reports observations of *P. falcinellus* in South Sumatra Province, Indonesia, considered the first record for this species in southern Sumatra.

On 13 August 2022, a wetlands survey in Pasir River Village (03°35'42"S, 105°49'34"E), Cengal Subdistrict, Ogan Komering Ilir District, South Sumatra Province, Indonesia was conducted. The Pasir River Village, located in the east coastal zone of southern Sumatra, comprises

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a mix of mudflat, mangrove forest, and aquaculture pond habitats. *P. falcinellus* was observed on two occasions. First, at 1200 h, we saw a flock of 72 large dark waterbirds with decurved bill was seen flying from south to north directions (Image 1). This sighting took place at the mouth of Pasir River from a speedboat. Second, at 1600 h, we found a flock with similar characteristics and numbers in aquaculture ponds in Pasir River Village, presumed to be the same flock that we saw at noon (Image 1a). When the birds landed in an aquaculture pond, we observed them closely and documented them. They exhibited distinct morphological characteristics, relatively bigger for waterbirds but quite small for wading birds groups (Storks, ibises, and spoonbills), a decurved bill like Curlew *Numenius* sp., and all dark bodies. A few individuals displayed breeding plumage, characterized by the forecrown; glossed dark chestnut on the head, neck, chin, throat, lower back, and rump; and darkish green wing coverts (Image 1b). We referred field guides and confirmed the species to *P. falcinellus* (MacKinnon & Phillipps 1993; Sonobe & Usui 1993; Robson 2011; Eaton et al. 2021).

The presence of *Plegadis falcinellus* was previously considered doubtful in Sumatra (Marle & Voous 1988; MacKinnon & Phillipps 1993) until confirmed records emerged from northern Sumatra (Putra et al. 2013). The observations from Pasir River Village represent a significant number of individuals suggesting an expansion of the species' range into southern Sumatra. The historical records of *P. falcinellus* in Sumatra are summarized below:

1. On 22 March 1977, unconfirmed single *P. falcinellus* was reported in Tanjung Pura, North Sumatra Province (Marle & Voous 1988).
2. On 30 September 2010, four *P. falcinellus* were observed in Tanjung Rejo Utara Village, Pantai-Labu Subdistrict, Deli Serdang District, North Sumatra Province (Putra et al. 2013).
3. On 01 January 2011, four *P. falcinellus* were observed again in Tanjung Rejo Utara Village, Pantai-Labu Sudistrict, Deli Serdang District, North Sumatra Province (Putra et al. 2013). It was presumed that the birds are similar to birds observed in 2010.
4. On 13 February 2011, four *P. falcinellus* were observed again in Tanjung Rejo Utara Village, Pantai-Labu Subdistrict, Deli Serdang District, North Sumatra Province (Putra et al. 2013). It was presumed that the birds were similar to birds previously found in 2010 and 2011 based on the number of individuals in the flock and their observed physical.
5. On 21 April 2021, three *P. falcinellus* were documented at an aquaculture pond in Margasari Village, Labuhan Maringgai Subdistrict, Lampung Timur District, Lampung Province (iNaturalist 2022).
6. On 13 August 2022, a flock of 72 *P. falcinellus* was observed twice in Pasir River Village, South Sumatra Province (this survey).
7. On 29 January 2025, three *P. falcinellus* were documented in Braja Slebah Subdistrict, Lampung Timur District, Lampung Province (eBird 2025). This area is in the same district as the location mentioned in observation six.

Our recent observation, supported by two observations from Lampung Province, represents an extended range for *P. falcinellus* in southern Sumatra (Figure 1).

The wetlands in the east coastal zone of southern Sumatra are documented as important habitats for waterbirds (Verheugt et al. 1993; Iqbal et al. 2019; Setiawan et al. 2019, 2020). It is likely these wetlands

Image 1. A flock of 72 *Plegadis falcinellus* in Pasir River Village, South Sumatra Province, Indonesia, 13 August 2022: a—A flock in flight | b—Breeding and non-breeding birds roosting at aquaculture ponds. © Muhammad Iqbal.

Figure 1. Historical records of *Plegadis falcinellus* in Sumatra. Yellow triangles represent previous records from northern Sumatra, and black triangles indicate recent records from southern Sumatra. Numbers in the map denote localities: 1—Tanjung Pura (North Sumatra Province) | 2–4—Tanjung Rejo Utara (North Sumatra Province) | 5—Pasir River (South Sumatra Province) | 6—Margasari (Lampung Province) | 7—Braja Slebah (Lampung Province).

provide good habitats for other waterbirds from bordering regions. Since first being seen in 2010, the Black-winged Stilts *Himantopus leucocephalus* have been recorded at aquaculture ponds in the Banyuasin Peninsula, South Sumatra Province, and have successfully colonized the area recently (Iqbal et al. 2019, 2022). Putra et al. (2013) presumed that *P*. *falcinellus* found in northern Sumatra could be originally from the southeastern Asian population, rather than from the Javan population.

This assumption is based on the distances: localities of *P. falcinellus* in northern Sumatra are approximately 500 km from the southeastern Asian population, compared to about 3,000 km from the nearest location in Java. Following this assumption, *P. falcinellus* recently observed in southern Sumatra could have originated from Java, where the nearest breeding sites (Pulau Dua and Pulau Rambut, West Java; Marle & Voous 1988) are located approximately 100–250 km from Margasari and Pasir River Village, compared to about 600 km from mainland Southeastern AsiaIn the Atlantic, Santoro (2014) reported about *P*. *falcinellus* distance range in Trinidad (one in the summer of 2008) and Bermudas (one in autumn 2013) indicating that this species can disperse across the Atlantic, flying almost 6,000 km away from natal sites. Further surveys are needed to monitor the status of *P*. *falcinellus* population in Sumatra in the future, to learn whether the species is a visitor or able to breed and colonize on the eastern coast of southern Sumatra.

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BOOK REVIEW

A whisper of silken wings

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The Indian subcontinent, with its varied landscapes and climatic zones, is a biodiversity hotspot, teeming with life both visible and often overlooked. Among the more enigmatic inhabitants of this region are the moths, belonging to the order Lepidoptera. Often overshadowed by their diurnal cousins, the butterflies. Moths represent a significantly larger and more diverse group. A comprehensive field guide, 'Moths of India', would be a valuable resource, filling a crucial gap in our understanding of Indian Lepidoptera and serving as a vital tool for researchers, conservationists, and amateur enthusiasts alike. This review will examine its success in achieving this ambitious goal.

The book is divided into various sections based on the different families of moths found in India. This field guide records 1,500 species with well-defined illustrations. The taxonomic framework employed by the author is crucial for its scientific validity. It provides classification from family to species level. This field guide includes basic information about best time period of moth watching, moth photography, ethical guidelines, and dos and don'ts which is necessary for any taxa. A total of 33 different families representing a total of 1,478 species with illustrations and distribution has been provided. Among them approximately 13 species are classified up to the generic level. This field guide has provided more than 30 species with illustrations of both the sexes. Also, the polymorphic form of *Ercheia cyllaria* (Cramer, [1782]) has been illustrated. The book lacks information on diagnostic characters to easily identify the species. The author could have added information on host plants of the species which is crucial for moth fauna, as they are the important pest and pollinators of many plant species. Besides, the information about distribution of some of the species in India is lacking.

The book presents the 398 species of Erebidae which was dominant in it followed by Geometridae with 373

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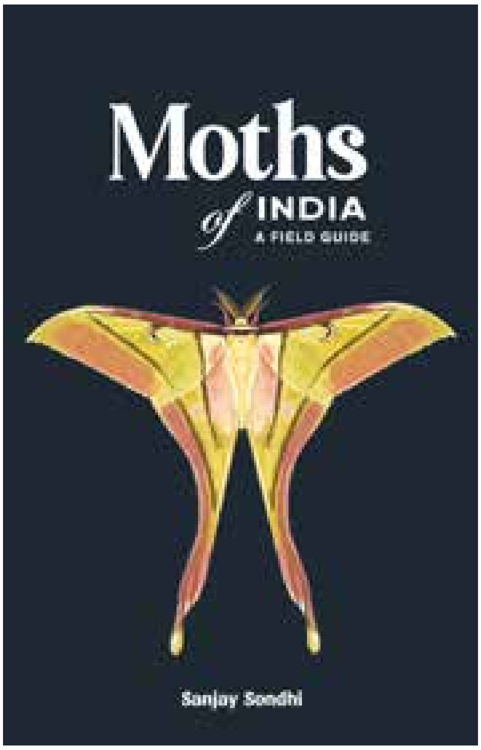

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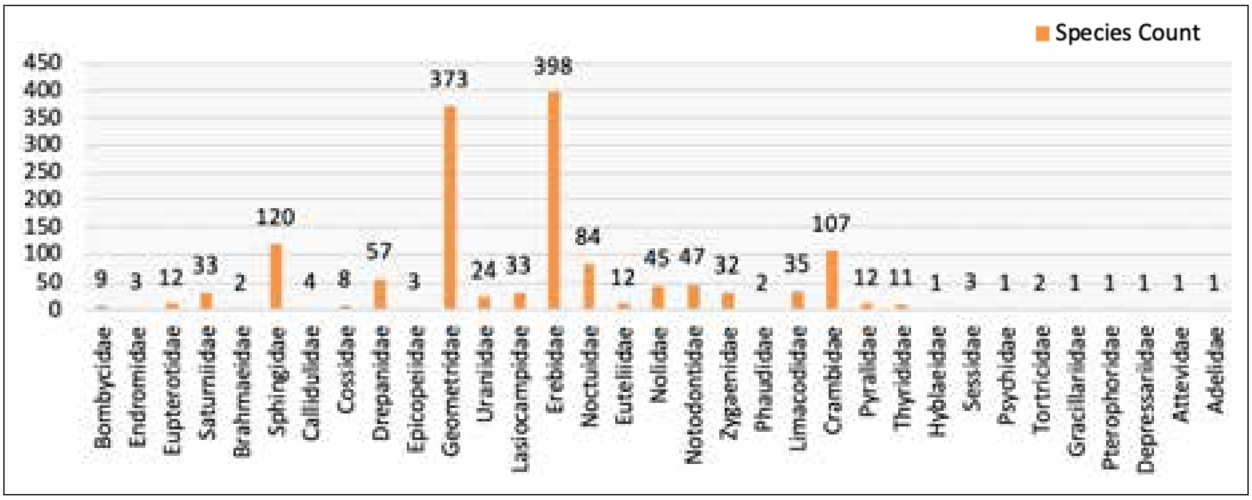

Figure 1. Family-wise species count provided in Moths of India field guide.

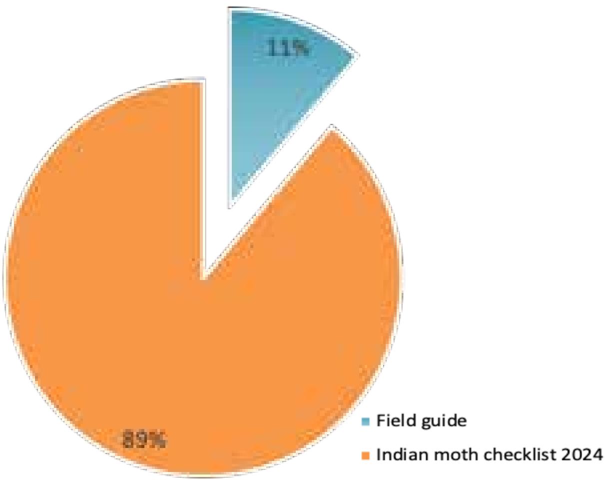

Figure 2. Comparison of species included in field guide to Moths of India checklist, 2024.

species and Sphingidae with 120 species, Crambidae with 107 species, etc. (Figure 1). As per the checklist of moths of India, published in 2024 by Zoological Survey of India, India harbours 11,745 species of moths and in this book, author has covered 11% of it (Figure 2). One of the strengths of the book is the use of good quality photographs, which provides a visual treat for the readers. Also, proper comparison in the species of the same genus is possible from the plates. The photographs are accompanied by scientific names.

'Moths of India: A Field Guide' is an informative and engaging book that provides a comprehensive scientific exploration of the diverse world of Indian moths. As a testament to the beauty and importance of these nocturnal creatures, the book serves as a call to action for the conservation of biodiversity and the preservation of the natural world.

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Articles

Communications

Short Communications

Notes

Book Review

Publisher & Host

Zoo Outreach Organisation

Threatened Taxa