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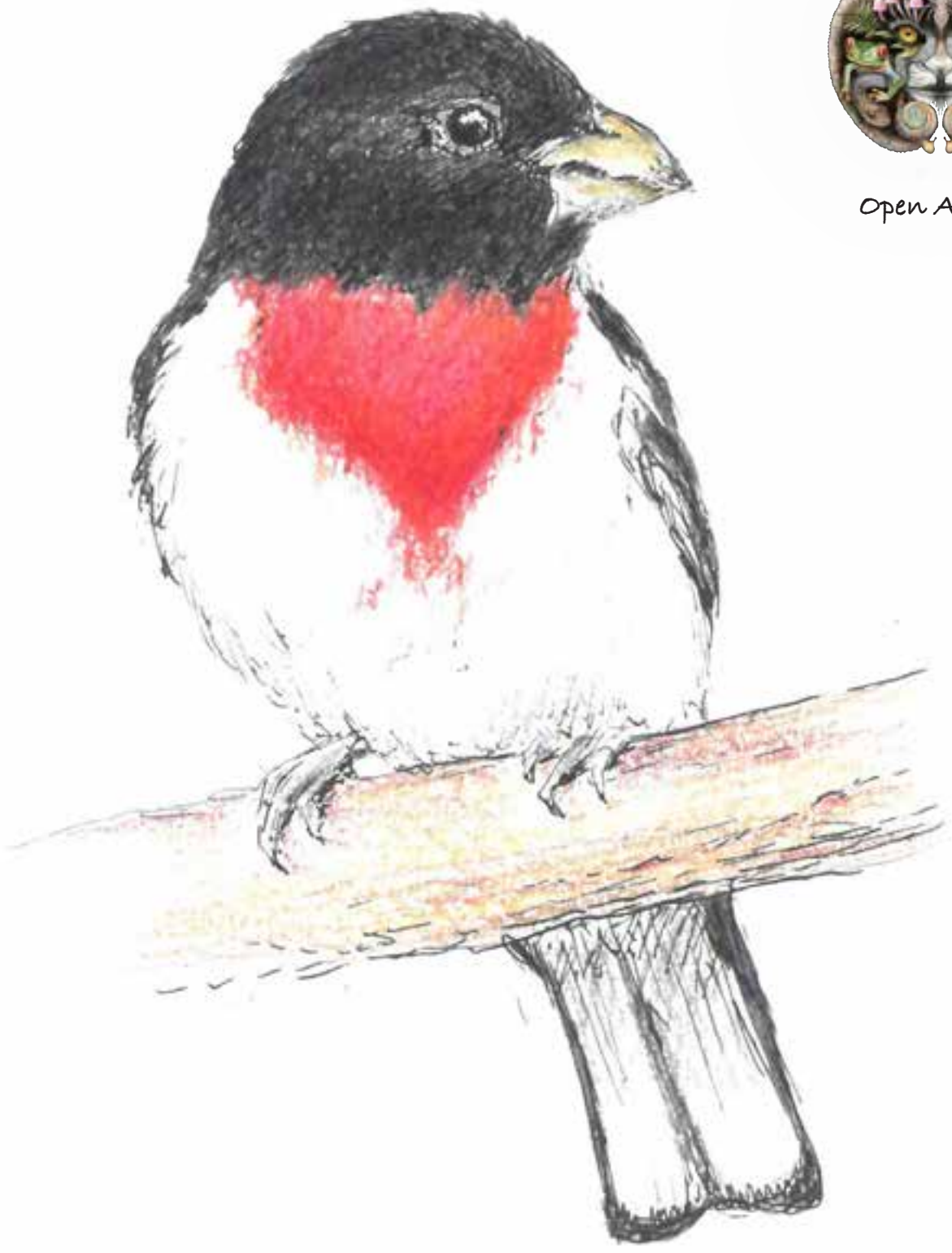

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Cover: Rose-breasted Grosbeak *Pheucticus ludovicianus*, pen & ink with colour pencil. © Lucille Betti-Nash.

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ARTICLE

Tree architecture model of Sumatran Orangutan *Pongo abelii* Lesson, 1827 (Mammalia: Primates: Hominidae) nests at Soraya Research Station, Leuser Ecosystem, Indonesia

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Abstract: The relationship between tree architectural models and the nesting behavior of the Sumatran Orangutan *Pongo abelii* Lesson, 1827 at the Soraya Research Station, Sumatra, Indonesia was determined by examining the preference for particular nest tree architectural models in relation to the frequency of nest occurrence. This investigation included the study of tree architectural models, tree types, nest profiles, vegetation, environmental factors, and geospatial data, collected within a 20 × 1,000 m (2 ha) observational area during a nest survey. A total of 59 orangutan nests were identified across 47 trees, categorized into 31 species and nine varied tree architectural models. Among these, the most prevalent models observed were Cook, Scarrone, and Attims, which exhibit features assumed to enhance orangutan nesting behaviors. Based on the Neu approach to nest qualities, the analytical test findings show a correlation between the preference ratings for nesting trees. Our results are expected to serve as a reference for selecting tree species in rehabilitation or habitat restoration programs and the development of separated forest block corridors as conservation efforts for orangutans.

Keywords: Animal behavior, arboreal animal, conservation, forest, habitat restoration, preferences, primate.

Bahasa Abstrak: Hubungan model arsitektur pohon dengan perilaku bersarang Orangutan Sumatera *Pongo abelii* Lesson, 1827 di Stasiun Penelitian Soraya, Sumatra, Indonesia ditentukan dengan memeriksa preferensinya terhadap model arsitektur pohon sarang tertentu dalam kaitannya dengan frekuensi kehadiran sarang. Penelitian ini mencakup studi model arsitektur pohon, jenis pohon, profil sarang, vegetasi, faktor lingkungan, dan data geospasial, yang dikumpulkan dalam area observasi seluas 20 × 1.000 m (2 ha) selama survei sarang. Sebanyak 59 sarang orangutan teridentifikasi di 47 pohon, dikategorikan ke dalam 31 spesies dan sembilan model arsitektur pohon yang bervariasi. Di antara model-model tersebut, model yang paling umum diamati adalah Cook, Scarrone, dan Attims, yang menunjukkan fitur-fitur yang diasumsikan meningkatkan perilaku bersarang orangutan. Berdasarkan pendekatan Neu terhadap kualitas sarang, hasil analisis menunjukkan adanya korelasi antara tingkat preferensi terhadap model pohon sarang tertentu. Hasil penelitian ini diharapkan dapat menjadi acuan awal dalam memilih jenis pohon yang sesuai untuk program rehabilitasi atau restorasi habitat dan pengembangan koridor blok hutan terpisah sebagai upaya konservasi orangutan.

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Author contributions: AGPL—designed the project, analyzed the data, and wrote the first draft of the manuscript. NP—proofread and assisted in the project and final editing of the manuscript.

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INTRODUCTION

Tree architecture refers to the morphological progression observed in tree-like plant development. It characterizes a sequence of structural stages of trees (Halle et al. 1978). Various species are identified by distinct architectural models, presenting 24 different models. Architecture significantly influences the ecological role of trees in the environment and plays a vital role in understanding their interactions with other life forms, particularly arboreal animals (Halle et al. 1978; Turner 2004).

Arboreal animals, particularly certain primate species, are often observed on trees with specific architectural features (Larson 2018). For instance, Javan Langurs *Trachypithecus auratus* have been seen using trees with the Schoute and Cook architectural models while feeding (Ayunin et al. 2014). When moving, resting, and seeking shelter, they were observed using trees with the Cook and Leeuwenberg models (Hendrawan et al. 2019). The Schoute model involves growth from meristems, producing orthotropic or plagiotropic trunks with equal dichotomy at regular but distant intervals, and lateral inflorescences. The Leeuwenberg model consists of equivalent orthotropic modules determined by terminal inflorescence production, while the Cook model results from continuous growth with spiral or decussate phyllotaxis, producing phyllomorphic branches (Halle et al. 1978). Proboscis Monkeys *Nasalis larvatus* favor the Rauh or Attims architectural models, where the Rauh architecture involves rhythmic growth of a monopodial trunk with tiered branches, and the Attims model is characterized by continuous growth with lateral flowering that does not affect shoot construction. These architectural models are distinguished by perpendicular branches suitable for resting or sleeping (Widiastuti et al. 2017).

Orangutans are arboreal mammals that highly rely on trees, particularly for nesting. They select a new tree for nesting and resting each day, considering specific characteristics and types of trees. Orangutans strategically place their nests to maintain a clear view of the surrounding forest. Trees with dense horizontal branches and a compact crown with uniformly spread leaves (a ball crown) are commonly preferred, as these features facilitate nest building. This preference is related to the tree's architectural model (Nowak 1999; Muin 2007; Nasution et al. 2018). Understanding the architectural models of orangutan nest trees is crucial to identify trends in the prevalence of specific models and their association with nest characteristics. Such knowledge can serve as a guideline for selecting tree species in habitat restoration initiatives, especially in creating distinct forest block corridors as part of orangutan conservation efforts.

METHODS

Study Area

The Leuser Ecosystem Area (KEL) is a critical natural environment characterized by its unique flora and fauna, forming a balanced ecosystem essential for maintaining biodiversity. This ecosystem supports several Critically Endangered species, including the Sumatran Orangutan *Pongo abelii*, Sumatran Rhinoceros *Dicerorhinus sumatranus*, Sumatran Tiger *Panthera tigris sumatrae*, and Sumatran Elephant *Elephas maximus sumatranus*. A notable protected area within the Leuser Ecosystem is the Soraya Research Station, which is recognized for its importance as an orangutan habitat. According to Mariana et al. (2020), the quality of orangutan habitat is primarily determined by the availability of food and nesting trees. In 2016, the Leuser Conservation Forum (FKL), in collaboration with the Aceh Forestry Environmental Service (DLHK), undertook the management of the Soraya Research Station (SRS), situated in a tropical environment with an annual rainfall of 2,450 mm. The temperature in this location ranges between 25–30 °C, with humidity averaging 98% in the morning and 95% in the afternoon. The SRS region has a hilly topography and is located at an elevation of 75–350 m. This research station area is classed as lowland tropical rainforest. Dipterocarpaceae, such as *Shorea* spp. and 'keruing' (Bahasa: Dipterocarp trees), *Dipterocarpus* spp., dominate the vegetation of the SRS. Other plant families that dominate at this location include Euphorbiaceae, Meliaceae, Lauraceae, Moraceae, and Anacardiaceae (Iqbar 2015).

Sampling Procedure

This study was conducted at the SRS from November to December 2020 using the principle of purposive sampling and an observation approach in the form of a nest survey on the path/trail. Strip transects with plots were used for observations and data gathering. The transect length was 100 m, with a single plot running the length and a width of 20 m at 10 observation locations (stations), for a total observation area of 2 ha (Figure 1).

Nest Survey

Nest surveys are conducted by strolling slowly down the trail, paying attention to the canopy at a 180° viewing angle, as well as direct surveys at the locations of nest trees discovered and recorded at the SRS (Atmoko & Rifqi 2012). The discovery of orangutan nest trees serves as the foundation for establishing observation locations. The nest tree is any tree that has an orangutan nest in a condition that allows for observation and collection, such as when practically all of the leaves have fallen or the structure of the twigs is evident.

Nest Tree Profile

Orangutan nest tree profile data, including tree type, diameter, total tree height, free branch height, and canopy area were observed with recordings featuring both common and scientific names, along with essential characteristics for identification. The diameter at breast height (DBH) was used to estimate the diameter of the tree, i.e., approximately 110–120 cm or 30 cm from the top of the buttress. A rangefinder was used to determine the total height of the tree as well as the free height of its branches. The crown area was calculated by measuring the distance between the outermost diagonal line and the tree canopy.

Nest Profile

Height of the nest was measured with a rangefinder, as was the position of nest and canopy of orangutan nest on tree. Orangutan nest position category included (Atmoko & Rifqi 2012):

a. Position 1, nest is at base of main branch of tree.
b. Position 2, nest is in middle or end of a tree branch.
c. Position 3, nest is at top of tree.
d. Position 4, nest is between two or more trees.
e. Position 0, nest is on the ground.

Type of orangutan nest canopy category (Atmoko & Rifqi 2012):

a. Opened canopies,
b. Semi-opened canopies, and
c. Closed canopies.

Vegetation Analysis

Vegetation analysis is an approach to quantify the composition, diversity, and richness of plant community with some parameters described as follow:

a. Density and Frequency (Rahman 2010):

$$\text{Density} = \frac{\text{Total number of individuals of the species in all sampling units}}{\text{Total number of sampling units studies}}$$

$$\text{Frequency} = \frac{\text{Number of sampling units in which species occur}}{\text{Total number of sampling units employed for the study}}$$

$$\text{Relative Density} = \frac{\text{Total number of individuals of the species in all sampling units}}{\text{Total number of all species}} \times 100\ \%$$

$$\text{Relative Frequency} = \frac{\text{Number of occurrences of the species}}{\text{Total number of occurrences in all sampling units}} \times 100\ \%$$

b. Species diversity index (H') analysed using Shannon-Wiener formula:

$$H' = -\Sigma\ P_i \ln P_i\ (P_i = n_i/N)$$

Where:

P_i = Proportion number of individuals to number of individuals all species,

ln = Natural logarithm.

Criteria for diversity index (Magurran 1988):

a. H'>3, species diversity is high
b. 1<H'≤3, species diversity is medium
c. H'<1, species diversity is low

c. Margalef species richness index (D_{mg}) analyzed using the formula:

$$D_{mg} = (S-1)/\ln N$$

Where, S = Number of species observed,

N = Total number of individuals of all species.

Criteria for richness index (Magurran 1988):

a. $D_{mg} \leq 3.5$, richness index is low
b. $3.5 < D_{mg} < 5$, richness index is medium
c. $D_{mg} \geq 5$, richness index is high

Preference Test

The analysis employs the Neu approach, which is based on the frequency of habitat utilization in certain proportions. The assumption is that preference for nest tree type is exactly related to the frequency of nest presence in that tree type. Table 1 includes preference index criteria for data processing to generate preferences for nest tree architectural models (Neu et al. 1974; Bibby et al. 1998; Muin 2007):

a. w <1, not too likely
b. w ≥1, likely

Correlations test

The Statistical Package for the Social Science (SPSS) software was used to conduct quantitative data analysis to investigate the link between nest tree architectural model preferences and nest characteristic data in the form of nest profiles and nest tree profiles (Cantrell et al. 2016). Pearson correlation testing was performed

on the assumption of correlation coefficient value (r), correlation coefficient criteria (Sarwono 2009), specifically:

a. r = 0, uncorrelated
b. 0 > r > 0.25, very week
c. 0.25 > r > 0.5, enough
d. 0.5 > r > 0.75, strong
e. 0.75 > r > 0.99, very strong
f. r = 1, perfect

RESULTS AND DISCUSSION

Orangutan Nest Survey

During the observation at the Soraya Research Station, a total of 59 orangutan nests were identified in 47 distinct trees. Numerous individual nest trees contained more than one orangutan nest.

Distribution of trees encountered along the transects is illustrated in Figure 2. The density of individual trees is a crucial factor in the preference test. The highest number of individual trees was observed at an altitude of 90 m with gentle to steep slope conditions. The vegetation in this area is quite dense, with tree heights ranging from 7–33 m and canopy widths varying from 1–19 m. Due to its proximity to a river, the canopy is partially open. Factors such as height, slope, canopy, and proximity to a river significantly affect orangutan nest establishment (Rijksen 1987; Muin 2007; Prayogo et al. 2016).

Nest Architecture Model

Nests were discovered in 31 of the 103 tree species that were studied (Table 2). Nine of the sixteen tree architectural models that were seen included the kind of tree that contained the nest.The Attims model had the most types (20) among the various nest tree types (six), while the Stone model had nine types with several nest tree variations (Figure 3). The Stone model was observed in all surveyed locations within the lowland rainforests, while the Cook, Fagerlind, and Prevost models were challenging to locate in some observation areas. Seven architectural models where no orangutan nests were discovered are listed in Appendix 8, including Leeuwenberg, Aubreville, Massart, Nozeran, Rauh, Champagnat, and Troll. The number of nest tree species is more influenced by tree attributes such as trunk diameter, tree height, canopy area, and tree architectural model rather than the number of tree species. The architectural models of discovered nest trees feature robust trunks, multiple branches, and are compactly arranged. These features support their suitability as orangutan nest trees. Architectural models of trees without nests exhibit weaker trunks with few poorly organized branches, making them unsuitable as orangutan nest trees due to their inability to support the orangutan's weight. The main factor influencing the selection of nest trees is the stem character, with orangutan nests being predominantly located in large, sturdy trees (Rijksen 1978; Muin 2007; Putro et al. 2019; Mardiana et al. 2020).

The number of tree species suitable for nesting is influenced more by specific tree attributes—such as trunk diameter, tree height, canopy area, and tree

Figure 1. Profile of orangutan nests at Soraya Research Station.

Table 1. Summary of nest tree data in preferences index formula.

Nest Tree	P	N	u	e	W	b
1						
2						
...						
k	Pk	Nk	uk	ek	wk	bp
Total	1000	Σn	1000	Σe	Σw	1000

p—individual proportion of tree architecture models | n—frequency of nest's presence | u—proportion of nests presence (n/Σn) | e—expected value (p × Σn) | w—preference index (u/p).

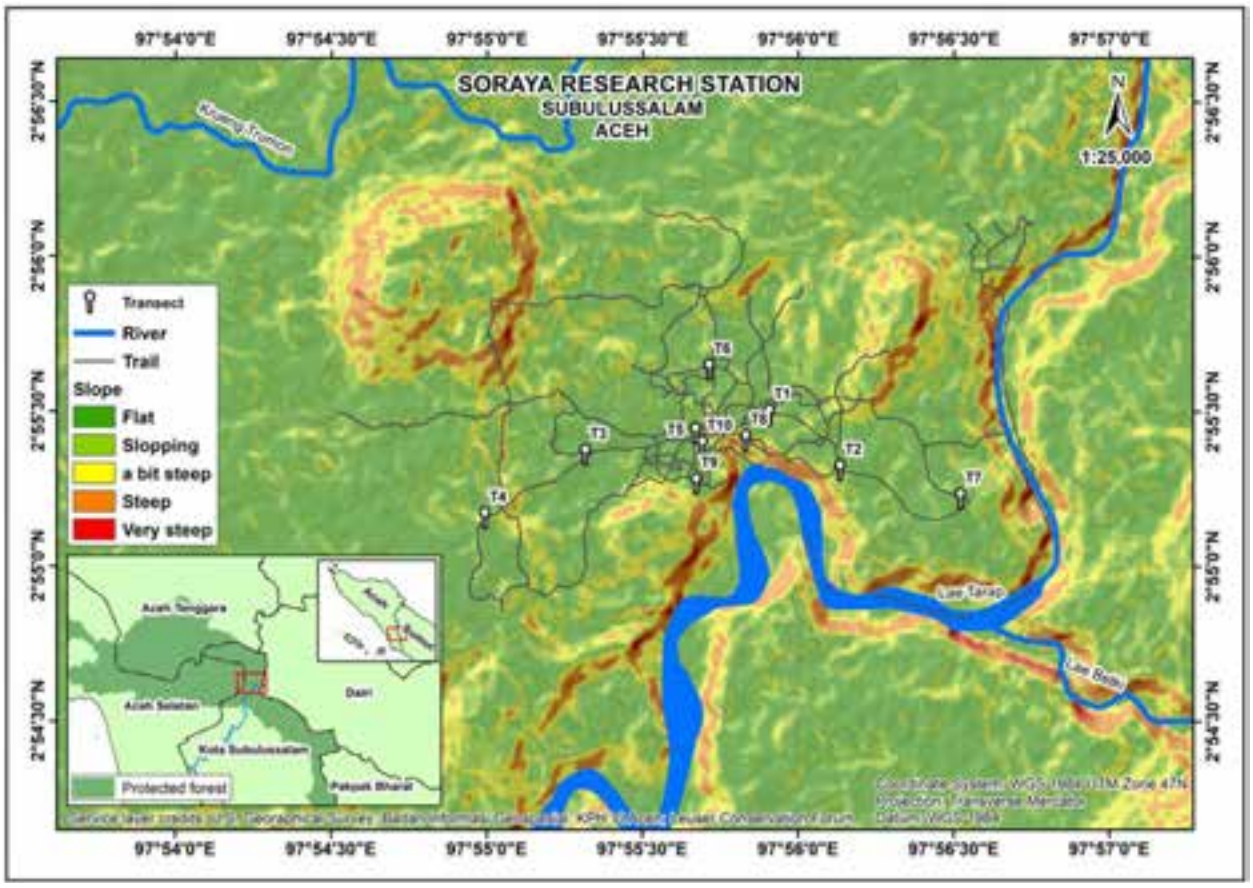

Figure 2. Map of Soraya Research Station showing sampling point of nest survey.

architectural model—rather than merely the number of tree species available. Trees exhibiting the appropriate nest architectural model typically feature strong trunks, numerous well-organized branches, and close compactness, making them well-suited as orangutan nest trees. Conversely, trees lacking these nest features present weaker trunks and fewer, disorganized branches, rendering them unsuitable as orangutan nest trees due to their inability to support the orangutan's weight. Consequently, the main factor in nest tree selection is the tree's physical structure, with orangutan nests most frequently found in larger, sturdier trees (Rijksen 1987; Prayogo et al. 2016).

Vegetation composition and ecology

The assessment of 103 identified species revealed 10 species with the highest RD and RF values (Table 3). Of these, nests are found in eight species. *Shorea multiflora* (Burck) Symington boasted the highest RD value (10.57%), while *Streblus elongatus* (Miq.) Corner, *Shorea leprosula* Miq., and *Palaquium rostratum* (Miq.) Burck exhibited the highest RF value (3.33%). These four tree species are frequently used by orangutans for nesting purposes. The region exhibits a rich diversity of tree species (*H'*) with a Shannon-Wiener diversity index of 4. Moreover, the richness of tree species in the region is substantial with a Margaleff Index (D_{mg}) of 15.96. As a critical element of the orangutan habitat, vegetation plays a significant role. The diversity and richness of plant species impact various aspects of orangutan survival, including feeding, migration, and nesting behaviors. A habitat containing a wide array of food and nest trees improves significantly with the high diversity and richness of plant species. Conducting a vegetation analysis helps understand the composition of the vegetation in a given area. It helps differentiate land cover types and habitat variations based on the most relevant plant species (Rahman 2010; Kuswanda 2014b; Regina et al. 2020).

Preference Test

The findings from the preference test suggest that three tree architectural models are highly favored (Figure 4). Orangutans exhibit a tendency to construct nests based on various factors such as tree height, diameter,

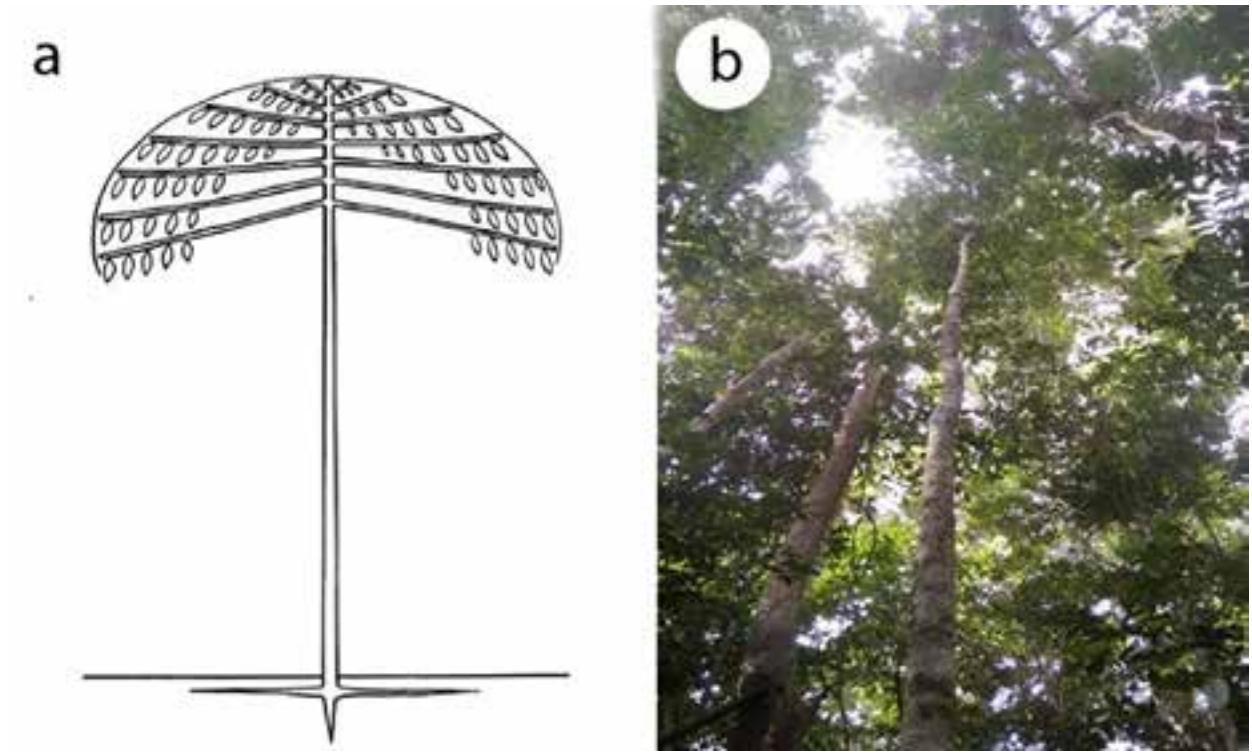

Image 1. a—Illustration of Cook architectural model (Halle et al. 1978) | b—*Monocarpia maingayi* (Hook.f. & Thomson) I.M. Turner. © Anugrah Gilang Permana Lubis.

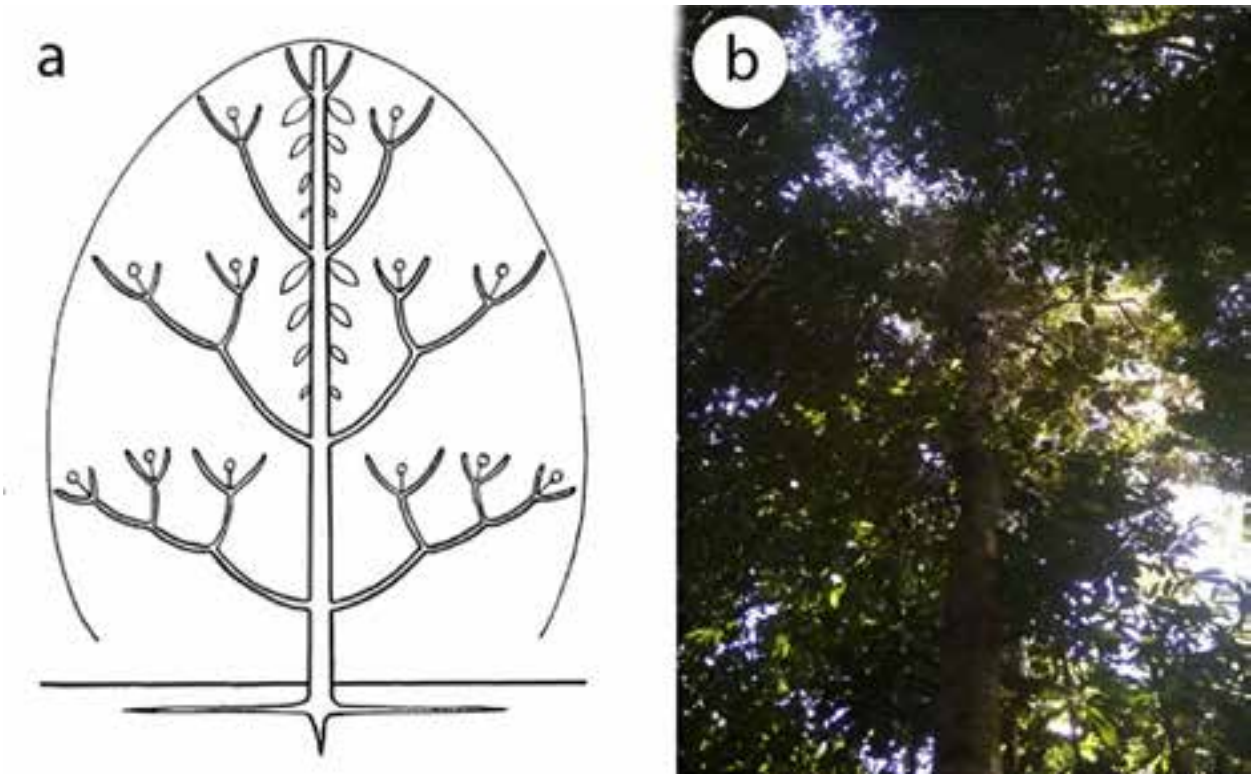

Image 2. a—Illustration of the Scarrone architectural model (Halle et al. 1978) | b—*Lithocarpus javensis* Blume. © Anugrah Gilang Permana Lubis.

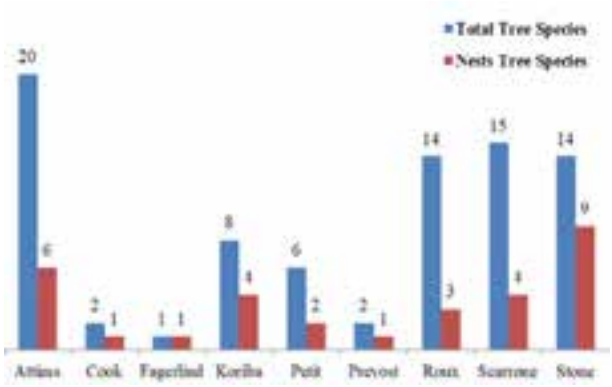

Figure 3. Number of species with nest each architecture models.

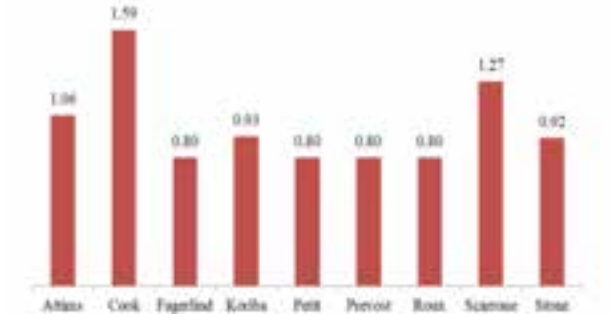

Figure 4. Diagram of preference test result.

crown size, and crown shape, nest height, nest position, and nest canopy. These aspects have a direct bearing on the appearance of the nest. The branch shape and tree size are key characteristics of tree architecture (Muin 2007; Nababan et al. 2021).

The Cook tree model represents a branching structure with a central trunk and multiple branches (Image 1). This type of architecture results from continuous branching originating from the main stem, showing either spiral or crossing (decussate) phyllotaxis. The phyllomorphic branching structure resembles compound leaves and is a subset of plagiotropic branching that includes non-modular or equivalent monopodial or sympodial branches. In this model, branches are closely spaced and leaves are evenly distributed, giving rise to a robust architectural design (Halle et al. 1978).

Scarrone is a branching tree architectural form (Polyaxial) with a vegetative axis divided into trunks and branches (Image 2). Growth takes the form of rhythmic ramification from orthotropic monopodial stems. Sympodial branching consists of non-equivalent orthotropic branches. This model has a strong architectural style and several branches (Halle et al. 1978).

Table 2. Distribution of species across tree architecture models that orangutan nest exist in Soraya Research Station.

Tree architecture models	Species
Attims	*Aglaia* sp.
	Dacryodes costata (A.W.Benn.) H.J. Lam.
	Palaquium rostratum (Miq.) Burck
	Payena lucida A.DC.
	Shorea glauca King
	Shorea multiflora (Burck) Symington
Cook	*Monocarpia maingayi* (Hook.f. & Thomson) I.M.Turner
Fagerlind	*Cyathocalyx sumatranus* Scheff.
Koriba	*Aglaia korthalsii* Miq.
	Aglaia speciosa Blume
	Aporosa antennifera (Airy Shaw) Airy Shaw.
	Streblus elongatus (Miq.) Corner
Petit	*Diospyros pyrrhocarpa* Miq.
	Durio oxleyanus Griff.
Prevost	*Knema cinerea* (Poir.) Warb.
Roux	*Garcinia celebica* L.
	Shorea leprosula Miq.
	Syzygium spp.1
Scarrone	*Barringtonia scortechinii* King
	Lithocarpus javensis Blume
	Mangifera foetida Lour.
	Xanthophyllum vitellinum (Blume) D.Dietr.
Stone	*Aporosa lunata* (Miq.) Kurz
	Diospyros bangkana Bakh.
	Garcinia dioica Blume
	Gluta renghas L.
	Lithocarpus sp.
	Lithocarpus wrayi (King) A.Camus
	Mischocarpus sundaicus Blume
	Rinorea sclerocarpa (Burgersd.) Melch.
	Syzygium spp.2
Total	
nine models	31 Species

Attims is a tree architectural model that belongs to the branching tree (Polyaxial) category, with a vegetative axis that is separated into trunk and branches (Image 3). Continuous ramification from orthotropic monopodial stems drives growth. Monopodial branching is equivalent to orthotropic growth direction. The branches are grouped tightly together with the same size, and the leaves are evenly distributed with many twigs, resulting

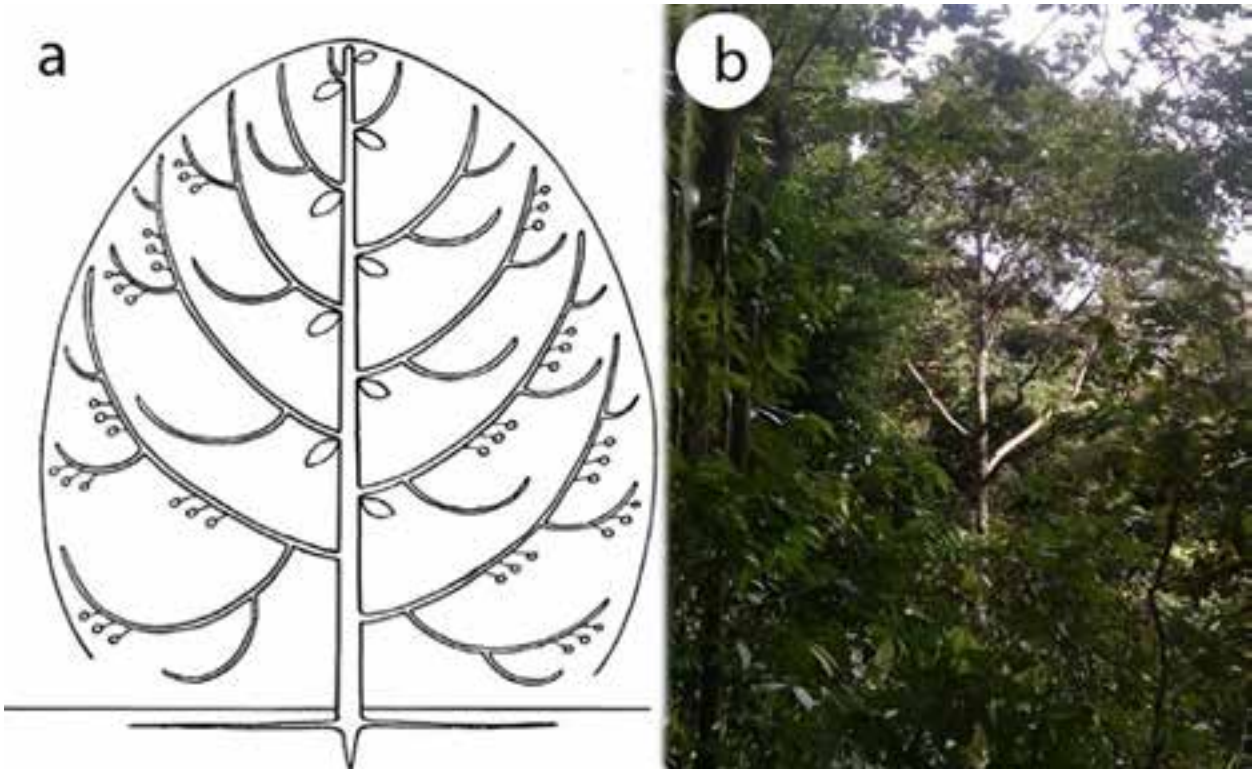

Image 3. a—Illustration of the Attims architectural model (Halle et al. 1978) | b—*Parashorea lucida* Kurz. © Anugrah Gilang Permana Lubis.

Table 3. Major tree species utilized by orangutan and its ecological indices in Soraya Research Station.

	Species	Models	RF (%)	RD (%)	H	D_{mg}
1	*Shorea multiflora* (Burck) Symington	Attims	2.59	10.57	4	15.96
2	*Streblus elongatus* (Miq.) Corner	Koriba	3.33	7.89		
3	*Artocarpus kemando* Miq. *	Champagnat	2.96	5.37		
4	*Shorea leprosula* Miq.	Roux	3.33	4.7		
5	*Palaquium rostratum* (Miq.) Burck	Attims	3.33	3.86		
6	*Barringtonia scortechinii* King	Scarrone	2.96	2.35		
7	*Gluta renghas* L.	Stone	2.22	3.02		
8	*Syzygium* sp. 1	Roux	2.59	1.51		
9	*Monocarpia maingayi* (Hook.f. & Thomson) I.M.Turner	Cook	2.22	1.85		
10	*Macaranga pruinosa* (Miq.) Müll. Arg. *	Rauh	1.85	2.18		

*—non-nest tree

in a solid architecture (Halle et al. 1978).

Three tree architectural models—Cook, Scarrone, and Attims—demonstrate a structure with trunks and branches. While Scarrone displays a sympodial growth form, both Cook and Attims exhibit monopodial growth. These models are characterized by robust branches and a closely spaced design, enabling the trunk, branches, and twigs to support the orangutan's weight. Cook's architectural design features a circular crown with horizontal branches, whereas Attims and Scarrone present a ball-shaped crown with vertical branches.

Correlation test

In terms of the correlation test, the preference index for the nest tree architecture model displays a sufficient, yet statistically insignificant correlation with parameters

Table 4. Pearson's correlation coefficient (r) of related parameters.

Parameter	Correlation coefficient (Pearson correlation)							
	w	PS	KS	TS	TPS	TBC	LT	LB
w	1	0.108	0.161	0.348	0.350	0.305	0.264	0.289
PS	0.108	1	0.954**	0.794*	0.930**	0.409	0.819**	0.616
KS	0.161	0.954**	1	0.658	0.909**	0.306	0.752*	0.659
TS	0.348	0.794*	0.658	1	0.779*	0.665	0.710*	0.419
TPS	0.350	0.930**	0.909**	0.779*	1	0.339	0.899**	0.695*
TBC	0.305	0.409	0.306	0.665	0.339	1	0.358	-0.079
LT	0.264	0.819**	0.752*	0.710*	0.899**	0.358	1	0.780*
LB	0.289	0.616	0.659	0.419	0.695*	-0.079	0.780*	1

w—preference index | PS—nest position | KS—nest canopy | TS—nest height | TPS—nest tree height | TBC—free branch height | LT—canopy area | LB—basal area | **—significant at the 0.01 level | *—significant at the 0.05 level.

tested. The factors correlating in descending order are nest tree height, nest height, branch free height, basal area, and crown area (Table 4). On the other hand, there is a weak correlation between nest position and nest canopy. A moderate to extremely strong and significant association exists between nest profile parameters and the nest tree profile. The primary aim of this investigation was to explore the relationship between nest tree selection and the preference index value for the nest tree profile.

The architectural structure of trees, encompassing branching forms and crown shapes, significantly influences orangutan nesting preferences, as evidenced by the adequate correlation between the preference index and nest features. These elements, including the nest site, canopy, and height, play pivotal roles in defining the nest qualities (Muin 2007). Nest profile and nest tree profile stand as influential determinants of orangutan nesting behavior. The correlation test findings strongly demonstrate a positive and substantial association between the nest profile and the nest tree profile. The height of the nest correlates directly with the height of the nest tree, while the position of the nest is governed by the dimensions of the nest tree, such as basal area and crown area (Khoetiem et al. 2014). Moreover, the tree's architectural model, particularly characterized by a canopy shielding the orangutan's nest, affects the selection of nest trees. Previous research has suggested that orangutan nests are more commonly found in trees with a canopy structure and area sufficiently large to shelter the nest or canopy (Nasution et al. 2018).

CONCLUSION

The preference index value was determined by calculating the proportion of the frequency of orangutan nests across eight architectural models of trees observed during the study. Among these models, the Cook, Scarrone, and Attims architectures emerged as the most preferred for nesting activities. This preference is supported by the correlation coefficient results, which indicate a significant relationship between orangutan nesting behaviors and specific tree architecture models. These findings highlight the importance of these models in shaping habitat components critical for the conservation of orangutans.

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ARTICLE

Small Wild Cats Special Series

Diet of Rusty-spotted Cat *Prionailurus rubiginosus* (I. Geoffroy Saint-Hilaire, 1831) (Mammalia: Carnivora: Felidae) in Sanjay Gandhi National Park, Mumbai, India

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Abstract: The 103.68 km^2 Sanjay Gandhi National Park (SGNP), Mumbai, exists amidst human densities that figure among the highest in the world. The rich biodiversity of SGNP includes the Rusty-spotted Cat *Prionailurus rubiginosus*, endemic to India, Sri Lanka, and Nepal, and categorised as 'Near Threatened' on the IUCN Red List. Little is known about its ecology and the dynamics of its coexistence with the other small carnivores in SGNP. We conducted a study with citizen volunteers to explore the diet of the Rusty-spotted Cat and other sympatric small carnivores in SGNP and in the adjoining human-dominated areas of Yeur village, Shivaji Nagar, Dahisar Quarry, and Aarey Milk Colony. After initial training, the volunteers collected scat samples from all forest ranges in SGNP and the surrounding areas outside, following defined protocols. Seventy-eight scat samples were analysed for species assignments using standardised molecular techniques, felid-specific primers, and DNA sequencing, and 24 were identified as of the Rusty-spotted Cat. The contents of the samples were examined under a microscope to identify prey remains. Results were presented as the mean number of scat samples containing remains of specific taxa with 95% Confidence Intervals. Diet estimated from 22 Rusty-spotted Cat scat samples and 52 samples of other small carnivores revealed rodents to be the major prey of the entire group. However, a higher proportion of Rusty-spotted Cat scat samples had remains of rodents (95%) and reptiles (6%) as compared to samples of other small carnivores, i.e., 79% with rodent remains and none with remains of reptiles. On the other hand, a lower proportion of Rusty-spotted Cat scat samples had remains of insects (14%), plant matter (9%), and birds (5%) than samples of other small carnivores (40% plant matter, 38% insects, 17% birds). Our results highlight the role of small carnivores, especially Rusty-spotted Cat in regulatory services through pest control.

Keywords: Ecosystem services, molecular tools, rodent prey, scat analysis, small carnivores.

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Author contribution: SM, NK and PVK conceptualised the study. PK, ARG, KP, SM and PVK analysed and mapped the samples. SM wrote the manuscript. PVK, PK and NK reviewed and edited the manuscript.

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INTRODUCTION

Small carnivores have demonstrated their value in controlling pests, drawing attention to the larger effort required to monitor their responses to changes in their environment, in order to effectively plan their conservation (Marneweck et al. 2021; Bandyopadhyay et al. 2024). Further, Marneweck et al. (2022) argue that small carnivores are an ideal group to study for understanding the effects of global change due to their higher diversity, intermediate trophic position, wider ecological niches, and higher reproductive rates than of large carnivores.

Sanjay Gandhi National Park (SGNP), spread over an area of 103.68 km^2, is unique in being located within one of the world's most densely populated cities and is popularly referred to as the lungs of Mumbai (Everard 2019). However, the protected area faces severe threats from human encroachments and rapid development along its boundary (Zérah & Landy 2013; Shinde 2017; Engineer 2018). Although several studies on various taxa have been undertaken in SGNP, the Leopard *Panthera pardus* has received most research attention, largely due to severe conflict issues (Munde & Limaye 2013; Surve et al. 2022). Eight other carnivore species have been reported in SGNP, including the Rusty-spotted Cat *Prionailurus rubiginosus* and Jungle Cat *Felis chaus,* Small Indian Civet *Viverricula indica*, Asian Palm Civet *Paradoxurus hermaphroditus*, Indian Grey Mongoose *Herpestes edwardsii*, Ruddy Mongoose *Herpestes smithii*, Golden Jackal *Canis aureus* and Striped Hyena *Hyaena hyaena* (Surve et al. 2015; Mukherjee et al. 2020). All these species are placed in Schedule I of the Wildlife (Protection) Amendment Act, 2022. Among these, the Rusty-spotted Cat is a species of conservation priority in India and SGNP, as the larger part of its relatively restricted global distribution falls within the country (Munde & Limaye 2013; Mukherjee et al. 2016a).

The Rusty-spotted Cat is categorised as 'Near Threatened' on the IUCN Red List, and is endemic to India, Sri Lanka, and Nepal (Mukherjee et al. 2016a). It is the smallest member of the cat family, weighing 2 kg on average (Pocock 1939; Nowell & Jackson 1996; Sunquist & Sunquist 2002). Based on preliminary information on habitat requirements, a population decline of up to 25% is predicted in the next decade, largely due to habitat loss associated with large-scale expansion of agriculture, development and urbanisation (Mukherjee et al. 2016a; Sharma & Dhakad 2020). Some observations on the cat suggest that it largely feeds on small mammals (Patel 2006; Athreya 2010; Langle 2019). Although SGNP has a captive breeding facility for the Rusty-spotted Cat, there is very little information available on its ecology within SGNP. The same applies to all the other small carnivores with only sporadic reports from by-catch data on camera traps placed for the Leopard.

Dietary studies can provide useful insights into several aspects of small carnivore ecology, e.g., community dynamics, competition, and niche spaces, and provide information on ecosystem services and functioning (McNab 2002; Ćirović et al. 2016; Everard 2019; Müller et al. 2022). A reason for this low volume of information on small carnivores is perhaps the difficulty in studying their ecology, especially diet and behaviour due to their largely cryptic habits. With molecular techniques, these aspects can now be explored through non-invasive means (Piggott & Taylor 2003). Available literature on the diet of some small cats suggests that rodents form the major prey of the Jungle Cat (Mukherjee et al. 2004; Majumdar et al. 2011), of the Leopard Cat *Prionailurus bengalensis* (Rabinowitz 1990; Grassman et al. 2005; Rajaratnam et al. 2007; Shezad et al. 2012; Lorica & Heany 2013, Parchizadeh et al. 2023) and of the Caracal *Caracal caracal* (Mukherjee et al. 2004; Braczkowski et al. 2012). In contrast, viverrids and herpestids feed largely on insects and plant matter (Su & Sale 2007; Kalle et al. 2012; Akrim et al. 2023).

We involved citizen volunteers in our research and exposed them to the scientific methods used in studying the diets of small carnivores (Mukherjee et al. 2021). In this paper, we present results from our study on the diets of Rusty-spotted Cat and other co-occurring small carnivores in SGNP and the adjoining areas in Yeur village, Shivaji Nagar, Dahisar Quarry, and Aarey Milk Colony.

Study area

SGNP is credited with providing several ecosystem services, including provisioning of water to the metropolis, recreation to tourists who visit daily and supporting services for maintaining biodiversity (Everard 2019) (Figure 1). Tulshi and Vihar lakes are located within SGNP and provision part of the city's water requirements; several streams and rivers flow through SGNP and into the Arabian Sea (Munde & Limaye 2013).

Due to its proximity to the coastal region, SGNP experiences a mean humidity of 75% (Munde & Limaye 2013). The southwest monsoon occurs from June to September with an average of 2,000 mm of rain (Munde & Limaye 2013). The mean annual temperature is 27 °C, occasionally soaring up to 40 °C, and January is generally the coolest month with a mean minimum temperature

Figure 1. Locations of scat samples of the Rusty-spotted Cat and small carnivores in Sanjay Gandhi National Park and adjoining areas.

of 19 °C (Munde & Limaye 2013).

The major forest types in SGNP are Southern Moist Teak-bearing, Southern Moist Mixed Deciduous, Mangrove Scrub, and Western Subtropical Hill forests (Champion & Seth 1968). SGNP falls within the 5A-Malabar Plains Biogeographic Zone (Rogers et al. 2002).

The faunal diversity list of SGNP includes 172 species of butterflies, 50 species of herpetofauna, 286 species of birds, and around 43 mammalian species (Kasambe 2012). Apart from the Leopard and smaller carnivores, mammals occurring in SGNP include Sambar *Rusa unicolor*, Chital *Axis axis*, Southern Red Muntjac *Muntiacus muntjac*, Indian Chevrotain *Moschiola indica,* Wild Pig *Sus scrofa*, Northern Plains Gray Langur *Semnopithecus entellus*, Bonnet Macaque *Macaca radiata,* Rhesus Macaque *M. mullata*, Black-naped Hare *Lepus nigricolis*, Indian Crested Porcupine *Hystrix indica*, palm squirrels *Funambulus* and several species of murid rodents (Edgaonkar & Chellam 1998; Pradhan 2002; Surve et al. 2015). Due to numerous human settlements within SGNP, several domestic mammals are also present, including Domestic Dog *Canis familiaris*, Domestic Cat *Felis catus*, Goat *Capra hircus*, Water Buffalo *Bubalus bubalis* and Cattle *Bos taurus* (Surve et al. 2015).

MATERIALS AND METHODS

In March and April 2017, volunteers from Mumbai were trained in field techniques which included locating and collecting scats, using field instruments and software such as hand-held GPS, mobile phone applications for marking coordinates and uploading data, monitoring water bodies and streams, camera trapping, and the basics of GIS applications (Mukherjee et al. 2021). Soon after the training, from 16 April 2017 to 15 May 2018, volunteers formed three groups, one for each of the three Forest Ranges closest to their residences and visited various locations within SGNP to collect scat samples. Each group had a team leader who prepared a schedule for sampling, which was restricted to weekends and holidays. Each team comprised two to four volunteers who walked trails within the Forest Range and collected scat samples following a specific protocol. Only intact samples were collected. Once a scat was located, it was photographed along with a labelled vial with the date, geographic coordinates and sample number, a scale and GPS unit or android phone with the geo-coordinates visible, placed next to it. This photograph, along with the names of members of the sampling team, date, time, name of the Forest Range, and geographic coordinates were uploaded onto the android application Epicollect 5 (Aanenson et al. 2009),

which could be accessed by the investigators.

The scat samples were shipped to the Indian Institute of Science Education and Research (IISER) Tirupati for further analysis. Due to the large number of scat samples collected and the limited time to analyse them, they were initially assigned to cats because of their compact shape that is segmented and with tapering ends (Chame 2003) and based on personal observations by the first author. A small portion of the samples that was most intact and smooth, and visually assigned to cats, was kept aside for molecular analysis and assignment to a predator species. These samples were weighed and analysed for diet remains. Prey remains such as teeth, bones, feathers and other undigested matter were observed under a microscope. The percentage of samples containing specific prey remains was determined (Klare et al. 2011). Data were analysed using R version 3.2.3 (R Development Core Team 2016), package "boot" version 1.3–24 (Canty & Ripley 2019). Sub-samples equalling original sample sizes (n=22 for Rusty-spotted Cat and n=52 for other unidentified small carnivores) were analysed using non-parametric bootstrap analysis with 6,000 simulations. Results were presented as the mean number of scat samples containing remains of specific taxa with basic 95% Confidence Intervals.

We used a commercially available stool DNA extraction kit from HiMedia Laboratories following the manufacturer's protocols, with a control in each set of extractions to detect any contamination. We targeted the 16s rRNA region of the mitochondrial DNA for assigning the samples to predators, using primers designed by Mukherjee et al. (2016b). The primers amplified a region of 200 bp and their sequences were as follows:
Felid16srRNA Forward: 5' AATTGACCTTCCCGTGAAGA 3'
Felid16srRNA Reverse: 5' TCCGACTGGTTAGTCTAGAT 3'

The T_m of both primers was 58 °C, and we used an annealing temperature of 50 °C in the Polymerase Chain Reaction (PCR) programme. PCR reactions were set up in volumes of 20 µl with a PCR Master Mix (MM) (Origin Diagnostics, Kerala). Bovine Serum Albumin (BSA) (Sigma-Aldrich) was added to the reactions for better results. The volumes and concentrations of the reagents used were as follows: 5 ml of MM, 2 µl of 2 mM primers, 2µl of 4 mg BSA, 7 µl of Mili-Q water, and 4 µl of DNA extract. Specifications of the PCR program used were initiation at 94 °C for 10 minutes, denaturation at 94 °C for 30 seconds, amplification at 50 °C for 45 seconds, elongation at 72 °C for 50 seconds, and final elongation 72 °C for 10 seconds. The 2nd, 3rd and 4th steps were repeated for 59 cycles.

We used UV-treated hoods and had PCR negative controls to detect any contamination during the PCR stage.

We viewed the PCR products through gel electrophoresis on a 2% agarose gel (HiMedia laboratories) with Orange G loading dye from Sigma-Aldrich and GelRedTM DNA stain (Life Technologies, India). We loaded a 100 bp ladder (HiMedia laboratories) along with the PCR products as reference. The PCR products that amplified with the felid primers were sent to Chromgene Biotech Private Limited for forward and reverse reaction sequencing. We used Chromas version 2.6.5 (Technelysium Pty Ltd.) to view and clean sequences, and then used the BLAST analysis (Basic Local Alignment Search Tool) on NCBI (McGinnis & Madden 2004) for identifying species. We aligned sequences using ClustalW in MEGA 6.0 (Tamura et al. 2013) for alignments. For sequences that were identified as Rusty-spotted Cat, we constructed a Neighbour Joining phylogenetic tree in MEGA 6.0 (Tamura et al. 2013), rooted with members of the genus *Felis* (Domestic Cat, Accession Number: AF006453.1; Afro-Asiatic Wildcat *F. lybica*, Accession Number: AF006395.1; Jungle Cat, Accession Number: AF006393.1). We also included Leopard Cat *P. bengalensis* (Accession Number: AF006437.1), Fishing Cat *P. viverrinus* (Accession Number: AF006451.1) and an existing sequence of Rusty-spotted Cat (Accession Number: NC_028304.1) to depict the accuracy of the assignments. All existing sequences were obtained from NCBI (Clark et al. 2016). We mapped the locations of Rusty-spotted Cat and other small carnivore scat samples used in the diet analysis using QGIS Version 2.8.2-Wien (QGIS 2015).

RESULTS

Over approximately five months, 126 scat samples were collected in Yeur, Tulshi and Borivali Forest Ranges within SGNP and surrounding areas in Yeur village, Shivaji Nagar, Dahisar Quarry and Aarey Milk Colony (Figure 1). From these, 78 were visually assigned to small cats based on their shape. These 78 were subjected to DNA analysis, of which 30 samples (38%) gave positive results with the felid primers and were sent for sequencing. Results from BLAST revealed that 24 of these were of Rusty-spotted Cat, comprising 20 from Yeur Range, two from Shivaji Nagar, and one each from Tulshi Range and Dahisar Quarry area. Five were not of felids but most similar to mongoose species. One scat did not generate a good enough sequence for assignment. The average weight of Rusty-spotted Cat scat was 4 g (range: 1.2–16.5

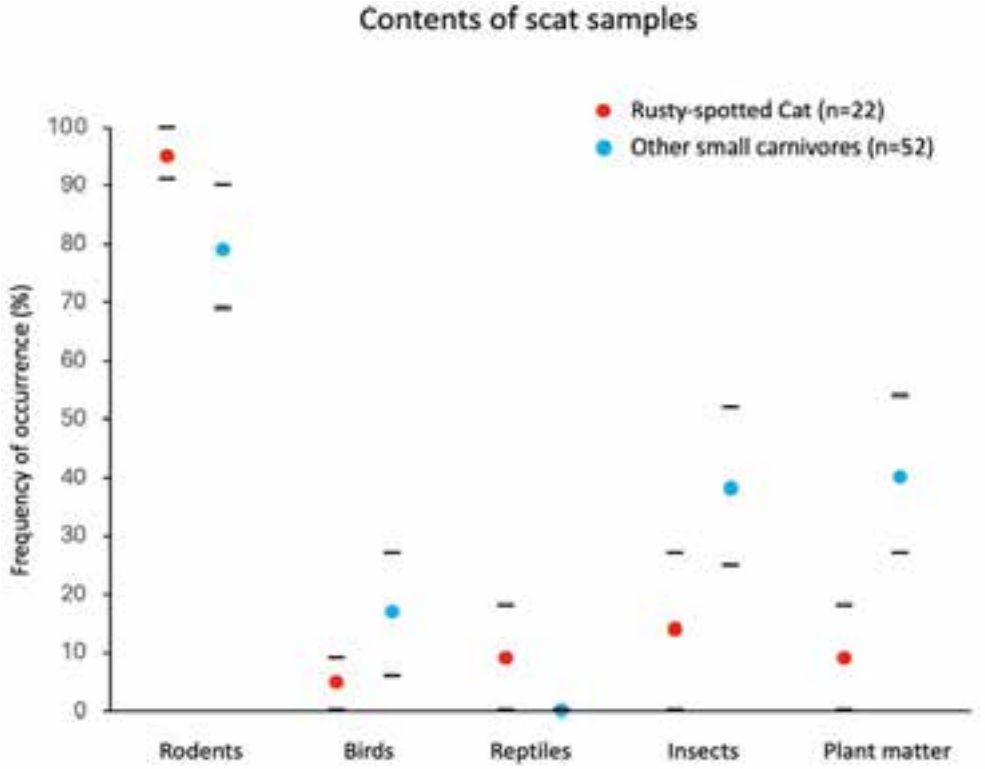

Figure 2. Diet of Rusty-spotted Cat and other small carnivores in SGNP showing bootstrap means with confidence Intervals.

g). No Jungle Cat scat was reported through molecular analysis.

Seventy-four scat samples with discernible food remains were analysed for diet and showed a predominance of rodent remains (Figure 2). Of the 24 scat samples assigned to Rusty-spotted Cat, two from Yeur Range had no identifiable remains and were not included in the diet analysis. The phylogeny of the sequences supported the BLAST results of assignments to Rusty-spotted Cat (Figure 3). A comparison of diets revealed a higher presence of rodents in the diet of the Rusty-spotted Cat (Table 1).

We presume that the rodents consumed by the Rusty-spotted Cat belong to the *Mus* genus, based on size and morphological characteristics of rodent molars found in the sample (Image 1).

Table 1. Mean percentage frequency of prey items in scat of Rusty-spotted Cat and other unidentified small carnivores from Sanjay Gandhi National Park and surrounding areas in Mumbai, India, with bootstrap 95% confidence intervals (CI)

Prey	Rusty-spotted Cat (n = 22) Mean (%), (95% CI)	Other small carnivores (n = 52) Mean (%), (95% CI)
Rodents	95, (91–100)	79, (69–90)
Birds	5, (0–27)	17, (6–27)
Reptiles	6, (4–18)	0
Insects	14, (0–27)	38, (25–52)
Plant matter	9, (0–18)	40, (27–54)

DISCUSSION

Our study is the first to involve citizen volunteers in sampling scat of small carnivores in India and to systematically document Rusty-spotted Cat diet. Our results of murid rodents forming the predominant diet of the Rusty-spotted Cat corroborate earlier observations (Patel 2006; Athreya 2010; Langle 2019). Systematic studies on the diets of other small cat species in varied habitats reiterate the role of small cats as rodent control agents and highlight their ecosystem services (Rabinowitz 1990; Mukherjee et al. 2004; Grassman et al. 2005; Rajaratnam et al. 2007; Majumdar et al. 2011; Braczkowski et al. 2012; Shezad et al. 2012; Lorica & Heany 2013, Mukherjee et al. 2016b; Parchizadeh et al. 2023).

In contrast, the diets of the other small carnivores show a much higher proportion of insects and plant matter than consumed by the Rusty-spotted Cat. This is in

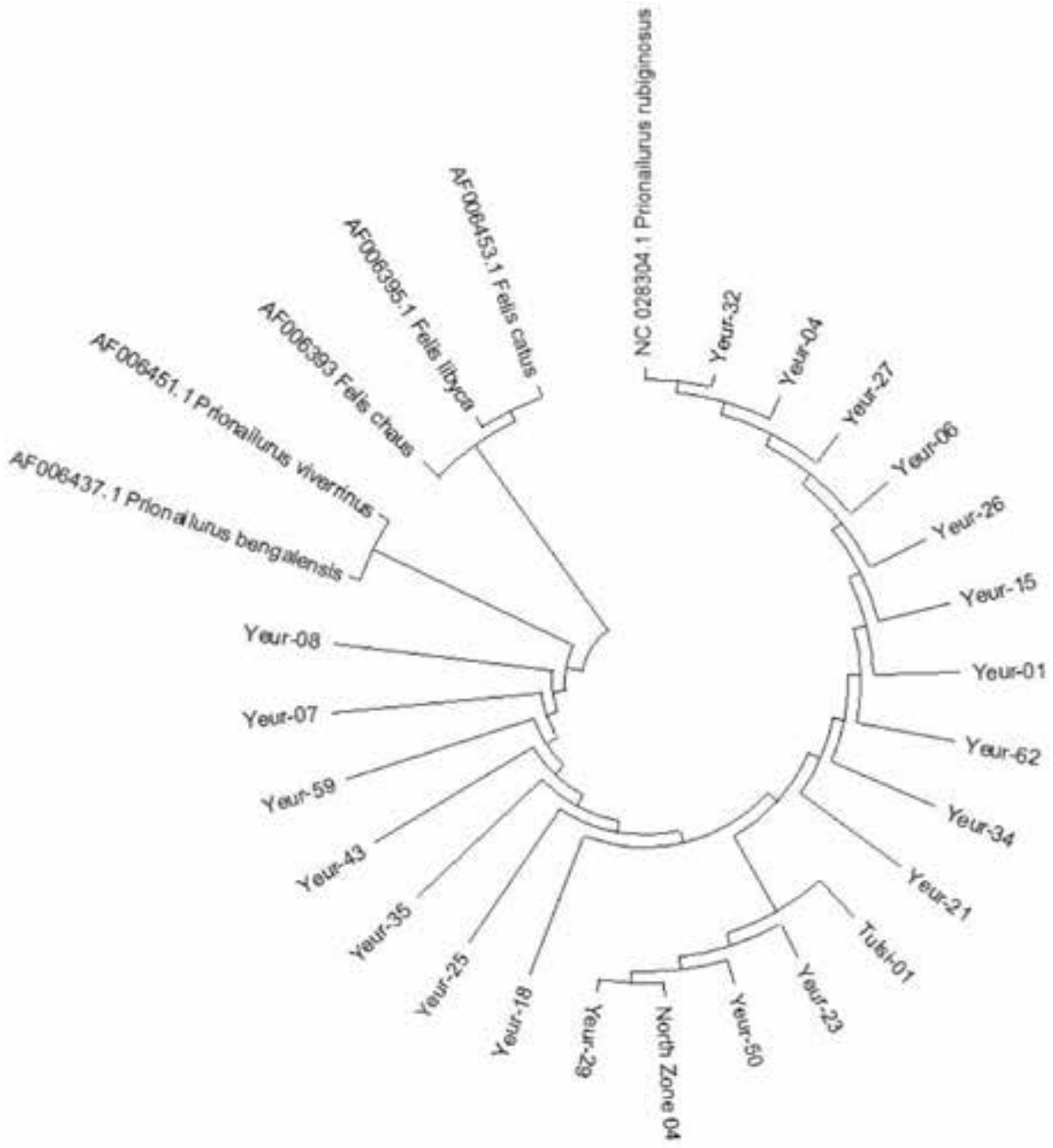

Figure 3. Neighbour Joining Tree of Rusty-spotted Cat 16s rRNA mitochondrial DNA sequences from scat samples used for diet analysis.

line with existing information (Su & Sale 2007; Kalle et al. 2012; Akrim et al. 2023).

Future studies can focus on standardising primers for other carnivore species, identifying the prey remains in scat with greater precision through Next Generation Sequencing work, quantifying diets and estimating prey abundance for more precise and meaningful results (Mukherjee et al. 2004; Klare et al. 2011; Shezad et al. 2012).

Visual assignment of scat had an error of more than 60%, where scat samples of other carnivores were assigned to small cats. The primers designed for detecting felids gave an error of 17%, where five mongoose scat samples were amplified, an error that was noticed after sequencing. Based on these, we recommend using PCR amplification followed by sequencing for assigning scat to species for obtaining reliable results. Further, there is a possibility of false negatives where the primers

Image 1. Rodent dentition found in a scat sample of Rusty-spotted Cat identified as *Mus* sp., scale: 1 mm. © Arati Gawari & Kartik Pillai.

did not amplify small cat DNA, and some scat samples could have erroneously been placed in the unidentified carnivore group, biasing the diet results. In the future, this can be addressed by using additional primer sets designed on other regions of the DNA (Liu et al. 2023).

Studies conducted in other parts of the country had a larger proportion of 47–67% of scat assigned to felids using molecular tools (Mukherjee et al. 2010, 2016b), whereas only 38% in the current study in SGNP were detected as being felid scat. This can either be attributed to the poorer condition of the scat samples during collection or smaller populations of small cats in SGNP. A drawback of this study was that most scat samples were collected in the Yeur Range, which could reflect the possible unequal effort put in by volunteer teams, since each team was assigned to a specific forest range and adjoining areas outside.

A report by Everard (2019) listing the potential ecosystem services of SGNP includes possible regulatory services by predators that can be hampered by habitat destruction. The results of our project highlight the importance of generating information on such services, especially around the fringes and outside the perimeter of SGNP. We also found scat near human habitation outside the boundary in Yeur and Dahisar Quarry, though most of the sampling was restricted within SGNP. Unlike the Leopard, small carnivores do not pose a threat to human lives, so the conflict with humans is unidirectional where developmental activities are directly responsible for habitat loss.

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ARTICLE

An avifaunal checklist of the Bani Wildlife Sanctuary, Jammu & Kashmir, India

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Abstract: Protected areas are important for biodiversity conservation as they offer suitable habitats and protection from anthropogenic activities that harm wildlife. Establishing additional protected areas such as National parks, Wildlife sanctuaries, and Biosphere reserves reduces the threat to a species compared to non-protected areas. Before designating an area as protected, it's crucial to identify which species are threatened and require urgent conservation efforts. The present study was undertaken in the Bani Wildlife Sanctuary, which falls in the western Himalayas, from March 2021 to February 2022 to compile an avifaunal checklist of the sanctuary. The checklist was created by conducting systematic field surveys and opportunistic bird sightings. A total of 135 bird species belonging to 45 families were recorded during the present study. The family Muscicapidae, represented by 17 species, dominates the list. Our study confirmed that the Bani Wildlife Sanctuary supports a rich avifaunal community with three species Western Tragopan *Tragopan melanocephalus,* Cheer Pheasant *Catreus wallichi,* and Bearded Vulture *Gypus barbatus* classified as Threatened in the global Red List by the International Union for Conservation of Nature (IUCN).

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Author contributions: IQ—conceptualization, methodology, field Work and manuscript writing. BAB—conceptualization, supervision, review and editing of the manuscript. WSM—conceptualization, methodology and field work. TS—methodology and field work. ANL—methodology and original draft preparation.

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INTRODUCTION

Birds form an important component of an ecosystem and hold a significant place because they are quite noticeable and immensely appreciated by humans (Mahmood et al. 2021). They have largely been considered as indicators in the conservation and monitoring of biodiversity (French 1999; Browder et al. 2002). Birds play an informational role in gaining public attention towards natural habitats. Their abundance and diversity in pristine habitats can serve as an indicator of the health status of that habitat (Collar & Andrew 1988; Piersma & Lindstrom 2004; Mahmood et al. 2021). Birds are very susceptible to habitat changes (Browder et al. 2002; Perrow & Davy 2002) and provide a gamut of important services in an ecosystem. They act as long-distance pollinators, scavengers, seed dispersers, and bio-control agents for various crop pests (Malik et al. 2023). Their high or low density is directly linked to the health status of an ecosystem (Loreau et al. 2001; Mahmood et al. 2021) and provides an early warning for climatic change (Pearce et al. 2015).

The Union Territory (UT) of Jammu & Kashmir is bestowed with fascinating avifaunal diversity, which is remarkable at higher altitudes, due to its distinct climatic conditions and unique physiography. This region is recognized for its significant avian diversity, harboring 28 Important Biodiversity Areas (IBAs) (Islam & Rahmani 2004; Rahmani et al. 2012; Sohil & Sharma 2019). As per the recent IUCN assessment, 32 species of birds have been included in different threatened categories of the IUCN Red List (Suhail et al. 2020).

The Indian avifaunal checklist recognizes a total of 1,317 bird species for India, which constitute about 12.5% of the world's avian species (Praveen et al. 2019; Praveen & Jayapal 2022). Birds of mountainous regions display a wide range of distributional patterns with some limited to lower elevation bands and others occupying higher altitudinal ranges (Price et al. 2011). Moreover, climatic variations, including temperature, moisture, and oxygen levels, play a significant role in determining species diversity, with mountainous regions experiencing greater turnover and variety at specific elevations, as observed by Graham et al. (2014).

In understanding the consequences of habitat degradation and climate change on a species and ecosystem, baseline data is necessary before initiating any conservation effort (Llanos et al. 2011). Bird surveys provide valuable information about basic and applied ecology and help designate conservation priority sites (Daniels et al. 1991; Peterson et al. 2000; Byju et al. 2023). Biodiversity inventories/checklists serve as crucial repositories for documenting species distribution, biogeography, and conservation status. Given the pivotal role of birds in conservation and environmental assessments, there's a pressing need to enhance our ecological understanding of how bird diversity patterns and avian community structures influence conservation decisions (Kati & Sekercioglu 2006). Against this backdrop, the current study was conducted in the newly established Bani Wildlife Sanctuary (hereafter BWS) to compile an avifaunal checklist for future research endeavors.

MATERIAL AND METHODS

Study area

The newly declared BWS is named after the major town Bani of District Kathua. The sanctuary spreads over an area of 99.67 km². The area is located between 32.758–32.889˚ N and 74.680–75.871˚ E with an altitude range of 1,960–4,000 m (Figure 1). The sanctuary experiences a temperate type of climate and is characterized by several habitat types: coniferous forest, mixed forest, oak forest, riparian forest, alpine scrub, alpine meadows, rocky mountains, and cultivated land. The prominent fauna of the sanctuary includes Himalayan Serow *Capricornis sumatraensis thar*, Himalayan Tahr *Hemitragus jemlahicus*, Himalayan Goral *Naemorhedus goral*, Kashmir Musk Deer *Moschus cupreus*, Leopard *Panthera pardus*, Black Bear *Ursus thibetanus*, and Himalayan Brown Bear *Ursus arctos isabellinus* (Quyoom et al. 2023).

Data collection

The present study was conducted from March 2021 to February 2022. Systematic field surveys were conducted early in the morning before 0800 h and late evening after 0500 h aligning with birds' most active periods, as highlighted by Thakur (2010). Field binoculars (Nikon 10 × 50) and digital cameras (Nikon D-500 24 MP with 200–500 mm lens) were used for observation and capturing bird photographs. Birds were identified using established field guides of Ali & Ripley (1987), and Grimmett et al. (2016), in addition to consulting avian experts, birding groups/clubs, and verified Facebook groups, as suggested by Sharma et al. (2018). The threatened status of birds provided in the checklist is as per the IUCN Red List (IUCN 2022) and the birds were categorized as A – Abundant (sighted more than 30 times), C – Common (sighted up to less than 15 times), O

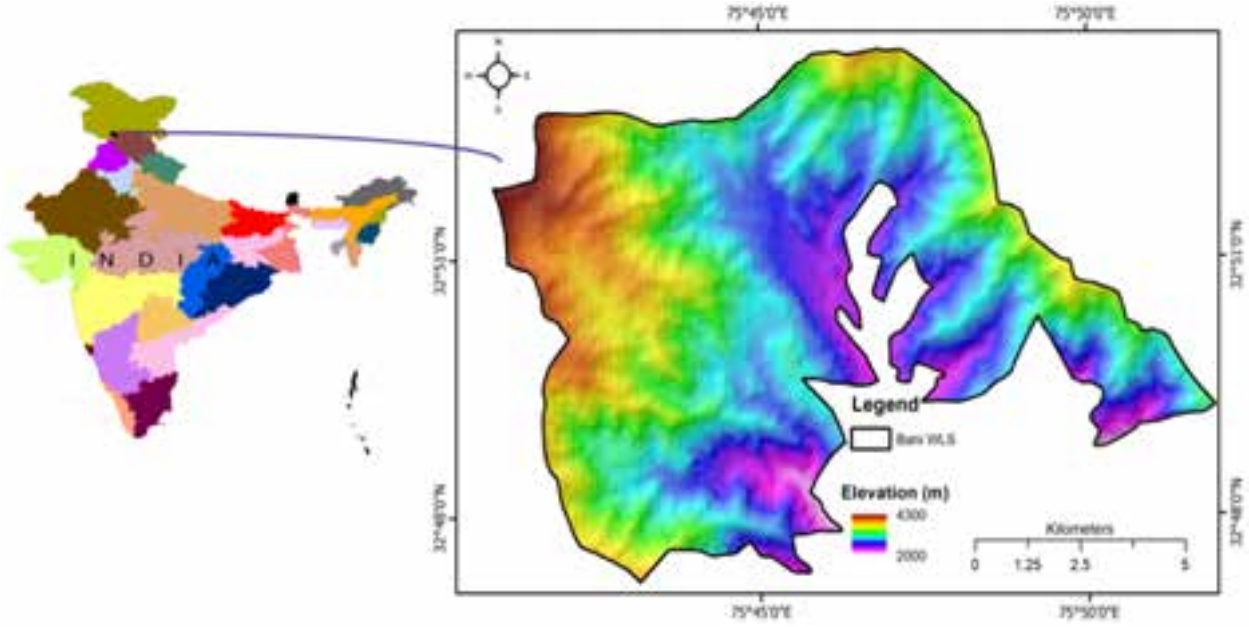

Figure 1. Location map of the study area.

– Occasional (sighted less than 10), and R – rare (sighted less than 5 times) following (MacKinnon & Philips 1993; Thakur 2008) with slight modification.

RESULTS

The avifaunal checklist of BWS documented 135 bird species from 45 families. The Muscicapidae family had the highest representation with 17 species, followed by Fringillidae with 11 species. Accipitridae, Columbidae, and Leiothrichidae each had seven species, while Corvidae, Paridae, Phasianidae, and Picidae each had six species. Among the recorded species, 36 were abundant, 40 were common, 33 were occasional, and 26 were rare (Table 1).

DISCUSSION

Monitoring the diversity and population status of indicator species is crucial for assessing ecosystem health, identifying conservation priorities, and guiding decision-making in conservation efforts (McComb et al. 2010; Fitzpatrick & Rodewald 2016). Birds are used as monitoring targets because they inhabit a vast array of environments and fill various ecological niches within those environments (Kahl et al. 2021). The ecological significance of birds is unparalleled. They are useful as pollinators, and seed dispersers and act as indicators of the health of an ecosystem (Klein et al. 2007). Among all the faunal species, birds stand at the top in gaining human attention towards natural habitats. Of the total 555 species of birds known from the State of Jammu and Kashmir (Suhail et al. 2020), 135 (24.3%) were reported from the BWS during the present study. This number is much higher than that of the nearby Manali Sanctuary of Himachal Pradesh (81 species) and the Overa-Aru Sanctuary of Kashmir (70 species) (Price et al. 2003). Such a good number could be attributed to the diverse habitats and tree species that provide suitable environments for these birds to live and breed.

Singh et al. (1990) compiled an initial inventory of 100 bird species from the Gamgul Siyabehi Wildlife Sanctuary (GSWS) and reported the presence of four notable pheasant species: Western Tragopan, Cheer Pheasant, Himalayan Monal, and Koklass Pheasant. The GSWS is situated to the north-east of the BWS and falls within an area designated as an Endemic Bird Area (EBA) (Stattersfield et al. 1998). As per BirdLife International's classification, the BWS and its environs should be classified within Biome 7 (Sino-Himalayan Temperate Forest), given the altitudinal range of 1,800–3,600 m of the sanctuary which falls within this biome's criteria. Despite having an area of only around 100 km^2, the sanctuary's significant altitudinal variation and diverse habitats make it a critical conservation site for globally threatened pheasants and numerous high-altitude forest birds.

Table 1. Avifaunal checklist of the Bani Wildlife Sanctuary.

Sno	Species	Common name	IUCN status	Status	Habitat
Passeriformes: Aegithalidae					
1.	*Aegithalos concinnus*	Black-throated Tit	LC	O	MF, OF, AS
2.	*Aegithalos niveogularis*	White-throated Tit	LC	O	OF, MF, CL
Campephagidae					
3.	*Pericrocotus ethologus*	Long-tailed Minivet	LC	C	OF, MF, CL
Certhiidae					
4.	*Certhia himalayana*	Bar-tailed Treecreeper	LC	A	OF, RF
Cinclidae					
5.	*Cinculus pallasii*	Brown Dipper	LC	R	RF, AM
Cisticolidae					
6.	*Prinia crinigera*	Himalayan Prinia	LC	C	MF, CF
Corvidae					
7.	*Corvus macrorhynchos*	Large-billed Crow	LC	A	MF, OF, CL
8.	*Garrulus glandarius*	Eurasian Jay	LC	C	MF
9.	*Garrulus lanceolatus*	Black-headed Jay	LC	C	MF, CL
10.	*Pyrrhocorax graculus*	Alpine Chough	LC	O	OF, AS, AM
11.	*Urocissa flavirostris*	Yellow-billed Blue Magpie	LC	A	MF, CL, CF
12.	*Corvus corax*	Common Raven	LC	O	CL
Dicruridae					
13.	*Dicrurus leucophaeus*	Ashy Drongo	LC	C	CL, CF
Emberizidae					
14.	*Emberiza cia*	Rock Bunting	LC	A	CL, OF
15.	*Emberiza fucata*	Chestnut-eared Bunting	LC	O	MF, CF
16.	*Emberiza lathami*	Crested Bunting	LC	O	OF, MF, AM
Estrildidae					
17.	*Lonchura punctulate*	Scaly-breasted Munia	LC	C	CL
Fringillidae					
18.	*Carduelis carduelis*	European Goldfinch	LC	C	CL,
19.	*Carpodacus erythrinus*	Common Rosefinch	LC	O	CL, CF
20.	*Carpodacus rodochroa*	Pink-browed Rosefinch	LC	O	MF,
21.	*Fringilla coelebs*	Common Chaffinch	LC	C	MF, OF, RF
22.	*Carpodacus thura*	White-browed Rosefinch	LC	O	CL, RF
23.	*Chloris spinoides*	Yellow-breasted Green Finch	LC	C	CL
24.	*Fringilla montifringilla*	Brambling	LC	A	MF
25.	*Leucosticte nemoricola*	Plain Mountain Finch	LC	A	MF, OF, RF
26.	*Serinus pusillus*	Fire-fronted Serin	LC	O	CL
27.	*Mycerobas carnipes*	White-winged Grosbeak	LC	R	OF, AS
28.	*Mycerobas icterioides*	Black and Yellow Grosbeak	LC	R	OF, AS
Hirundinidae					
29.	*Cecropis daurica*	Red-rumped Swallow	LC	C	CL
30.	*Hirundo rustica*	Barn Swallow	LC	C	CL
Laniidae					
31.	*Lanius schach*	Long-tailed Shrike	LC	A	AS
Leiothrichidae					
32.	*Actinodura strigula*	Chestnut-tailed Minla	LC	R	CL, MF

Sno	Species	Common name	IUCN status	Status	Habitat
33.	*Heterophasia capistrata*	Rufous Sibia	LC	A	MF, OF
34.	*Trochalopteron variegatum*	Variegated Laughing Thrush	LC	A	CL, CF, RF
35.	*Trochalopteron lineatum*	Streaked Laughing Thrush	LC	A	CL, CF
36.	*Trochalopteron erythrocephalum*	Chestnut-crowned Laughing Thrush	LC	R	MF
37.	*Pterorhinus albogularis*	White-throated Laughing Thrush	LC	O	MF, RF
38.	*Garrulax leucolophus*	White-crested Laughing Thrush	LC	O	CL
Monarchidae					
39.	*Terpsiphone paradisi*	Indian Paradise Flycatcher	LC	C	CL, CF
Motacillidae					
40.	*Motacilla alba*	White Wagtail	LC	C	RF
41.	*Motacilla cinereal*	Grey Wagtail	LC	C	RF
42.	*Motacilla citreola*	Citrine Wagtail	LC	C	RF
43.	*Motacilla flava*	Yellow Wagtail	LC	A	RF
44.	*Anthus hodgsoni*	Olive-backed Pipit	LC	O	AM, AS
45.	*Anthus roseatus*	Rosy Pipit	LC	O	AM
Muscicapidae					
46.	*Chaimarrornis leucocephalus*	White-capped Redstart	LC	A	RF
47.	*Phoenicurus frontalis*	Blue-fronted Redstart	LC	O	RF
48.	*Phoenicurus coeruleocephala*	Blue-capped Redstart	LC	A	RF
49.	*Rhycornis fuliginosa*	Plumbeous Water Redstart	LC	A	RF
50.	*Tarsiger rufilatus*	Himalayan Bluetail	LC	A	MF
51.	*Muscicapa sibirica*	Dark-sided Flycatcher	LC	A	MF, CF
52.	*Eumyias thalassinus*	Verditer Flycatcher	LC	A	CL, CF
53.	*Ficedula superciliaris*	Ultramarine Flycatcher	LC	A	CF
54.	*Myophonus caeruleus*	Blue Whistling Thrush	LC	A	MF, CF, CL, RF
55.	*Saxicola ferreus*	Grey Bushchat	LC	C	CL, MF
56.	*Saxicola maurus*	Siberian Stonechat	LC	C	CL, MF
57.	*Saxicola torquatus*	Common Stonechat	LC	C	CF, OF
58.	*Enicurus scouleri*	Little Forktail	LC	C	RF
59.	*Enicurus maculatus*	Spotted Forktail	LC	O	RF
60.	*Monticola rufiventris*	Chestnut-bellied Rockthrush	LC	R	MF, CF
61.	*Monticola cinclorhyncha*	Blue-capped Rock Thrush	LC	C	MF, CF
62.	*Monticola solitarius*	Blue Rock Thrush	LC	C	CF
Nectariniidae					
63.	*Aethopyga siparaja*	Crimson Sunbird	LC	O	CL
Oriolidae					
64.	*Oriolus kundoo*	Indian Golden Oriole	LC	O	CF
Paridae					
65.	*Parus cinereus*	Cinerous Tit	LC	O	MF, OF
66.	*Parus monticolus*	Green-backed Tit	LC	R	MF, OF
67.	*Machlolophus xanthogenys*	Himalayan Black Lored Tit	LC	R	CF, MF
68.	*Periparus ater*	Coal Tit	LC	C	MF, CL
69.	*Periparus melanolophus*	Spot-winged Tit	LC	C	CF
70.	*Periparus rubidiventris*	Rufous-vented Tit	LC	C	MF, CF
Passeridae					
71.	*Gymnoris xanthocollis*	Yellow-throated Sparrow	LC	R	CL

Sno	Species	Common name	IUCN status	Status	Habitat
72.	*Passer rutilans*	Russet Sparrow	LC	A	CL
73.	*Passer domesticus*	House Sparrow	LC	A	CL
Phylloscopidae					
74.	*Phylloscopushumei*	Hume's Leaf Warbler	LC	C	CL, CF
75.	*Phylloscopus nitidus*	Green Warbler	LC	C	CF, OF
76.	*Phylloscopus xanthoschistos*	Grey-hooded Warbler	LC	A	MF, OF
Prunellidae					
77.	*Prunella himalayana*	Altai Accentor	LC	C	MF, OF
78.	*Prunella strophiata*	Rufous-breasted Accentor	LC	C	MF, OF
Pycnonotidae					
79.	*Hypsipetes leucocephalus*	Black Bulbul	LC	C	CL, CF
80.	*Pycnonotus leucogenys*	Himalayan Bulbul	LC	A	CL
Rhipiduridae					
81.	*Rhipidura albicollis*	White-throated Fantail	LC	R	RF
Sittidae					
82.	*Sitta cinnamoventris*	Chestnut-bellied Nuthatch	LC	C	CF, MF
83.	*Sitta himalayensis*	White-bellied Nuthatch	LC	A	CF
Sturnidae					
84.	*Acridotheres tristis*	Common Myna	LC	A	CL
85.	*Acridotheres fuscus*	Jungle Myna	LC	C	CL, CF
Stenostiridae					
86.	*Culicicapa ceylonensis*	Grey-headed Canary Flycatcher	LC	O	MF
Timaliidae					
87.	*Cyanoderma pyrrhops*	Black-chinned Babbler	LC	R	CL
Tichodromidae					
88.	*Tichodroma muraria*	Wallcreeper	LC	R	RF, RM
Troglodytidae					
89.	*Troglodytes hiemalis*	Winter Wren	LC	R	RF
Turdidae					
90.	*Turdus atrogularis*	Black-throated Thrush	LC	O	MF
91.	*Turdus viscivorus*	Mistle Thrush	LC	O	MF, OF
92.	*Turdus rubrocanus*	Chestnut Thrush	LC	R	CF
93.	*Turdus boulboul*	Gray-winged Blackbird	LC	O	CF
Vireonidae					
94.	*Pteruthius aeralatus*	White-browed Shrike Babbler	LC	R	CF
Zosteropidae					
95.	*Yuhina flavicollis*	Whiskered Yuhina	LC	R	MF, CF
96.	*Zosterops palpebrosus*	Indian White Eye	LC	C	MF
Columbiformes: Columbidae					
97.	*Columba leuconota*	Snow Pigeon	LC	A	RM, OF,
98.	*Sterptopeli adecaocto*	Eurasian Collared Dove	LC	O	MF, CL
99.	*Streptopeli aturtur*	Oriental Turtle Dove	LC	O	MF, OF
100.	*Spilopelia chinensis*	Spotted Dove	LC	C	CL, CF
101.	*Columba livia*	Rock Pigeon	LC	A	CL, CF
102.	*Treron phoenicopterus*	Yellow-footed Green Pigeon	LC	R	CL
103.	*Treron sphenurus*	Wedge-tailed Green Pigeon	LC	R	CL, CF

Sno	Species	Common name	IUCN status	Status	Habitat
Galliformes: Phasianidae					
104.	*Lophura leucomelanos*	Kalij Pheasant	LC	R	MF, CF, AS
105.	*Pucrasia macrolopha*	Koklass Pheasant	LC	R	MF, OF, AS
106.	*Lophophorus impejanus*	Himalayan Monal	LC	O	MF, OF
107.	*Tragopan melanocephalus*	Western Tragopan	VU	R	OF, AS
108.	*Catreus wallachii*	Cheer Pheasant	VU	R	CF, MF
109.	*Francolinus francolinus*	Black Francolin	LC	R	CL
Psittaculiformes: Psittaculidae					
110.	*Psittacula himalayana*	Slaty-headed Parakeet	LC	A	CL
111.	*Psittacula krameri*	Rose-ringed Parakeet	LC	C	CL
Cuculiformes: Cuculidae					
112.	*Clamator jacobinus*	Pied Cuckoo	LC	R	CF, MF
113.	*Cuculus canorus*	Common Cuckoo	LC	C	CL, MF
114.	*Eudynamys scolopaceus*	Asian Koel	LC	O	MF
Falconiformes: Accipitridae					
115.	*Accipiter badius*	Shikra	LC	O	MF, CL
116.	*Buteo refectus*	Himalayan Buzzard	LC	C	CL, MF
117.	*Buteo buteo*	Common Buzzard	LC	C	OF, MF, CV
118.	*Gypaetus barbatus*	Bearded Vulture	NT	O	MF, OF, AM
119.	*Gyps himalayensis*	Himalayan Griffon	LC	A	MF, RF, OF
120.	*Milvus migrans*	Black Kite	LC	C	CL, CF
121.	*Nisaetus nipalensis*	Mountain Hawk Eagle	NT	O	CF, MF
Falconidae					
122.	*Falco tinnunculus*	Common Kestrel	LC	A	CL, MF, OF
Strigiformes: Strigidae					
123.	*Glaucidium cuculoides*	Asian Barred Owlet	LC	R	CF, OF
Coraciiformes: Alcedinidae					
124.	*Alcedo atthis*	Common Kingfisher	LC	C	RF
125.	*Halcyon smyrensis*	White-throated Kingfisher	LC	O	RF
126.	*Megaceryle lugubris*	Crested Kingfisher	LC	C	RF
Piciformes: Picidae					
127.	*Dendrocopos auriceps*	Brown-fronted Woodpecker	LC	A	CL
128.	*Dendrocopos himalayensis*	Himalayan Woodpecker	LC	A	CF, CL
129.	*Picus canus*	Grey-headed Woodpecker	LC	A	CF, CL
130.	*Picus squmatus*	Scaly-bellied Woodpecker	LC	A	CL
131.	*Picus chlorolophus*	Lesser Yellow Nape	LC	R	MF
132.	*Picumnus innominatus*	Speckled Piculet	LC	O	OF, MF
Megalaimidae					
133.	*Megalaima virens*	Great Barbet	LC	A	CL
Bucerotiformes: Upupidae					
134.	*Upupa epops*	Common Hoopoe	LC	A	CL
Charadriiformes: Scolopacidae					
135.	*Actitis hypoleucos*	Common Sandpiper	LC	O	RF

LC—Least Concern | NT—Near Threatened | VU—Vulnerable | C—Common | F—Frequent | O—Occasional | R—Rare | CF—Coniferous forest | MF—Mixed forest | OF—Oak forest | CL—Cultivated land | RF—Riparian forest | AS—Alpine scrub | AM—Alpine meadow | RM—Rocky mountain.

Birds contribute most to the chordate diversity of the UT of Jammu and Kashmir (Hilaluddin 1997). The newly created BWS supports an interestingly rich avifauna. Most of our sightings were observed in spring and summer and less in autumn and winter. These seasonal fluctuations in bird sightings occur due to changes in weather conditions and alterations in food productivity and habitat quality (Loiselle & Blake 1991; Norris & Marra 2007). A total of five species of Himalayan Pheasants were recorded during the current study. These include Western Tragopan *Tragopan melanocephalus*, Cheer Pheasant *Catreus wallichi*, Himalayan Monal *Lophophorus impejanus*, Koklass *Pucrasia macrolopha* and Kalij Pheasant *Lophura lecucomelanos*. The Kalij Pheasant is typically found at lower elevations and has recently been declared as the union territory bird of Jammu and Kashmir (Lone et al. 2024). Among the 135 bird species recorded in the sanctuary, three have been Red Listed by the IUCN: the Western Tragopan and Cheer Pheasant, both categorized as 'Vulnerable,' and the Bearded Vulture classified as 'Near Threatened' (IUCN 2022).

The sanctuary is currently facing widespread ecological degradation that may severely affect its avian population. This deterioration is primarily due to an increase in human settlement, the expansion of roads from Bani to Bhaderwah, and illegal activities such as the extraction of medicinal herbs, fuelwood, and timber, which collectively threaten the delicate ecosystem balance of the Bani Valley. Moreover, the surge in tourism in the Sarthal area, coupled with the practice of pilgrimages to higher elevations at various times of the year, places significant strain on both the flora and avian species, mirroring the ecological challenges observed across the Himalayan region (Chetri et al. 2001; Acharya et al. 2011; Sharma et al. 2018). Compounding these issues are the nomadic communities from Punjab and the Kathua plains, whose seasonal migrations lead to the unsustainable extraction of indigenous trees like oaks, firs, rhododendrons, and junipers for fuelwood and the construction or maintenance of temporary shelters known as Dhokes. All these activities negatively impact the biodiversity of the sanctuary.

CONCLUSION

Due to the ongoing surge in human activities, the sanctuary has been under severe pressure. Hunting, overexploitation of resources, and habitat disturbances not only strip the region of its native vegetation but may also endanger the bird's survival by eradicating their feeding, roosting, and critical breeding grounds. Poaching of Himalayan Pheasants, especially during winters, is of paramount concern. The rich bird community along with some notable mammalian species such as Himalayan Serow, Himalayan Tahr, Kashmir Musk Deer, and Brown Bear underscores the importance of this area for biodiversity conservation. Besides, the sanctuary is a treasure of important medicinal plants. We recommend elaborate scientific studies to be carried out on the bird community of the sanctuary and a stringent monitoring and conservation plan to be undertaken for the long-term sustainability of the sanctuary.

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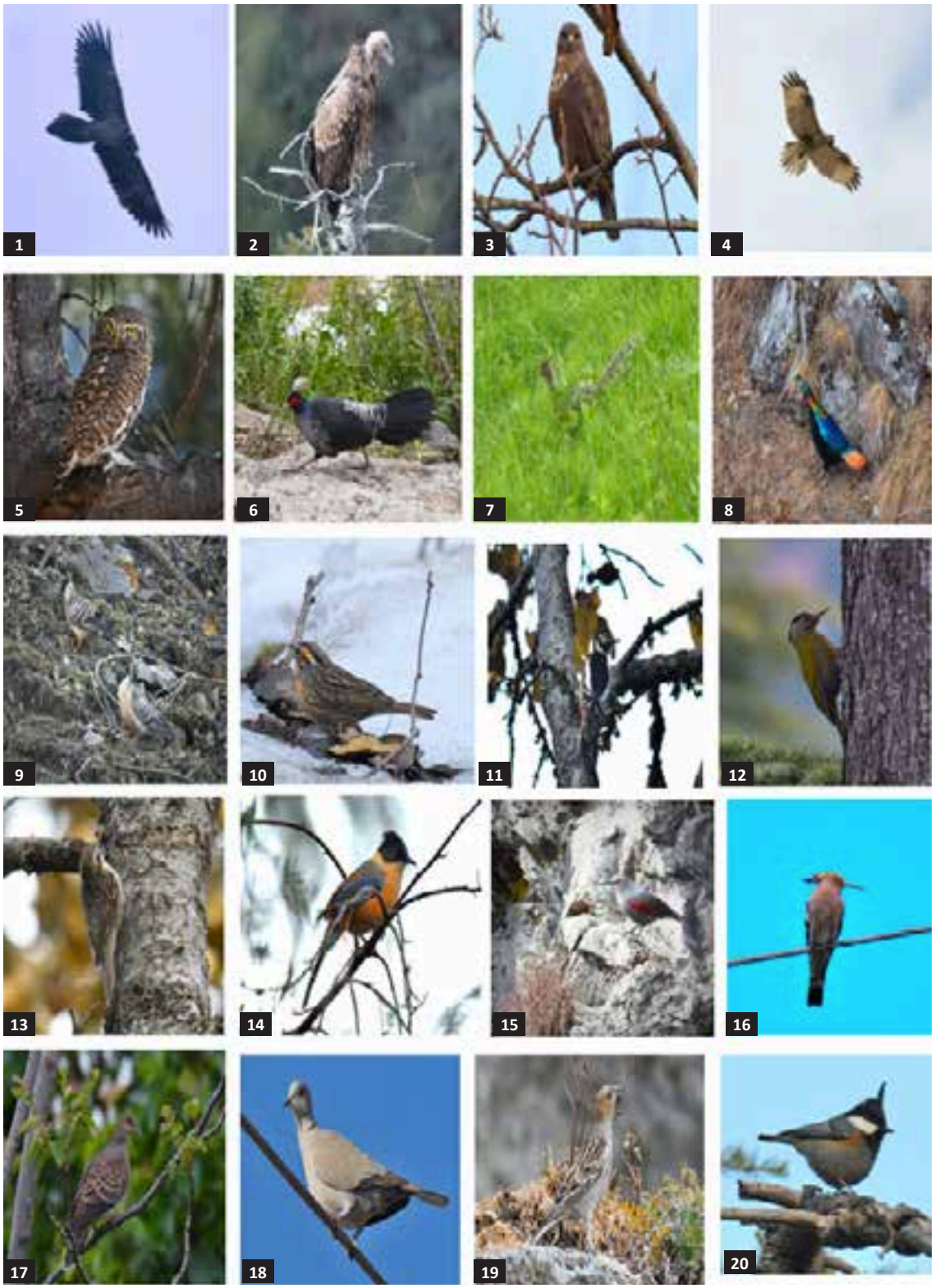

Images 1–20. 1–Bearded Vulture *Gypaetus barbatus* | 2–Himalayan Griffon *Gyps himalayensis* | 3–Common Buzzard *Buteo buteo* | 4–Common Kestrel *Falco tinnunculus* | 5–Asian Barred Owlet *Glaucidium cuculoides* | 6–Kalij Pheasant *Lophura leucomelanos* | 7–Cheer Pheasant *Catreus wallichi* | 8–Himalayan Monal *Lophophorus impejanus* | 9–Snow Pigeon *Columba leuconota* | 10–Rufous Breasted Accentor *Prunella strophiata* | 11–Himalayan Woodpecker *Dendrocopos himalayensis* | 12–Grey Headed Woodpecker *Picus canus* | 13–Bar-tailed Tree Creeper *Certhia himalayana* | 14–Rufous Sibia *Heterophasia capistrata* | 15–Wallcreeper *Tichodroma muraria* | 16–Common Hoopoe *Upupa epops* | 17–Oriental Turtle Dove *Streptopeli aturtur* | 18–Eurasian Collared Dove *Sterptopeli adecaocto* | 19–Plain Mountain Finch *Leucosticte nemoricola* | 20–Coal Tit *Periparus ater*. ©Wasim Sajad Malik and Arif Nabi Lone.

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ARTICLE

Traditional harvesting practices employed for freshwater turtles by the indigenous communities along Shilabati River, West Bengal, India

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Abstract: A survey was conducted through semi-structured interviews, involving 38 local fishermen of three villages in the Gangani region along Shilabati River in West Bengal, India. The survey revealed that three threatened species of turtles—*Nilssonia gangetica*, *Nilssonia hurum*, and *Lissemys punctata*—were clandestinely harvested by the riverine communities. These species are also being documented for the first time from this area, popularly called Jangal Mahal. *N. gangetica* was the most commonly harvested species, followed by *L. punctata* and *N. hurum*, mostly for consumption, local sale, and as traditional medicine. The most frequently used method for capturing turtles was the 'multiple hook bait'; exclusively practiced by adult males of the fisher community, usually belonging to the age group 21–40 years, between February and June. The study indicated that the respondents knew that harvesting of turtles was clandestine, yet they continued to do so as their traditional right, as they believed minor catches will not harm local turtle populations. It is assumed that *N. hurum*, which is an endangered species, is already rare and on the brink of local extinction, whereas other two species are coping with the harvest in the specialized riparian habitat and adjacent ponds. In this study the harvesting of threatened turtle species was ardently associated with the socio-cultural customs rather than an economic compulsion but to check rising threat to these species, the uncontrolled harvest needs to be addressed urgently as a high priority conservation issue. This requires further explorations on the ecology of turtles, initiatives by enforcement agencies, and utilizing the inherent knowledge of indigenous people.

Keywords: Clandestine harvesting, conservation, riparian habitat, Soft-shell Turtle, Trionychidae, wildlife utilisation.

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Author contribution: All enlisted authors have collaborated in developing and designing the paper. Supervision and administration for the research activity was offered by PHM. Drafting of initial manuscript, field data collection, visualization and analyses were done by PM with the assistance of PKJ. Final shape to the manuscript along with technical guidance was given by SS, PHM and TB. All authors have carefully gone through the final manuscript and approved it.

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INTRODUCTION

Local and indigenous people have been dependent on wildlife for their livelihood and subsistence in every corner of the globe from ancient times. Throughout the world, hunting and trafficking of animals or their parts pose serious threats to wildlife (Milner-Gulland & Bennett 2003). Hunting by indigenous people is prevalent in India and many wild regions of the world, as it is closely connected to local culture and rituals. Though hunting can provide a significant source of income for local communities, and particularly indigenous groups, it is generally considered a conservation issue (Nasi et al. 2008). Wild meat is an important source of nutrition and earnings for millions of people in developing countries (Brashares et al. 2011). In Asia, hunting practices are not well understood and research is mainly focused on trade (Banks et al. 2006). The local community around a river may rely on native bio-resources, including turtles, for food, economic support and cultural expression. However, the adoption of uncontrolled hunting practices has become more severe due to population growth, resulting in the over-exploitation of many species beyond sustainable levels (Apaza et al. 2002).

Various tools and techniques have been used for catching freshwater turtles in different regions of the world. In Mahanadi basin of India, floating hooks, harpoons and baits are used (Krishnakumar et al. 2009). In northwestern Ecuador and Chittagong Hill Tracts in Bangladesh, pitfall traps are employed (Carr et al. 2014; Rahman et al. 2015). Harpoons are used in Bangladesh (Rashid & Khan 2000) and Brazil (Fachín-Terán et al. 2004), while spear rods are utilized in Pakistan (Noureen et al. 2012). In addition to these methods, different types of nets such as gill nets and drag nets in Brazil (Fachín-Terán et al. 2004), fishing nets and hook lines are used in Pakistan and Bangladesh (Rashid & Khan 2000; Noureen et al. 2012). Baited fishing lines are employed in Indonesia (Shepherd 2000) and physical diving is a common practice in Bangladesh (Rashid & Khan 2000) and the Amazon basin (Fachín-Terán et al. 2004). Direct Hand Capture (DHC) is also a popular method used during rainy and winter seasons (Fachín-Terán et al. 2004; Carr et al. 2014). Other methods used in various parts of the world include hunting dogs (Rahman et al. 2015), wooden pole & jatica (Fachín-Terán et al. 2004), muddling (Rashid & Khan 2000), pool cleaning, turtle basket, probing (Carr et al. 2014), and electric current (Shepherd 2000). The biomass of wildlife populations has significantly decreased in areas where hunting is prevalent, leading to changes in the age distribution of species (Peres 2000). River turtles play a vital role in the local economy and ecology by dispersing seeds, controlling prey, and scavenging in aquatic ecosystems. Protecting vulnerable nesting areas and eggs is crucial for turtle conservation (Fachín-Terán et al. 2004).

Globally, chelonians are the second most endangered vertebrate group after primates in terms of their rate of extinction (Rhodin et al. 2018). Turtle populations are steadily declining due to a variety of factors, including over-exploitation of turtles and their eggs for food, traditional medicines and the global pet trade, as well as habitat degradation (Stanford et al. 2020). Hunting of threatened animals is strictly prohibited in India and carries legal consequences under the Wildlife (Protection) Act, 1972. Several turtle species are protected under this Act (Yadav et al. 2021). However, turtle hunting continues to be widespread in several regions of India even though it is refuted (Krishnakumar et al. 2009; Kanagavela & Raghavana 2013; Behera et al. 2019). Turtle harvesting is also prevalent in the Shilabati River of the Paschim Medinipur district of West Bengal, where meat consumption has led to a significant conservation issue. Three species that are being harvested in this area are *N. gangetica* (Cuvier, 1825), *N. hurum* (Gray, 1831), and *L. punctata* (Bonnaterre, 1789). According to the IUCN Red List, *N. gangetica* and *N. hurum* are 'Endangered' and *L. punctata* is 'Vulnerable' (IUCN 2024). All three species are listed in Schedule-I of the Wildlife (Protection) Act, 1972 of India and are protected live or dead and parts thereof (Yadav et al. 2021). Each of the three species mentioned belong to the Trionychidae family and are known as softshell turtles. These turtles are mostly found in the Indian subcontinent, particularly in countries such as India, Pakistan, Bangladesh, and Nepal but *L. punctata* has a wider distribution range that extends to Myanmar (Hmar et al. 2020; Yadav et al. 2021). Understanding the harvesting practices and factors that influence local harvesting is crucial for conservation of these species.

This study was designed to gather information on the techniques used to capture river turtles in the Shilabati River, and investigate the effects of turtle harvesting in the region vis-a-vis the socioeconomic and cultural backdrops of the local inhabitants for delving deeper into the conservation issue of threatened turtle species. A better understanding of harvesting practices is necessary to comprehend the socioeconomic features leading to these activities and their ecological consequences.

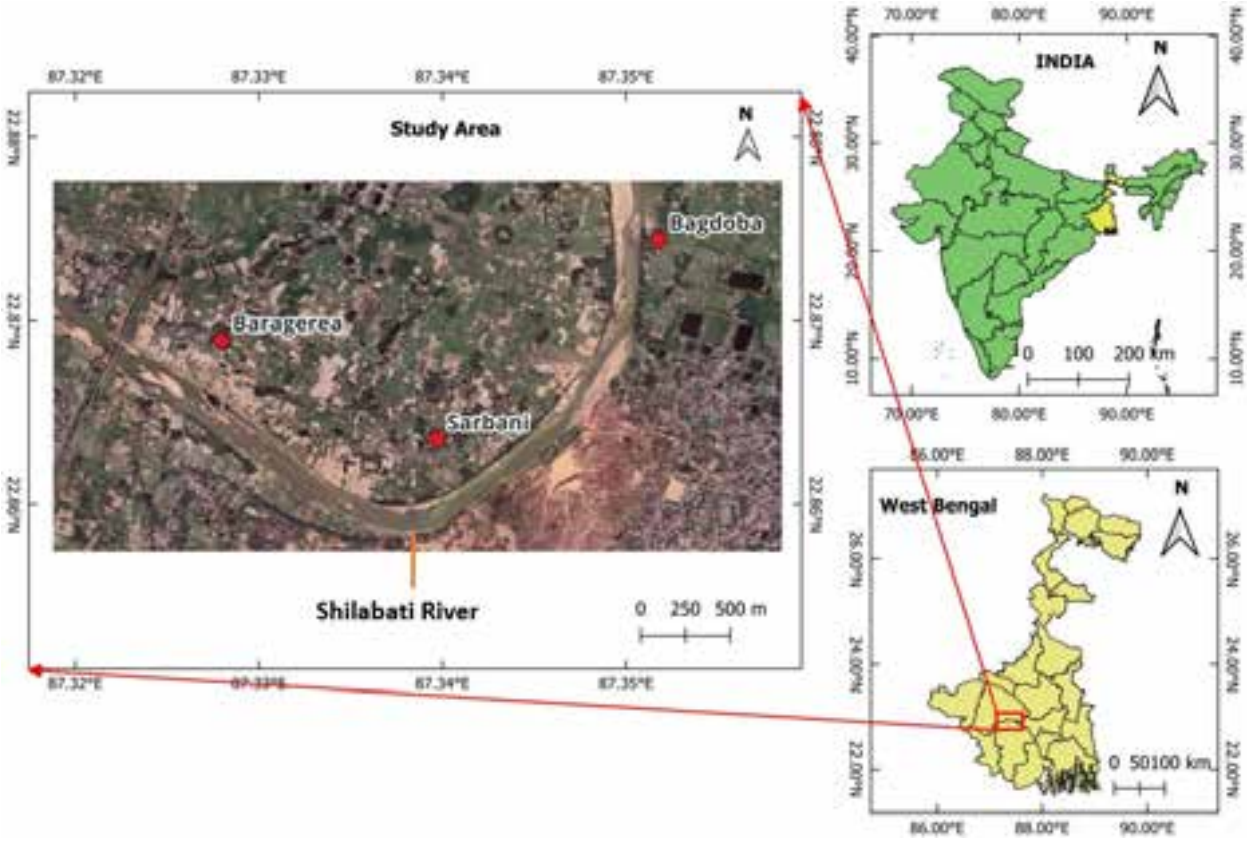

Image 1. Study area with three villages along Shilabati River.

MATERIALS AND METHODS

The study was conducted over an area spanning a 5-km stretch along Shilabati River in Paschim Medinipur District of West Bengal including three villages Baragerea, Sarbani, and Bagdoba (22.866°N, 87.323°E to 22.883°N, 87.350°E) in the Gangani area of Jangal Mahal (Image 1) inhabited by local people who mostly depend on the nearby natural resources. This area of the Shilabati River has been found to be an ideal habitat for turtles, with large submerged rocks suitable for hiding. To ensure high accuracy, the coordinates were recorded using a GPS device (Garmin Etrex- 30).

The data presented here are from 12-month surveys in 2021, and partly from an ongoing study. Weekly visits were made to gather a combination of qualitative and quantitative data through surveys and conducting semi-structured interviews, incorporating both open ended and close ended questions following Mueller & Segal (2014). Thirty-eight fishermen who came to the river on a regular basis from three different villages primarily for fishing were interviewed. All respondents agreed to be interviewed with the assurance that their identities would remain confidential and each interview was performed individually. Consent of the interviewees were obtained prior, as a part of human ethics for research. Indigenous community members involved in turtle harvesting parallel to fishing were divided into four age groups: A (11–20 years), B (21–30 years), C (31–40 years), and D (41–50 years). Our objective was to prepare a database about the harvesting practices adopted in the area including tools and techniques, targeted species, frequency, number of turtles captured, preferred season and time of harvesting, purpose of harvesting, clandestine trade, cultural practices and age-structure of fishermen.

Photographs of various Indian freshwater turtle species were presented during the survey, validating the identification of the species. Statistical analyses of data were done by SPSS-26 and illustration of results were done using MS Excel 2019. Map of the study area was designed using QGIS 3.28.2 software.

RESULTS

Our routine survey revealed occurrence of three species of turtles from Shilabati River (Image 2) and

Image 2. Photographs of the three species of turtles encountered during survey from Shilabati River: A—*Lissemys punctata* |B—*Nilsonia gangetica* | C—*Nilsonia hurum*. © Prasun Mandal.

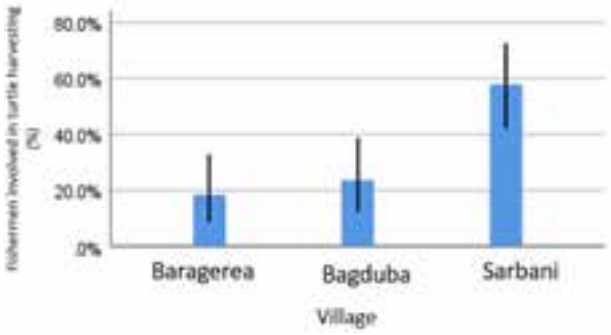

Figure 1. Number of fishermen involved in turtle harvesting (%) across three villages.

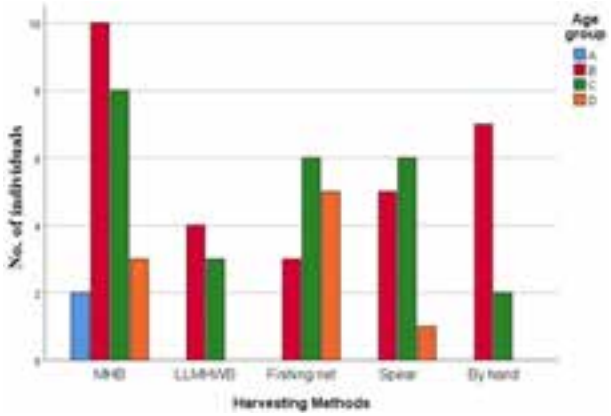

Figure 2. Age group-wise distribution A (11–20 years), B (21–30 years), C (31–40 years), and D (41–50 years), individuals adopting different harvesting techniques to catch turtles.

adjoining ponds, viz., *L. punctata*, the most common aquatic turtle in India, *N. gangetica* and *N. hurum*. The local inhabitants confessed to harvesting all three turtle species, although they knew that turtle harvesting was clandestine in general (Table 1). Kruskal Wallis test was used as an alternative to ANOVA as normality assumption was not met as far as difference in the number of individuals involved in harvesting of turtles from the three villages were concerned. Findings suggested that the number of harvesters were significantly different ($H = 53.386$, $p < 0.001$) among villages. Pairwise comparison revealed that significantly higher number of harvesters were from Sarbani village as compared to Bagduba ($H = 55.308$, $p < 0.001$) and Baragerea ($H = 54.163$, $p < 0.001$) villages (Figure 1). No significant difference, however, could be observed between the number of harvesters from Bagduba and Baragerea village ($H = -1.144$, $p = 0.895$).

During the study period of about a year, fishermen reported to encounter an average of 43 turtles per month. In total 518 turtles were reported to be harvested during those 12 months (Table 2), of which maximum number (N = 299) were captured by the residents of Sarbani village. The most common species in the study area was *N. gangetica* (N = 334) followed by *L. punctata* (N = 182). Only two *N. hurum* were reported to be captured during this period. However, there is no evidence to prove these figures beyond doubt. Of the five harvesting practices used, viz., multiple hook bait (MHB), fishing net, spears, long line multiple hook without bait (LLMHWB) and manual capture, MHB was the most preferred method (N = 225) followed by fishing net (N = 120) in that order (Figure 2). Though all age groups preferred MHB method, it was exclusively used by age group A. Most of the harvesting was done by people belonging to age groups B and C (Figure 2); 31.5% of respondents were illiterate while 60.5% had only basic schooling (Table 1). In MHB, the hooks were left with attached baits dangling in water. Baits used in MHB included snails, shrimp, small fish, crabs, earthworms and pieces of chicken

Table 1. Summary of the responses by respondents N (%).

Questions	Answer	Number (%)
Gender	Male	38 (100 %)
	Female	0 (0 %)
Age group	A (11–20)	2 (5 %)
	B (21–30)	18 (48 %)
	C (31–40)	13 (34 %)
	D (41–50)	5 (13 %)
Education	Graduation	3 (8 %)
	School	23 (60.5 %)
	Illiterate	12 (31.5 %)
Annual income	< 30000 INR	0 (0 %)
	30000–60000 INR	2 (5 %)
	60000–90000 INR	16 (42 %)
	90000–120000 INR	12 (32 %)
	>120000 INR	3 (8 %)
	No response	5 (13 %)
From which village do you belong?	Sarbani	22 (58 %)
	Bagduba	9 (24 %)
	Baragerea	7 (18 %)
Do you catch turtles in addition to fishes?	Yes	38 (100 %)
	No	0 (0 %)
Which method do you prefer most?	MHB	18 (47 %)
	Fishing net	8 (21 %)
	Spear	4 (11 %)
	LLMHWB	3 (8 %)
	No preference	5 (13 %)
Which season do you mostly catch a turtle?	Summer	26 (69 %)
	Winter	10 (26 %)
	Monsoon	2 (5 %)
Which time of the day do you prefer to catch turtles?	1000–1400 h	8 (21 %)
	1400–1800 h	21 (55 %)
	1800–2200 h	6 (16 %)
	No Preference	3 (8 %)
What for do you catch turtles?	Eating	3 (8 %)
	Selling	8 (21 %)
	Both eating & selling	24 (63 %)
	Other	3 (8 %)
What do you do if a juvenile is caught?	Release	32 (84 %)
	Keep as pet	6 (16 %)
Is turtle population increasing or decreasing?	Increasing	25 (66 %)
	Same	7 (18 %)
	Don't know	6 (16 %)
Do you know turtle harvesting is an offence?	Yes	38 (100 %)
	No	0 (0 %)
Would you continue turtle harvesting in future?	Yes	35 (92%)
	No	3 (8%)

Table 2. Turtle hunting by various methods N (%).

Method	*Lissemys punctata* (local name: 'Kachim')	*Nilssonia gangetica* (local name: 'Boro Bargol')	*Nilssonia hurum* (local name: 'Bargol')	Total
MHB	60 (26.66 %)	164 (72.88 %)	1 (0.45 %)	225 (43.44%)
LLMHWB	0 (0 %)	67 (100 %)	0 (0 %)	67 (12.93%)
Fishing net	53 (44.16 %)	67 (55.83 %)	0 (0 %)	120 (23.17%)
Spear	43 (62.31 %)	26 (37.68 %)	0 (0 %)	69 (13.32%)
By hand	26 (70.27 %)	10 (27.02 %)	1 (2.7 %)	37 (7.14%)
Total	182 (35.13%)	334 (64.48%)	2 (0.39%)	518 (100%)

intestine. One end of the rope contained five to ten baited hooks, whereas remaining hooks were left bait-free with a weight attached at the end before throwing it into the river (Image 3) and leaving it for at least two hours. Usually, hooks were baited around 1500 h and sometimes left overnight. This was the most suitable method for catching turtles particularly *N. gangetica* but not practiced during rainy season when water level was higher, animals disperse rather than congregating due to high tide conditions. LLMHB was generally used during pre-monsoon period when water level was low but never in rainy season (July–September). This method was only effective for *N. gangetica*. A total of 67 individuals were harvested by this method (Table 2). In summer, fishing nets were commonly used between 1000 h to 1430 h to avoid the afternoon. This method was stated as very effective for small-sized turtles, which was, however, not used during monsoon. A total of 53 *L. punctata* and 67 *N. gangetica* were harvested by this method. During winter and harvesting festival (locally known as 'Bartch'), spears were used to locate and capture buried turtles by the sound produced as a result of the impact of the iron tip of the spear on the carapace and captured by hand. Spears were also used to capture turtles from crevices in rocks. This method was generally not used from July to September. During bartch, a group of 10–15 people go out for harvesting in river, spend 7–8 hours or even more and harvest the riverine fauna including turtles. Harvesters mostly used turtles in addition to fishes for domestic consumption. Gravid females migrating to the breeding sites were sometimes picked up by hand following their trails.

Juveniles were never caught for consumption, and rarely kept as pets. One juvenile *N. hurum* was captured from the river bank during sand dredging but was later released back into the river. Anonymous information collected stated that sometimes large-sized softshell turtles caught from the river and were kept in small cemented tanks by tying rope on to their legs for consumption during forthcoming festivals.

Turtle harvesting was done by adult male community members, majority of which (48%) belonged to age group B followed by (34%) age group C; 69% of respondents preferred to catch turtles during pre-monsoon or summer (February–June) and the most preferred time was between 1400 h to 1800 h (55%) (Table 1). A substantial proportion of respondents (92%) wanted to continue clandestine turtle hunting; 89% of respondents used carapace as traditional medicine and hung that on the wall of cowsheds (Image 4a), around the neck of livestock as amulet (Image 4b) for their protection. Moreover, children also used them as playing tools (Image 4c). Of the interviewed, 66% respondents believed that turtle population was not declining rather increasing. Despite the fact that every family had access to other proteinaceous food sources (goat, pig, duck, and chicken), turtle meat was always esteemed over others. One-way ANOVA revealed that number of *N. gangetica* and *L. punctata* caught were significantly more ($p < 0.001$) with F value being 20.75 and 9.13, respectively, as compared to *N. hurum* ($F = 0.75$; $p = 0.599$).

DISCUSSION

Softshell turtles (Family Trionychidae) are considered to be the finest of all freshwater turtles consumed because of their low bone-to-body ratio, along with extra cartilage and gelatinous skin (Krishnakumar et al. 2009). Due to the substantial demand, these turtles are being regularly harvested and traded in Asian countries including India. Over 58,000 individuals of turtles, belonging to at least 15 different species, including 10 identified as threatened by the IUCN have been illegally harvested in India between 2011 and 2015 (Mendiratta et al. 2017). Rana & Kumar (2023) highlighted that a total of 37,267 turtles were confiscated between 2015

Image 3. Indigenous harvesting gears used for turtles: A—MHB | B—Spear | C—LLMHWB | D—Fishing net. © Prasun Mandal.

Image 4. Use of turtle carapace by local residents of the study area: A—as a good omen, hung on the wall of cow-shed | B—a piece around neck of buffalo as amulet | C—kid using carapace shaft as a toy. © Prasun Mandal.

and 2016, indicating that the government officials seized 100 individuals on an average every day. This shows that turtle harvesting is quite rampant in India. Present study also revealed that harvesting of threatened turtle species in the region under study is in vogue and needs to be checked with proper vigilance of the local authorities and stringent enforcement of the Wildlife (Protection) Act, 1972. It is hinted that clandestine harvesting might have followed secret sale by personal or online channels instead of open market, and demand for turtles from urban people for consumption, or high prices offered by smugglers, might have lured some of the poor people to take the risk of turtle harvesting and trading. These three species, although widely distributed in India (Singh et al. 2021), have been documented for the first time from Shilabati River. As such harvesting and trading of these live, dead or parts thereof is a punishable act which the local people are ignoring. Number of such fishermen were significantly more from Sarbani village as compared to remaining two villages.

The total number of individuals harvested in one year in the present study was lower than that in Punnamada in Kerala (Krishnakumar et al. 2009) but higher than that in the Western Ghats (Kanagavela & Raghavana 2013).

L. punctata is heavily exploited and trafficked at both national and international markets for its meat and supposedly medicinal value across its distributional range (Bhupathy et al. 2014; Mendiratta et al. 2017). Illegal sale of *L. punctata* in West Bengal has been previously reported by Choudhury et al. (2000) and Mendiratta et al. (2017). Sale of turtle in the markets of Midnapore Town and Purba Medinipur District have also been reported by Pratihar et al. (2014) and Mahapatra et al. (2022) respectively but they did not mention anything about source and ways of harvesting. As in the present study, use of hooks, harpoons and baits has also been previously reported from India (Krishnakumar et al. 2009; Peng & Nobayashi 2021).

The connection between indigenous festivals and turtle harvesting is common around the world. Lovich et al. (2014) highlighted that turtle harvesting is scheduled before the 'Niam' festival in July at Arizona, USA when men go for turtle harvesting that lasts for 6–7 days. Likewise, in the present study it was seen that turtle harvesting precedes Bartch festival from April to June. In Jangal Mahal area another festival, 'Bandh Bibaha' is held in which turtles, tortoise and frogs are released in ponds and dams (Sarkar & Modak 2022) for mating, which is also a positive intention of villagers towards animal conservation. Kanagavel & Raghavan (2013) in Western Ghats, India reported that larger chelonian species were consumed immediately after harvesting and smaller ones were reared until those reached the desirable size for consumption. In contrast, in the present study it was seen that large sized turtles were kept in small water-filled cemented tanks with their legs tied for consumption during the forthcoming festivals. Indigenous communities generally prefer wild meat over domesticated meat (Aiyadurai et al. 2010; Brittain et al. 2022) for the sake of taste or religious reasons. The same was found to be true in case of the Gangani region as well.

Commonly, indigenous people use turtle shells for various traditional, cultural and religious customs (Das et al. 2012; Kanagavel et al. 2016). Mahawar & Jaroli (2007) stated that carapace ash was used as traditional medicine for cure of asthma, skin burn and tuberculosis in Rajasthan. In Western Ghats, shell and fatty tissue of turtles are used for their supposedly therapeutic value for curing piles, fissure, asthma, respiratory and gastric problem as well as in boosting strength (Kanagavel et al. 2016). In Assam and Bangladesh carapace is used for livestock treatment (Khatun et al. 2013). In Assam, shells are also hung in cowsheds and sometimes inside homes. They believe that this would keep livestock healthy and bring prosperity to the household (Barhadiya & Singh 2020). In the present study also, it was observed that carapace was hung on the wall of cowshed and as amulet hung round the neck of the cattle to protect against evil eyes. Moreover, children were also seen to play with those as toy. Earlier, a similar case was observed in the Dangi tribes, Dangs, Gujarat (Vyas 2006).

The most likely cause of clandestine harvesting seems to be traditional culture. They were also not aware of the adverse legal consequences of turtle harvesting. Tosakana et al. (2010) opined that a low level of education in the community might be associated with turtle harvesting, since they found that 62% of the surveyed people had not completed their primary education. Our findings also confirmed this contention as 92% of the respondents were either illiterate or had undergone only school education. Education is widely recognized as one of the foremost factors for knowledge acquisition and learning, exerting a profound impact on individual's perspectives towards environmental conservation and the responsible use of resources (Medeiros et al. 2023). It plays a pivotal role in enhancing employment prospects and alternative livelihood strategies, ultimately reducing the direct reliance on natural resources (Kideghesho et al. 2007). Due to lack of proper education 84% people of the area believed that turtle harvesting has no adverse effect on the turtle population.

CONCLUSION

Clandestine harvesting is prevalent in the forest-dominated Jangal Mahal area of West Bengal, and in most wild regions of the world as a traditional practice. Present study was an attempt to portray the socio-ecological set-up of the Gangani region focusing on the dynamic interaction of indigenous communities with these freshwater chelonians from socio-cultural point of view which clearly revealed that the hunting of threatened turtle species in the study area was emphatically associated with the traditional customs rather than the economic compulsion, as most of the respondents were not that poor economically. Absence of awareness regarding the present situation of aquatic wildlife seems to play an important role in persisting harmful activities as indigenous communities believed that turtle populations were not declining due to their

harvesting activities. Lack of knowledge regarding wildlife laws among fishermen, particularly ignorance of the distinction between unthreatened and threatened species, might be another reason for such ignorant activities. In this view, chelonian surveys become even more vital to fill the lacunae of scientific information in the region and subsequently promote conservation. Since only two individuals of *N. hurum* were captured during the study period it may be assumed that this species is in the brink of local extirpation. The remaining two species may be regarded as rare as those are still existing in small numbers. Forest authorities kept a watchful eye and released turtles to their natural habitat whenever found by their staff. Needless to mention, ethnic people are the ones deeply connected with nature so their knowledge may be constructively used to conserve the threatened species through concerted efforts. To frame a workable management strategy, not only further exploratory study is required on the status of turtle population; but also appropriate programs to create awareness among indigenous people regarding ecological importance of turtles, needs for its conservation and environmental sustainability for their own well-being in long term by government agencies, stakeholders as well as NGOs .

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ARTICLE

Diversity and abundance of mayflies (Insecta: Ephemeroptera) in Achenkovil River, southern Western Ghats, Kerala, India

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Abstract: Freshwater insects like Ephemeroptera are more comprehensive and direct indicators of the biological impacts of pollution. During the study period (2018–2020), a total of 4,374 individuals of mayflies were collected and categorized under nine families, 27 genera, and 36 species. The family Leptophlebiidae was found dominant with 13 species. In the post-monsoon season, a higher species diversity of Ephemeroptera was noticed in the river's upstream section with a Shannon-Wiener index value of H' = 1.814. ANOVA revealed a significant difference ($p < 0.05$) except for Ephemeridae ($p > 0.05$). Protecting rivers requires a holistic approach and collaboration among stakeholders is essential for successful implementation.

Keywords: ANOVA, biodiversity indices, D-frame nets, ecosystem, exotic species, environmental parameters, freshwater, hemimetabolous, species richness, van veen grab.

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Author details: S. Sujitha is a research scholar. R. Sreejai is an assistant professor. His research interests are biodiversity and ecology. C. Selvakumar, is assistant professor. He has described 25 new species and two new genera of mayflies. He also established a DNA barcode for 40 species of mayflies. Currently, he is studying the phylogeny and phylogeography of mayflies in India.

Author contributions: SS carried out fieldwork and drafted the manuscript, SR carried out fieldwork with the first author and reviewed the manuscript, CS helped in the identification of mayflies and reviewed the manuscript.

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INTRODUCTION

Freshwater ecosystems and their valuable resources are inevitable for the existence of human life (Surachita et al. 2022). Environmental parameters like the geography of the river bed (Wallace et al. 1996), heavy rain, oxygen concentration, nutrients, water velocity, land use patterns, substrate type, and water temperature (Popielarz et al. 2007; Mishra & Nautiyal 2011, 2016) play a major role in structuring the diversity and distribution of freshwater ecosystems. However, freshwaters also face severe biodiversity depletion and extinction of species which makes them much more imperilled than terrestrial and marine species (Farooq et al. 2021). When environmental quality degrades, the species composition, richness, and abundance of specialist species decreases, and generalist species occupy the area, thereby decreasing biodiversity. This adversely affects the distribution pattern of highly sensitive, riverine species (Axelsson et al. 2011) which finally results in the elimination of numerous species before they are brought to the knowledge of science. The catchment-wide conservation of freshwater ecosystems, maintenance of historic river dynamics, biological control of invasive water plants, removal of exotic species, and conservation of location-specific factors such as river network connectivity can conserve species diversity. Moreover, the maintenance of the natural dynamics of freshwater systems is very important for improved vegetation and insect heterogeneity (Samways et al. 2020).

Ephemeroptera includes a small order of hemimetabolous insects with approximately 3,500 species, 450 genera, and 42 families distributed globally (Hamada et al. 2018). The Ephemeroptera of the Oriental region was represented by 390 species, 84 genera, and 20 families out of which four suborders, 15 families, 60 genera, and 204 species occur in the Indian subregion (Sivaramakrishnan et al. 2009). According to Vasanth et al. (2023), the Ephemeroptera of Indian Himalaya includes 10 families, 34 genera, and 89 species. The Ephemeroptera of India was represented by four suborders, 15 families, 59 genera, and 172 species (Sivaramakrishnan et al. 2020) and the Western Ghats of India alone comprises 13 families, 42 genera and 82 species (Sivaramakrishnan et al. 2020). After 2020, more than 60 new species of mayflies were described in India by various researchers (Balasubramanian & Muthukatturaja 2021; Martynov et al. 2021; Srinivasan et al. 2022; Kluge et al. 2022; Muthukatturaja & Balasubramanian 2022; Sivaruban et al. 2022; Vasanth et al. 2023).

Research hasn't explored the variety and spread of mayflies (Ephemeroptera) along the Achenkovil River basin's latitudinal and longitudinal gradients. Because mayflies are crucial for benthic community structure, understanding their ecology, distribution, and diversity in remote freshwater ecosystems would significantly improve our grasp of their functions.

MATERIALS AND METHODS

Study area

The Achenkovil River is created towards the southern tip of the peninsula by the confluence of the Rishimala, Pasukidamettu, and Ramakkalteri rivers originating from Devarmalai of Western Ghats (10.4147 N, 77.0136 E). It enriches the Pathanamthitta District of Kerala State. The length of this river is 128 km; the basin size is 1,484 km² and the average water flow is 2,287 MCM. The river drains through highly varied geological formulations and covers the highland, midland, and lowland physiographic provinces of the state. The study area experiences a tropical climate with three distinct seasons – pre-monsoon (February–May), monsoon (June–September.), and post-monsoon (October–January.).

Sampling Methods

Study sites

A reconnaissance survey was conducted in the Achenkovil River basin to identify sampling sites (refer to Figure 1). Samples were collected bimonthly and seasonally, specifically in the early morning hours (0600–1130 h) throughout the study duration (2018–2020). The river was divided into three segments—upstream, midstream, and downstream—each with three stations, totaling nine sampling sites along the entire river stretch. In the Upstream region, dense forest covers approximately 60% of the area, while 5% is occupied by degraded forest, and agricultural land accounts for 10%. Moving to the midstream region, double-crop paddy farming occupies 40% of the land. The downstream region is occupied by 80% agricultural land and 10% under double crop paddy cultivation.

The research region experiences a tropical and semi-arid climate, with an annual rainfall between 2,000 and 5,000 mm. It is affected by two distinct monsoon seasons: the south-west monsoon (June–September) and the north-west monsoon (October–December) (Prasad & Ramanathan 2005).

Figure 1. Map showing the study sites in the Achenkovil River Basin, Kerala.

Mayflies, were collected using Van Veen grab (0.025 m^2) (used during rainy or flood months), D-frame nets 500 µm (used when water flow is slow), and handpicking methods (mostly in upstream stations), within a depth ranged 0.65–4.39 m (Abdelsalam et al. 2013). To ensure accuracy, triplicate samples were collected. The grab samples were sieved through a 0.5 mm sieve and sorted for mayflies in a white plastic tray. Similarly, samples collected with a D-frame net were carefully sorted in a white plastic tray. All mayfly larvae were preserved in 80% ethanol for later analysis. In the laboratory, preserved samples were examined and identified using a stereomicroscope (Magnus MSZ- BI LED) and standard taxonomic literature, including works by Merrit & Cummins (1996), Dudgeon (1999), Yule & Sen (2004), Thorp & Covich (2015), and Selvakumar et al. (2019).

The water samples for physicochemical analysis were collected in clean polyethylene bottles. The temperature was recorded immediately after collection at the field itself with a mercury thermometer (with ± 0.1°C accuracies). The samples for Dissolved Oxygen (DO) & Biochemical Oxygen Demand (BOD) were fixed with alkaline potassium iodide and manganous sulphate at the site itself. The water samples were then carried immediately to the laboratory for further analysis. DO (mg/l), BOD (mg/l) were analyzed using Winkler's method, pH (pH meter), turbidity (NTU) by Nephelometric method, conductivity (µS/cm) using Systronics water analyzer 371, TDS (mg/l) by gravimetric method, and nitrate (mg/l) by spectrophotometric method (APHA 2012).

Data analysis

ANOVA was carried out to study the significant variations between the water quality parameters. Diversity was estimated using Shannon-Wiener, Evenness, and Margalef's indices. The commonness or the rarity of species was calculated using relative abundance. The diversity indices were calculated using PAST software (Version 4.09), (Hammer et al. 2001). The relative abundance was calculated using Excel 2011 and ANOVA using SPSS (Version 22).

RESULTS

Physico-chemical Parameters

The atmospheric and water temperatures ranged 23.1–34.9 °C and 22.9–30.9 °C, respectively, with the highest temperature recorded during pre-monsoon and lowest during post-monsoon season (Table 1). The pH ranged from 6.42–7.42. A good value of DO indicates a good and healthy ecosystem. The DO ranged 3.91–8.69 with the highest value (7.54 ± 0.72) recorded during monsoon, and the least during pre-monsoon season (5.67 ± 0.86). BOD is a measure of organic pollution in the water body and it ranges 0.44–3.91 mg/l with the highest value noticed during the post-monsoon (2.71 ±

Table 1. Mean seasonal variation of the physico-chemical parameters in Achenkovil River Basin, Kerala.

Parameters	Range		Seasons (Mean ± SD)			F value	*P*-value
	Minimum	Maximum	Pre-monsoon	Monsoon	Post-monsoon		
Atm. temp. (°C)	23.1	34.9	31.08 ±1.92	29.11 ± 1.78	28.55 ± 2.57	14.013	0.000 *P* <0.001
Water temp. (°C)	22.9	30.9	28.93 ±0.99	27.38 ± 1.26	27.18 ± 1.96	15.418	0.000 *P* <0.001
pH	6.42	7.42	6.98 ±0.18	6.85 ± 0.16	6.65 ± 0.17	31.741	0.000 *P* <0.001
DO (mg/l)	3.91	8.69	5.67 ±0.86	7.54 ± 0.72	5.87 ± 0.64	67.313	0.000 *P* <0.001
BOD (mg/l)	0.44	3.91	2.38 ±0.58	1.59 ± 0.46	2.71 ± 0.65	36.6	0.000 *P* <0.001
Turbidity (NTU)	0.74	12.62	4.99 ±1.29	8.58 ± 2.43	4.31 ± 1.74	53.511	0.000 *P* <0.001
Conductivity (µS/cm)	44.2	358.7	127.3 ±109.1	103.2 ± 33.94	108.4 ± 79.08	0.896	0.411 *P* >0.05
TDS (mg/l)	32.2	342.6	112.6 ±107.7	87.9 ± 34.19	87.49 ± 78.29	1.187	0.309 *P* >0.05
Nitrate (mg/l)	0.38	1.56	0.76 ±0.14	1.08 ± 0.20	0.87 ± 0.14	34.244	0.000 *P* <0.001

0.65) season.

The turbidity ranged 0.74–12.62 NTU with the highest value in monsoon (8.58 ± 2.43), and the least in post-monsoon season (4.31 ± 1.74). The conductivity of water depends mainly on the concentration of ions, and it ranged from 44.2–358.7 µS/cm with the highest value (112.6 ± 107.7) recorded during pre-monsoon, and the least value (103.2 ± 33.94) recorded during monsoon season. Natural sources are the contributors to TDS in the water body. The amount of TDS ranged 32.2–342.6 mg/l with the highest value (112.6 ± 107.7) recorded during pre-monsoon season. The value of nitrate varied 0.38–1.56 mg/l with the highest value (1.08 ± 0.20) noticed during monsoon and the lowest during pre-monsoon season (0.76 ± 0.14).

All the studied physicochemical parameters showed variations between seasons that are statistically significant (p <0.05) (Table 2).

Species Richness

During the study period, a total of 36 species of mayflies under 27 genera belonging to nine families were identified (Table 2); out of which the major family Leptophlebidae constitutes 13 species with 1,279 Individuals(ind.)/m^2 in the upstream, 591 ind./m^2 in the midstream, and 80 ind./m^2 in the downstream. Family Caenidae was represented by *Caenis* sp. and *Clypeo caenis bisectosa* with maximum individuals (274 ind./m^2) in the upstream, 192 ind./m^2 in the midstream, and 34 ind./m^2 in the downstream segment. Leptophlebiidae, Caenidae, Baetidae, and Ephemeridae were present in all three segments of the river. The family Baetidae and Ephemeridae were represented by eight and two species, respectively. Teloganodidae (339 ind./m^2) and Tricorythidae (99 ind./m^2) were present only in the upstream stations. Heptageniidae (377 ind./m^2), Ephemerellidae (195 ind./m^2), and Prosopistomatidae (52 ind./m^2) were present in the upstream and also in the midstream with 98, 4, and 18 ind./m^2 respectively, but absent in the downstream stations. The seasonal variation in the distribution of major families except Ephemeridae shows maximum richness during post-monsoon followed by pre-monsoon and monsoon season.

The relative abundance of all species across different seasons at the three segments of the river is presented in Table 3. In the upstream segment, *Notophlebia* sp. exhibited the highest relative abundance (15.91%) during the monsoon, while *Teloganella indica* (0.07%) was the least abundant (0.07%) during the post-monsoon season. In the midstream segment, *Notophlebia ganeshi* dominated (19.55%) during the monsoon, with *Petersula courtallensis* and *Epeorus petersi* being the least dominant species, both reported during the pre-monsoon season. Similarly, in the downstream segment, *Caenis* sp. contributed the most (31.25%) during the monsoon, while *Tenuibaetis frequentus* was the least abundant (1.92%), reported during the pre-monsoon season.

In the Upstream segment (S1) of the river, higher species diversity of Ephemeroptera was observed during the post-monsoon season, with a Shannon-Wiener index value of H' = 1.814 (Figure 2). Maximum species richness and evenness were noted in the

Table 2. Checklist of mayflies in the Achenkovil River Basin.

Superfamily	Family	Genus and species
Prosopistomatoidea	Prosopistomatidae	*Prosopistoma indicum* Peters, 1967
Leptophlebioidea	Leptophlebiidae	*Choroterpes* (*Euthraulus*) *nambiyarensis* Selvakumar & Sivaramakrishnan, 2013
		Choroterpes (*Euthraulus*) *kalladaensis* Rekha, Anbalagan, Dinakaran, Balachandran & Krishnan, 2019.
		Choroterpes (*Euthraulus*) *nandini* Selvakumar & Sivaramakrishnan, 2015.
		Choroterpes petersi Tong & Dudgeon 2003
		Edmundsula lotica Sivaramakrishnan, 1985
		Indialis badia Peters & Edmunds, 1970
		Nathanella indica Sivaramakrishnan, Venkataraman & Balasubramanian, 1996
		Notophlebia ganeshi Kluge, 2014
		Notophlebia jobi Sivaramakrishnan & Peters, 1984
		Notophlebia sp.
		Petersula courtallensis Sivaramakrishnan, 1984
		Thraulus gopalani Grant & Sivaramakrishnan, 1985
Caenoidea	Caenidae	*Caenis* sp.
		Clypeocaenis bisetosa Soldan, 1978
Ephemerelloidea	Ephemerellidae	*Torleya nepalica* Allen and Edmunds, 1963
	Teloganodidae	*Derlethina tamiraparaniae* Selvakumar, Sivaramakrishnan & Jacobus, 2014
		Dudgeodes palnius Selvakumar, Sivaramakrishnan & Jacobus, 2014
Ephemerelloidea	Teloganodidae	*Dudgeodes bharathidasani* Anbalagan, 2015
		Dudgeodes sp. Sartori & Peters & Hubbard, 2008
		Teloganodes kodai Sartori, 2008
		Teloganella indica (Selvakumar, Sivaramakrishnan & Jacobus, 2014)
	Tricorythidae	*Sparsorythus gracilis* Sroka & Soldan, 2008
Ephemeroidea	Ephemeridae	*Ephemera* (*Aethephemera*) *nadinae* McCafferty and Edmunds, 1973
		Eatonigenia trirama McCafferty, 1973
	Heptageniidae	*Afronurus kumbakkaraiensis* Venkataraman & Sivaramakrishnan, 1989
		Epeorus petersi Sivaruban & Venkataraman & Sivaramakrishnan, 2013
		Thalerosphyrus flowersi Venkataraman and Sivaramakrishnan, 1987
	Baetidae	*Acentrella* (*Liebebiella*) *vera* Muller-Liebenau, 1982
		Indobaetis michaelohubbardi (Selvakumar, Sundar & Sivaramakrishnan, 2012)
		Baetis sp.
		Centroptella ornatipes Kluge 2021
		Centroptella (*Chopralla*) *ceylonensis* Müller-Liebenau 1983
		Cleon bicolor Kimmins, 1947
		Nigrobaetis paramakalyani Kubendran & Balasubramanian, 2015
		Tenuibaetis frequentus (Müller-Liebenau & Hubbard 1985)

post-monsoon, followed by the pre-monsoon and monsoon seasons. ANOVA analysis revealed a highly significant difference (p <0.001) for Leptophlebiidae, and Baetidae, and a significant difference (p <0.05) for Caenidae, Teloganodidae, Tricorythidae, Heptageniidae, Ephemerillidae, and Prosopistomatidae, while no significant difference was found for Ephemeridae (p >0.05) (Table 4). Spatial abundance was highest in the upstream segments, followed by the midstream and downstream segments. The ANOVA of abundance indicated significant differences both spatially and temporally (p <0.05) (Table 4).

DISCUSSION

Physico-chemical parameters play an important role in determining water quality and the distribution of biotic communities. The mean pH values of all seasons fall within the limits (6.5–8.5) as prescribed by BIS. The benthic macroinvertebrate including aquatic insects have a tolerance range to pH and most organisms can develop between 6.4–8.6 (Yorulmaz et al. 2021). Higher temperature during the pre-monsoon season fastens microbial degradation of water contaminants and reduces oxygen saturation which may be a reason for low DO (Liu et al. 2016). Heavy rainfall and cloudy sky in the monsoon season decrease the atmospheric temperature and thereby the water temperature, and

Table 3. Relative abundance of mayfly larvae at three segments in different seasons of the Achenkovil River Basin, Kerala.

	Family/Genus/Species	Upstream			Midstream			Downstream		
		PreM	Mons	PosM	PreM	Mons	PosM	PreM	Mons	PosM
A	**Leptophlebiidae**									
1	*Indialis badia*	0.28	1.26	0.26	4.13	6.77	2.86	5.77	8.33	7.14
2	*Choroterpes kalladensis*	6.83	5.78	3.30	10.00	8.27	9.54	9.62	4.17	14.29
3	*Choroterpes nambiyarensis*	3.51	7.23	2.64	10.87	6.77	6.68	-	-	-
4	*Choroterpes nandini*	4.17	6.51	2.31	-	-	-	-	-	-
5	*Choroterpes petersi*	2.27	1.63	3.04	-	-	0.95	-	-	-
6	*Edmundsula lotica*	7.88	9.58	1.78	13.26	7.52	8.78	5.77	2.08	7.14
7	*Nathanella indica*	0.09	-	0.13	3.04	6.02	3.63	9.62	10.42	4.76
8	*Notophlebia ganeshi*	3.22	5.06	4.49	6.09	19.55	7.63	5.77	12.50	2.38
9	*Notophlebia jobi*	4.27	5.24	5.61	3.26	4.51	4.58	17.31	2.08	9.52
10	*Notophlebia* sp.	7.59	15.91	6.86	3.48	4.51	2.48	11.54	12.50	4.76
11	*Petersula courtallensis*	1.71	1.63	2.51	0.22	-	0.38	-	-	-
12	*Thraulus gopalani*	0.19	-	0.40	0.43	1.50	0.57	-	-	-
B	**Caenidae**									
13	*Clypeocaenis bisetosa*	0.57	-	0.20	1.09	-	0.95	-	-	-
14	*Caenis* sp.	9.31	13.20	6.20	15.87	10.53	18.13	13.46	31.25	28.57
C	**Teloganodidae**									
15	*Teloganella indica*	0.38	-	0.07	-	-	-	-	-	-
16	*Teloganodes kodai*	5.60	1.63	9.70	-	-	-	-	-	-
17	*Dudgeodes bharathadasini*	0.28	-	0.53	-	-	-	-	-	-
18	*Dudgeodes* sp.	1.14	2.35	2.05	-	-	-	-	-	-
19	*Dudgeodes palnius*	0.47	0.36	0.59	-	-	-	-	-	-
20	*Derlethina tamiraparaniae*	0.38	3.61	0.79	-	-	-	-	-	-
D	**Baetidae**									
21	*Centroptella ceylonensis*	0.66	0.36	0.99	0.65	2.26	2.10	-	-	-
22	*Cloeon bicolor*	3.70	1.98	3.43	1.30	0.75	4.01	-	-	-
23	*Centroptella ornatipes*	1.04	1.63	0.86	0.87	1.50	1.34	-	-	-
24	*Indoaetis michaelohubbardi*	1.71	1.27	1.19	4.57	6.02	4.77	11.54	2.08	11.90
25	*Tenuibaetis frequentus*	3.70	0.90	3.10	4.13	3.76	3.44	1.92	4.17	-
26	*Baetis sp.*	1.90	1.45	0.79	0.43	0.75	0.57	-	-	-
27	*Acentrella vera*	0.76	0.54	0.13	1.09	-	1.53	3.85	-	-
28	*Nigrobaetis paramakalyani*	2.18	2.89	4.95	1.52	0.75	2.10	-	-	-
E	**Tricorythidae**									
29	*Sparsorythus gracilis*	7.12	0.90	4.69	-	-	-	-	-	-
F	**Heptageniidae**									
30	*Afronurus kumbakkaraiensis*	7.14	3.25	9.57	8.04	7.52	8.40	-	-	-
31	*Thalerosphyrus flowersi*	4.08	-	2.84	0.65	-	0.19	-	-	-
32	*Epeorus petersi*	1.04	0.36	2.64	0.22	-	0.38	-	-	-
G	**Ephemerellidae**									
33	*Torleya nepalica*	5.31	1.27	8.71	0.43	-	0.38	-	-	-
H	**Ephemeridae**									
34	*Ephemera* (*Aethephemera nadinae*)	1.42	1.27	0.66	2.61	0.75	1.72	3.85	10.42	9.52
35	*Eatoningenia trirama*	0.19	-	0.20	-	-	-	-	-	-
I	**Prosopistomatidae**									
36	*Prosopistoma indica*	1.90	0.90	1.78	1.74	-	1.91	-	-	-

PreM—Premonsoon | Mons—Monsoon | PosM—Post-monsoon.

Table 4. Spatial and seasonal abundance (Mean ± SD) in the number of species per family of mayflies in the Achenkovil River Basin.

Family	Upstream (Mean ± SD)			Midstream (Mean ± SD)			Downstream (Mean ± SD)			F value	*p*-value
	PreM	Mons	PosM	PreM	Mons	PosM	PreM	Mons	PosM		
Leptophlebiidae	221.5 ± 70.0	165.5 ± 109.6	252.5 ± 19.09	126.0 ± 59.39	43.50 ± 14.84	126.0 ± 26.87	17.00 ± 0.00	12.50 ± 10.60	10.50 ± 6.36	28.128	0.000 *P* <0.001
Caenidae	52.0 ± 24.04	36.5 ± 20.5	48.5 ± 2.12	39.0 ± 14.14	7.0 ± 1.41	50.0 ± 4.24	3.50 ± 2.12	7.50 ± 7.77	6.00 ± 4.24	12.877	*0.001* *P* <0.05
Teloganodidae	43.50 ± 28.99	22.0 ± 7.07	104.0 ± 26.87	-	-	-	-	-	-	12.902	*0.001* *P <0.05*
Baetidae	87.0 ± 29.69	30.5 ± 12.02	117.0 ± 4.24	33.50 ± 7.77	10.50 ± 2.12	52.0 ± 1.41	4.50 ± 2.12	1.50 ± 0.70	2.50 ± 3.53	23.002	*0.000* *P* <0.001
Tricorythidae	11.50 ± 3.53	2.50 ± 2.12	35.50 ± 13.43	-	-	-	-	-	-	7.271	*0.008* *P* <0.05
Heptageniidae	64.50 ± 12.02	10.0 ± 1.41	114.0 ± 32.52	20.50 ± 0.70	5.00 ± 1.41	23.50 ± 6.36	-	-	-	11.158	*0.002* *P* <0.05
Ephemerellidae	28.0 ± 21.21	3.50 ± 4.94	66.0 ± 57.98	1.0 0 ± 00	-	1.0 ± 1.41	-	-	-	4.175	*0.040* *P* <0.05
Ephemeridae	8.50 ± 3.53	3.50 ± 2.12	6.50 ± 6.36	6.0 ± 2.82	0.50 ± 0.70	4.50 ± 0.70	1.0 ± 1.41	2.50 ± 3.53	2.0 ± 2.82	3.07	*0.081* *P* >0.05
Prosopistomatidae	10.0 ± 5.65	2.50 ± 3.53	13.50 ± 3.53	4.0 ± 2.82	-	5.0 ± 2.82	-	-	-	11.064	*0.002* *P* <0.05

PreM—Premonsoon | Mons—Monsoon | PosM—Post-monsoon.

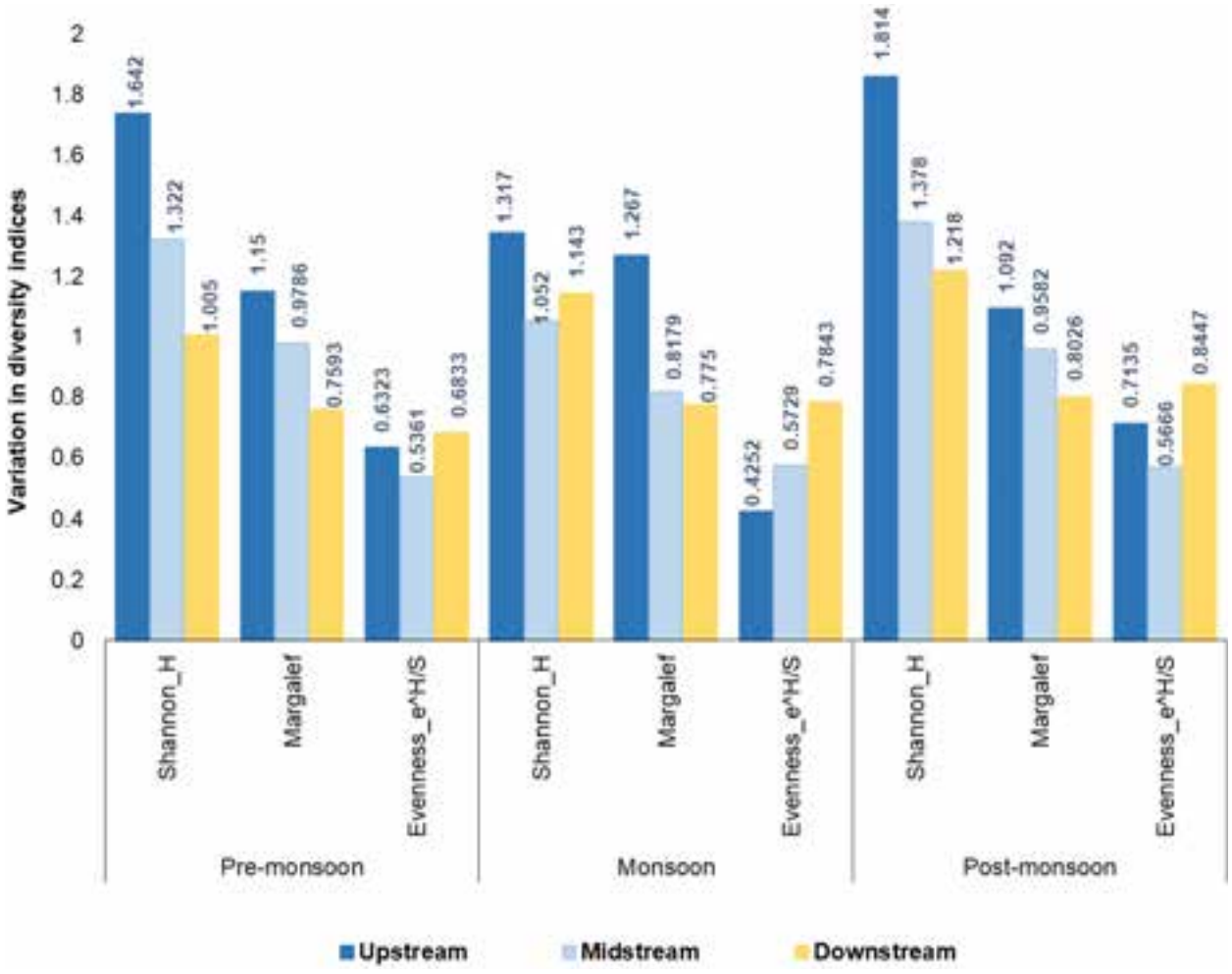

Figure 2. Spatial and seasonal variation of biodiversity indices in the Achenkovil River Basin, Kerala.

increase the turbulence, oxygenation, and DO level in the water body (Alam et al. 2007). BIS standard value for BOD is 2mg/l, which is exceeded up to 2.71±0.65 in the present investigation during the post-monsoon season. The biodegradation of organic matter and the impact of anthropogenic activities may contribute to a rise in BOD (Virha et al.2011). The permissive limit of turbidity is 5 NTU, which is exceeded to a small extent in the present study during the monsoon season. The turbid waters tend to fasten the growth of pathogenic microorganisms (Farahbaksh & Smith 2002) and thus hamper the quality of the drinking water. A sudden increase in conductivity indicates pollution in the water body (Gupta et al. 2009). The value of conductivity falls within the limits as prescribed by BIS (400µS/cm^2). An increase in both TDS (BIS limit, 500mg/l) and conductivity is toxic and a stressor to the mayfly community (Barathy et al. 2020). The main source of nitrate (BIS limit, 45mg/l) in the monsoon season is due to surface runoff carrying agricultural waste, fertilizers, domestic waste, etc. Rainwater itself contributes substantially to the supply of nitrates.

The record of 36 species of mayflies coming under 27 genera and 9 families in the present study from the Achenkovil River basin is the first report of the diversity and abundance of mayfly larvae (Ephemeroptera). In the present study, the diversity indices differ between seasons probably due to different seasonal changes and uneven geomorphological features of the river basin, as geomorphological heterogeneity plays a major role in determining species richness (Nichols et al. 1998). Habitat diversity influences the structure and composition of macro-benthic invertebrates. The different microhabitats present in the rocky substratum of the upstream segment of the river are home to diverse biotic communities. Studies reveal that thick canopy cover regulates water temperature and overall quality of water in the river and promotes the occurrence of macro-benthic invertebrates and provides favourable habitat (Bose et al. 2021).

The midstream and the downstream segments are facing severe anthropogenic pressures, such as the destruction of riparian forests, river regulation, and bank deterioration for agricultural purposes, which adversely affect the mayfly community structure (Ramulifho et al. 2020). During pre-monsoon season, the water level in the river falls and flow gets obstructed, as a result, saltwater intrusion from Kayamkulam Lake occurs in the downstream segment of the river. This adversely creates a lot of problems for salt-sensitive organisms. Protecting rivers requires a holistic approach, including watershed management, riparian buffer zones, water quality monitoring, restoration projects, and community engagement. Enforce regulations on pollution and unsustainable practices, manage floodplains, and integrate river protection into planning. Collaboration among stakeholders is essential for successful implementation.

CONCLUSION

Mayflies serve as water quality indicators, so monitoring their diversity and abundance provides insights into the river's ecological health. This work acts as a model ecosystem for biomonitoring studies and offers consistent data on the current state of the water quality and temporal variations in relation to the mayfly community structure in the Achenkovil River basin.

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ARTICLE

Legumes (Angiosperm: Fabaceae) of Birbhum District, West Bengal, India

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Abstract: The present paper deals with a comprehensive enumeration of leguminous taxa found in Birbhum District of West Bengal, India. We recorded 140 species, one subspecies, and two varieties, representing 82 genera from 24 tribes under four subfamilies, viz., Cercidoideae (6 species in 2 genera belonging to 1 tribe), Detarioideae (3 species in 3 genera belonging to 3 tribes), Caesalpinioideae (43 species in 24 genera belonging to 5 tribes), and Papilionoideae (91 taxa including 88 species, 1 subspecies and 2 varieties in 53 genera belonging to 15 tribes). Herbs (59 taxa) were the largest group, followed by trees (39), climbers (23), and shrubs (22). *Crotalaria* and *Indigofera* (7 species each) emerged as the dominant genera, followed by *Senna* (6) and *Bauhinia* and *Senegalia* with five species each. In this district, the legumes are represented under 24 tribes, of which the Phaseoleae is the largest comprising 24 taxa, followed by Desmodieae (16) and Cassieae (12). Regarding endemics, *Indigofera prostrata* exclusive to West Bengal is recorded from Birbhum District, while *Grona brachystachya*, *Hardwickia binata*, *Pterocarpus marsupium*, and *P. santalinus* are endemic to India.

Keywords: Checklist, conservation, endemic species, ethnobotany, Ethnomedicine, habit, exotic species, indigenous taxa, Leguminosae, life form analysis, LPWG classification, taxon status, tribe.

Bengali: সারমর্ম: বর্তমান গবেষণাপত্রটি ভারতের পশ্চিমবঙ্গের বীরভূম জেলায় পাওয়া লেগুম উদ্ভিদের একটি বিস্তৃত বিবরণের সাথে সম্পর্কিত। আমরা 140টি প্রজাতি, একটি উপ-প্রজাতি এবং দুটি জাত রেকর্ড করেছি, যা চারটি উপ-পরিবারের অধীনে 24টি উপজাতি থেকে 82টি প্রজাতির প্রতিনিধিত্ব করে, যেমন, Cercidoideae (1টি গোত্রের অন্তর্গত 2টি বংশের মধ্যে 6টি প্রজাতি), Detarioideae (3টি ট্রাইবের মধ্যে 3টি প্রজাতি) , Caesalpinioideae (5টি উপজাতির অন্তর্গত 24টি বংশের মধ্যে 43টি প্রজাতি), এবং Papilionoideae (91টি ট্যাক্সা সহ 88টি প্রজাতি, 1টি উপ-প্রজাতি এবং 15টি উপজাতির অন্তর্গত 53টি বংশের মধ্যে 2টি প্রজাতি)। তৃণ (59 ট্যাক্সা) ছিল বৃহত্তম দল, তারপরে বৃক্ষ (39), লতা (23), এবং গুল্ম (22)। ক্রোটালারিয়া এবং ইন্ডিগোফেরা (প্রতিটি 7 প্রজাতি) প্রভাবশালী বংশ হিসাবে আবির্ভূত হয়েছে, তারপরে সেনা (6) এবং বাউহিনিয়া এবং সেনেগালিয়া প্রতিটি পাঁচটি প্রজাতির সাথে আবির্ভূত হয়েছে। এই জেলায়, 24টি উপজাতির অধীনে লেগুমগুলিকে প্রতিনিধিত্ব করা হয়, যার মধ্যে 24টি ট্যাক্সা নিয়ে গঠিত Phaseoleae বৃহত্তম, তারপরে Desmodieae (16) এবং Cassieae (12)। আঞ্চলিকতা সংক্রান্ত, বীরভূম জেলা থেকে এক দিকে যেমন পশ্চিমবঙ্গের জন্য একচেটিয়া স্থানীয় প্রজাতি *ইন্ডিগোফেরা প্রোস্ট্রাটা* রেকর্ড করা হয়েছে, অন্যদিকে তেমনি আছে *গ্রোনা ব্র্যাচিস্টাচ্যা, হার্ডউইকিয়া বিনাটা, টেরোকারপাস মার্সুপিয়াম* এবং *পি. সান্টালিনাস-* এর মত ভারতীয় স্থানীয় প্রজাতি।

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INTRODUCTION

Fabaceae Lindl. (nom. alt. for Leguminosae Juss.) is the third-largest Angiosperm family, with about 770 genera and over 19,500 species (Lewis et al. 2005; LPWG 2013). The family encompasses a remarkable array of life forms, from diminutive herbs to towering trees (Sanjappa 2001). The defining characteristic of the Fabaceae is the presence of pods, which distinguishes them from other plant families. The LPWG (2017) recognized six distinct subfamilies under the family Fabaceae, viz., Caesalpinioideae DC. (148 genera & ca. 4,400 species), Cercidoideae LPWG [Azani et al.] (12 genera & ca. 335 species), Detarioideae Burmeist. (84 genera & ca. 760 species), Dialioideae LPWG [Azani et al.] (17 genera & ca. 85 species), Duparquetioideae LPWG [Azani et al.] (1 genus & 1 species), and Papilionoideae DC. (503 genera & ca. 14,000 species). In India, Baker (1876–1878) first documented 132 genera and 833 species with 109 varieties from British India. Subsequently, a substantial number of legume taxa were recorded from India, accounting for 174 genera and 1,110 species (Sanjappa 2020). Prain (1903) reported 90 genera & 320 species from undivided Bengal Province. In West Bengal, the family is represented by 96 genera, 309 species, one subspecies, and 14 varieties (Paul et al. 2015). In Birbhum District, Sarkar (2017) reported 58 legume species in his floristic study.

Legumes are known for multiple functions including providing food grain and feed, facilitating soil nutrient management and contributing to climate mitigation (Baddeley et al. 2013). Herbaceous and tree legumes help in restoring soil fertility, preventing land degradation and improving sustainable crop and livestock productivity (Kassie 2011). The legumes include economically important species which are used as grains, and for pasture and agroforestry purposes (Graham & Vance 2003). The grain and forage legumes account for 27% of the world's primary crop production, and grain legumes contribute 33% of the dietary nitrogen (N) needs for humans (Vance et al. 2000). The most important legume species are Pea *Pisum sativum* L., Chickpea *Cicer arietinum* L., Cowpea *Vigna unguiculata* (L.) Walp., Broad Bean *Vicia faba* L., Pigeon Pea *Cajanus cajan* (L.) Huth, and Lentils *Lens culinaris* Medik.; 37% of processed vegetable oil is derived from Soya Bean *Glycine max* (L.) Merr. and Peanuts *Arachis hypogea* L. worldwide (Graham & Vance 2003). The forage legume Alfalfa (*Medicago sativa* L.) plays vital role in maintaining the health of animals (Wattiaux & Howard 2001) for dairy and meat production (Russelle 2001). The woody tree legumes which are commonly used in agroforestry purposes usually belong to the genera, *Acacia* Mill., *Anadenanthera* Speg., *Calliandra* Benth., *Dalbergia* L.f., *Erythrina* L., *Gliricidia* Kunth, *Melanoxylum* Schott, *Parkia* R.Br., *Prosopis* L., *Pterocarpus* Jacq., and *Samanea* (Benth.) Merr. (Sprent & Parsons 2000). The other species which are interplanted with other crops in the field are *Sesbania* spp., *Glyricidia* spp., *Tephrosia* spp., *Crotolaria* spp., *Leucaena* spp., and *Cajanus* spp., for enhancing the fertility of the soil through nitrogen fixation by the root nodules (Sanchez 1999; Graham & Vance 2003). Ecologically, legumes display versatility similar to grasses, coexisting in a wide range of ecosystems. Some legume species serve as bottom-up control elements within their ecosystems, while others act as keystone species, exemplifying their ecological significance (Sanjappa 2001).

Due to its immense importance to human beings in various fields as stated above, the present study is an attempt to update the legume database and to shed light on the diversity and distribution of Fabaceae in Birbhum District, West Bengal.

MATERIALS AND METHODS

Study Area

Birbhum District (Figure 1) is located in the northernmost part of the Burdwan division in the state of West Bengal, India and covers an extensive area of 4,545 km^2 which lies between 23.3230–24.3500 ^{0}N and 87.0525–88.0140 ^{0}E. It is bordered by Santal Parganas of Jharkhand both on the north and west, Murshidabad and Purba Bardhaman districts on the east, whilst Paschim Bardhaman and Purba Bardhaman districts are on the south. The predominant soil type of the district is lateritic, characterized by its richness in iron and aluminum. The climate of Birbhum is monsoon marked by an oppressive hot and humid summer, well-distributed rainy season with a short winter. The forest cover area is about 159.26 km^2 with Sal forest as the major type.

Methods

Extensive field surveys were undertaken between April 2017 and March 2021 in the entire Birbhum District, West Bengal. The legume specimens were collected from the field along with their GPS location. The habit, habitat, and flower color was noted along with digital photographs (Nikon P900 camera). The plant specimens were identified with the help of relevant

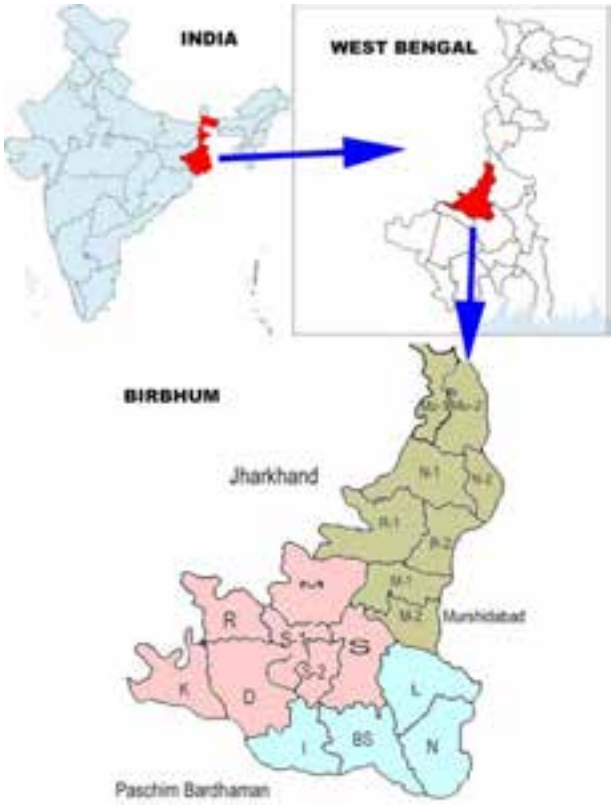

Figure 1. Study area (Birbhum District).

literature (Prain 1903; Bennet 1979; Guha 1984; Sanyal 1994; Debnath et al. 2013; Mitra & Mukherjee 2013; Ghosh & Mallick 2014; Paul et al. 2015; Santhosha & Kar 2017) and processed plant materials following standard procedures (Fosberg & Sachet 1965; Jain & Rao 1977; Bridson & Forman 1998). All processed and identified specimens were deposited in the Visva-Bharati Herbarium (VBH), Department of Botany, Visva-Bharati University, Santiniketan, West Bengal to serve as a reliable repository for future references.

The ethnobotanical information was collected through personal interview during the study period with the forest dwellers belonging to the Santal community. The detailed data was obtained from a total of 128 key informants which comprised common people, the local healers and cultivators of legumes from the district covering the forest area, agricultural fields and home gardens for comprehensive data for different uses in their daily life.

RESULTS AND OBSERVATION

The present study on legumes of Birbhum District, West Bengal was recorded with a total number of 143 taxa (Table 1; Figure 2; Images 1–9), comprising 140 species, 01 subspecies, and 02 varieties under 82 genera and 24 tribes within the four subfamilies, viz., Cercidoideae (Image 1a–f), Detarioideae (Image 1g–i), Caesalpinioideae (Images 1j–4d) and Papilionoideae (Images 4e–9o). The subfamily Papilionoideae exhibited the highest diversity with 91 taxa (88 species, 01 subspecies & 02 varieties) under 53 genera in 15 tribes, followed by Caesalpinioideae with 43 species under 24 genera and five tribes, Cercidoideae with six species under two genera and one tribe, and Detarioideae with three species under three genera and three tribes, respectively, as shown in Figure 2. The four major life forms—herbs, shrubs, trees, and climbers—were observed with the herbaceous growth forms exhibited the highest number (59 taxa), followed by trees (39 taxa), climbers (23 taxa), and shrubs (22 taxa), as depicted in figure percentage given in Figure 5. The tribe Phaseoleae recorded as the largest tribe with 24 taxa (22 species, 01 subspecies, & 01 variety), trailed by Desmodieae with 16 taxa (15 species & 01 variety), Cassieae (12 species), Dalbergieae and Acacieae (11 species each) as illustrated in Figure 3. The genus *Crotalaria* and *Indigofera* emerged as the most dominant (7 species each), followed by *Senna* (6 species), *Bauhinia* and *Senegalia* (5 species each) as shown in Figure 4.

DISCUSSION

The present investigation documented a total of 143 taxa (Images 1–9) belonging to the family Fabaceae from Birbhum District, which represents a significant 36% of the total 394 legume taxa (including cultivated species) reported by Paul et al. (2015) from West Bengal. This study recorded an additional 50 taxa (marked by '#' in the table 1) including 32 wild and 18 cultivated / planted taxa to the existing legume database that have not been documented in Birbhum by Paul et al. (2015) and Sarkar (2017). One taxon, *Cassia roxburghii* (Image 2n), was recorded as a new addition to the flora of West Bengal by the authors (Alam & Lokho 2019) during this study.

The present study also indicates that 41% of the Legume taxa recorded (143 taxa) are herbaceous species which is in congruent with the past studies as reported by others (Sarkar 2017) that a very high percentage of herbaceous legumes dominantly occupy the different local ecosystems. The present analysis depicts the subfamily Papilionoideae with the highest number of taxa (91 taxa), the tribe Phaseoleae with maximum taxa (24 taxa), and two genera—*Crotalaria* and *Indigofera*

Table 1. Checklist of legumes of Birbhum District as per latest classification LPWG (2017) with their Habit, Habitat, Ethnobotanical Uses, Taxon status and Exsiccata.

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
	Sub-family: **CERCIDOIDEAE** (1 tribe; 2 genera & 6 species)					
	I) Tribe: **Bauhinieae:** Genera:02; Species:06					
1	*#Bauhinia acuminata* L.	Shrub	Planted and escaped in wild (1,2,15)	-	Exotic	S. Alam 501
2	*#Bauhinia purpurea* L.	Tree	Deciduous forests and planted (Entire district)	-	Indigenous	S. Alam 1001
3	*Bauhinia tomentosa* L.	Shrub	Planted and Escaped (1,2,15)	-	Exotic	S. Alam 801
4	*Bauhinia variegata* L.	Tree	Planted as Avenue tree (1, 18)	-	Indigenous	S. Alam 301
5	*#Bauhinia blakeana* Dunn	Tree	Planted as Avenue tree (1)	-	Hybrid	S. Alam 1101
6.	*Phanera vahlii* (Wight & Arn) Benth.	Climber	Dry deciduous forests (11,18)	The peelings of the stem bark are used as ropes.	Indigenous	S. Alam 401
	Sub-family: **DETARIOIDEAE** (3 tribes; 3 genera & 3 species)					
	II) Tribe: **Amherstieae:** Genus:01; Species:01					
7	*Tamarindus indica* L.	Tree	Degraded forests and planted (Entire district)	i) The fruit pulp is used to enhance the taste of curries & chutneys. ii) Mature fruit pulp water is used to heal heat-shock during summer season.	Exotic	S. Alam 402
	III) Tribe: **Detarieae:** Genus:01; Species:01					
8	*#Hardwickia binata* Roxb.	Tree	Dry deciduous forests and Planted (1,11)	-	Indigenous & Endemic*	S. Alam 928
	IV) Tribe: **Saraceae:** Genus:01; Species:01					
9	*Saraca asoca* (Roxb.) de Wilde	Tree	Planted (1)	-	Indigenous	S. Alam 1201
	Sub-family: **CAESALPINIOIDEAE:** 5 tribes; 24 genera & 43 species)					
	V) Tribe: **Acacieae:** Genera:03; Species:11					
10	*Acacia auriculiformis* A. Cunn. ex Benth.	Tree	Planted and escaped forest (Entire district)	i) The wood is used for making doors, windows, almirah, bed and other furniture. ii) Fruit is used as an alternative soap for cleansing the body.	Exotic	S. Alam 802
11	*#Acacia holosericea* A.Cunn. ex G.Don	Shrub	Planted and escaped forest (1,2,14,15)	-	Exotic	S. Alam 1102
12	*Senegalia catechu* (L.f.) P. J. H. Hurter & Mabb.	Tree	Planted roadsides (1,15)	-	Indigenous	S. Alam 607
13	*#Senegalia intsia* (L.) Maslin, Seigler & Ebinger	Climber	Degraded forests and wastelands (1)	-	Indigenous	S. Alam 1008
14	*#Senegalia megaladena* (Desv.) Maslin, Seigler & Ebinger	Climber	Dry deciduous forests (15)	-	Indigenous	S. Alam 811
15	*#Senegalia polyacantha* (Willd.) Seigler & Ebinger	Tree	Dry deciduous forests (11,14,15,18,19)	-	Indigenous	S. Alam 712
16	*#Senegalia torta* (Roxb.) Maslin, Seigler & Ebinger	Scandent shrub	Dry deciduous forests (18)	-	Indigenous	S. Alam 903
17	*#Vachellia farnesiana* (L.) Wight & Arn.	Shrub	Degraded forests and Roadsides (1,11,13)	-	Exotic	S. Alam 1103
18	*#Vachellia leucophloea* (Roxb.) Maslin, Seigler & Ebinger	Tree	Dry deciduous forests and Roadsides (2,14,15,)	-	Indigenous	S. Alam 812
19	*Vachellia nilotica* (L.) P. J. H. Hurter & Mabb.	Tree	Dry deciduous forests and Roadsides (Entire district)	i) The wood is used for making handles of various agricultural tools. ii) The young twigs are used as tooth brush.	Indigenous	S. Alam 813
20	*#Vachellia tomentosa* (Rottler) Maslin, Seigler & Ebinger	Tree	Planted and Roadsides (1,2,15)	-	Indigenous	S. Alam 613
	VI) Tribe: **Caesalpinieae:** Genera:07; Species:07					
21	*Caesalpinia pulcherrima* (L.) Sw.	Shrub	Planted and Escaped Forest (Entire district)	-	Exotic	S. Alam 904

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
22	*Delonix regia* (Bojer ex Hook.) Raf.	Tree	Planted and Escaped (Entire district)	-	Exotic	S. Alam 403
23	*Guilandina bonduc* L.	Shrub	Along roadsides and open places (1,2,11,14,15,16)	Seeds are boiled and taken for treating gastro-intestinal problems.	Exotic	S. Alam 608
24	*#Mezoneuron cucullatum* (Roxb.) Wight & Arn.	Climber	Dry deciduous forests and Open areas (9,11,15)	-	Indigenous	S. Alam 111
25	*Moullava digyna* (Rottler) Gagnon & G.P.Lewis	Shrub	Dry deciduous forests (2)	-	Indigenous	S. Alam 905
26	*#Parkinsonia aculeata* L.	Tree	Roadsides and open places (3,17)	-	Exotic	S. Alam 1104
27	*Peltophorum pterocarpum* (DC.) Backer ex K. Heyne	Tree	Planted and Escaped Forest (Entire district)	-	Exotic	S. Alam 609
	VII) Tribe: **Cassieae:** Genera:03; Species:12					
28	*Cassia fistula* L.	Tree	Roadsides (Entire district)	The crushed bark juice is taken orally to treat hiccups.	Indigenous	S. Alam 515
29	*#Cassia javanica* L. subsp. *nodosa* (Buch. Ham. ex Roxb.) K. Larsen & S. S. Larsen	Tree	Planted along roadsides (1)	-	Exotic	S. Alam 425
30	*#Cassia roxburghii* DC.	Tree	Along roadsides and open places (1,17,19)	-	Indigenous	S. Alam 715
31	*#Chamaecrista absus* (L.) H. S. Irwin & Barneby	Herb	Deciduous forests (15)	-	Indigenous	S. Alam 924
32	*#Chamaecrista mimosoides* (L.) Greene	Herb	Degraded forests (2,14)	-	Indigenous	S. Alam 1019
33	*Chamaecrista pumila* (Lam.) V. Singh	Herb	Forest edges (15)	-	Indigenous	S. Alam 1015
34	*Senna alata* (L.) Roxb.	Shrub	Wastelands and Roadsides (Entire district)	The leaves are soaked in water, crushed into a paste and applied on the affected part (body) for treating ringworm & body rashes.	Exotic	S. Alam 713
35	*Senna occidentalis* (L.) Link	Herb	Open areas and Roadsides (Entire district)	Roots are crushed into paste and taken along with few drops of mustard oil to cure black discharge during menstrual cycle.	Exotic	S. Alam 614
36	*#Senna polyphylla* (Jacq.) H. S. Irwin & Barneby	Shrub	Planted as ornamental plant (1)	It is planted in the garden and used as avenue plant.	Exotic	S. Alam 302
37	*Senna siamea* (Lam.) H. S. Irwin & Barneby	Tree	Degraded forests and Roadsides (Entire district)	-	Exotic	S. Alam 516
38	*Senna sophera* (L.) Roxb.	Herb	Open areas and Roadsides (Entire district)	-	Exotic	S. Alam 814
39	*Senna tora* (L.) Roxb.	Herb	Open areas and Wastelands (Entire district)	Leaf decoction is taken to cure cold and cough.	Exotic	S. Alam 714
	VIII) Tribe: **Ingeae:** Genera:04; Species:05					
40	*Albizia lebbeck* (L.) Benth.	Tree	Dry deciduous forests and Roadsides (Entire district)	i) Leaf infusion in ghee is used to treat cold & cough. ii) Wood is used for making furniture & house building materials.	Indigenous	S. Alam 426
41	*#Albizia procera* (Roxb.) Benth.	Tree	Scrub forests and Roadsides (1,17,19)	-	Indigenous	S. Alam 615
42	*#Calliandra haematocephala* Hassk.	Shrub	Planted as Avenue plants (1)	-	Exotic	S. Alam 1104
43	*Pithecellobium dulce* (Roxb.) Benth.	Tree	Dry deciduous forests and Roadsides (Entire district)	-	Exotic	S. Alam 303
44	*Samanea saman* (Jacq.) Merr.	Tree	Planted and Roadsides (Entire district)	Wood is used for making house-building materials	Exotic	S. Alam 427
	IX) Tribe: **Mimoseae:** Genera:07; Species:08					
45	*#Adenanthera pavonina* L.	Tree	Planted (1,2,4,18)	Seeds are crushed into power and used for curing wounds.	Indigenous	S. Alam 715
46	*#Dichrostachys cinerea* (L.) Wight & Arn.	Tree	Planted as Sacred Avenue tree (1,17,18)	-	Indigenous	S. Alam 716
47	*#Leucaena leucocephala* (Lam.) de Wit	Tree	Planted & Roadsides (Entire district)	-	Exotic	S. Alam 717

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
48	*Mimosa pudica* L.	Herb	Open areas and Wastelands (Entire district)	Leaves are crushed and applied on the affected part to cure wounds.	Exotic	S. Alam 718
49	*Mimosa rubicaulis* subsp. *himalayana* (Gamble) H. Ohashi	Shrub	Dry deciduous forests and Roadsides (1,2,11,14,15,18)	-	Indigenous	S. Alam 814
50	*Neptunia oleracea* Lour.	Herb	Stagnant water bodies (1,2)	-	Indigenous	S. Alam 719
51	*#Prosopis juliflora* (Sw.) DC.	Tree	Roadsides (1,2,3,4,11,19)	-	Exotic	S. Alam 1105
52	*Xylia xylocarpa* (Roxb.) W. Theob.	Tree	Dry deciduous forests (9,11)	-	Indigenous	S. Alam 304
	Sub-family: **PAPILIONOIDEAE:** 15 tribes; 53 genera & 88 species; 1 subspecies; 2 varieties					
	X) Tribe: **Abreae:** Genus:01; Species:01					
53	*Abrus precatorius* L.	Climber	Dry deciduous forests & Roadsides (1,3,14,15,17)	i) Roots paste is taken to cure arthritis. ii) Stem extract along with leaves of *Adhatoda vasica* & honey are taken to cure Jaundice.	Indigenous	S. Alam 925
	XI) Tribe: **Cicereae:** Genus:01; Species:01					
54	*Cicer arietinum* L.	Herb	Cultivated farms (Entire district)	i) Seeds are cooked and eaten as pulses. ii) Tender leaves are cooked and eaten as leafy vegetables.	Exotic	S. Alam 1202
	XII) Tribe: **Crotalarieae:** Genus:01; Species:07					
55	*#Crotalaria juncea* L.	Herb	Cultivated field as fiber crop (3,14,16)	Bast fiber of the stem is used for making ropes & cordages.	Indigenous	S. Alam 720
56	*Crotalaria pallida* Aiton	Herb	Wastelands and roadsides (Entire district)	Aqueous extracts of root with milk & honey taken in empty stomach early morning to cure indigestion & weakness.	Indigenous	S. Alam 616
57	*Crotalaria prostrata* Rottler ex Willd.	Herb	Dry deciduous forests (2,11,15)	-	Indigenous	S. Alam 926
58	*#Crotalaria quinquefolia* L.	Herb	Wastelands and Cultivated fields (2,11)	-	Indigenous	S. Alam 927
59	*Crotalaria retusa* L.	Herb	Wastelands and Cultivated fields (19)	-	Indigenous	S. Alam 1203
60	*Crotalaria spectabilis* Roth	Herb	Open areas and Roadsides (Entire district)	-	Indigenous	S. Alam 1106
61	*Crotalaria verrucosa* L.	Herb	Open areas and Roadsides (5)	-	Indigenous	S. Alam 815
	XIII) Tribe: **Dalbergieae:** Genera:07; Species:11					
62	*#Aeschynomene americana* L.	Herb	Along roadsides (Entire district)	-	Exotic	S. Alam 1107
63	*Aeschynomene aspera* L.	Herb	Along water bodies (2,3,17)	-	Indigenous	S. Alam 721
64	*Aeschynomene indica* L.	Herb	Along water bodies (1,2,5)	-	Indigenous	S. Alam 816
65	*Arachis hypogaea* L.	Herb	Cultivated farms (1,2,13,14)	Seeds are roasted and eaten.	Exotic	S. Alam 201
66	*#Brya ebenus* (L.) DC.	Shrub	Planted as ornamental plant (1,2)	It is planted in the garden and used as avenue plant.	Exotic	S. Alam 428
67	*#Dalbergia lanceolaria* L.f.	Tree	Dry deciduous forests and Roadsides (1,2,6,11,13,14,15,16,17)	-	Indigenous	S. Alam 305
68	*Dalbergia sissoo* Roxb. ex DC.	Tree	Planted and Roadsides (Entire district)	i) The leaf crushed juice taken to treat chronic cough. ii) The hard & durable wood is extensively used for furniture and construction purposes.	Indigenous	S. Alam 306
69	*Pterocarpus marsupium* Roxb.	Tree	Dry deciduous forests and Roadsides (1,2,10,11)	Wood is used for making furniture, door and other wooden tools.	Indigenous & Endemic*	S. Alam 1016
70	*#Pterocarpus santalinus* L.f.	Tree	Dry deciduous forests (11)	-	Indigenous & Endemic*	S. Alam 437
71	*Smithia sensitiva* Aiton.	Herb	Wet grasslands (11,14,18)	-	Indigenous	S. Alam 929
72	*#Zornia gibbosa* Span.	Herb	Open areas and Grasslands (2,18)	-	Indigenous	S. Alam 930

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
	XIV) Tribe: **Desmodieae:** Genera:10; Species:15; Variety:01					
73	*Alysicarpus bupleurifolius* (L.) DC.	Herb	Muddy Brick wall (15)	-	Indigenous	S. Alam 817
74	*Alysicarpus monilifer* (L.) DC.	Herb	Grasslands and Roadsides (Entire district)	-	Indigenous	S. Alam 931
75	*Alysicarpus vaginalis* (L.) DC. var. *nummulariifolius* (DC.) Miq.	Herb	Grasslands and Roadsides (2,11, 17)	-	Indigenous	S. Alam 932
76	*Alysicarpus vaginalis* (L.) DC. var. *vaginalis*	Herb	Grasslands and Roadsides (Entire district)	-	Indigenous	S. Alam 933
77	*Christia vespertilionis* (L. f.) Bakh. f.	Herb	Planted as ornamental plant (18)	The plant is planted in the garden for beatification.	Exotic	S. Alam 722
78	*Codariocalyx motorius* (Houtt.) H. Ohashi	Shrub	Dry deciduous forests (11)	-	Indigenous	S. Alam 1017
79	*#Desmodium scorpiurus* (Sw.) Desv.	Herb	Roadsides and open areas (2,19)	-	Exotic	S. Alam 1018
80	*Grona brachystachya* (Graham ex Benth.) H. Ohashi & K. Ohashi	Herb	Dry deciduous forests (2,11,15)	-	Indigenous & Endemic*	S. Alam 1019
81	*#Grona heterocarpos* (L.) H.Ohashi & K.Ohashi	Herb	Dry deciduous forests (2,11,13,15)	-	Indigenous	S. Alam 723
82	*#Grona heterophylla* (Willd.) H.Ohashi & K.Ohashi	Herb	Dry deciduous forests (2)	-	Indigenous	S. Alam 934
83	*Grona triflora* (L.) H.Ohashi & K.Ohashi	Herb	Grasslands, Wastelands and Open areas (Entire district)	-	Indigenous	S. Alam 724
84	*#Phyllodium pulchellum* (L.) Desv.	Shrub	Dry deciduous forests (2, 11,13,14,15,18)	-	Indigenous	S. Alam 935
85	*Pleurolobus gangeticus* (L.) J.St. Hil. ex H. Ohashi & K. Ohashi	Herb	Grasslands, wastelands and Roadsides (Entire district)	i) Roots are made into paste and rubbed on chest to reduce pain. ii) Stem bark is used for making ropes.	Indigenous	S. Alam 818
86	*#Polhillides velutina* (Willd.) H. Ohashi & K. Ohashi	Herb	Dry deciduous forests (2,11,15)	-	Indigenous	S. Alam 936
87	*Pseudarthria viscida* (L.) Wight & Arn.	Herb	Grasslands (2)	-	Indigenous	S. Alam 937
88	*Uraria lagopodioides* (L.) DC.	Herb	Dry deciduous forests (11,15)	-	Indigenous	S. Alam 819
	XV) Tribe: **Diocleae:** Genus:01; Species:01					
89	*#Canavalia gladiata* (Jacq.) DC.	Climber	Dry deciduous forests and Open areas (1,2,5,9,17,18,19)	Young fruits are cooked and eaten as vegetables.	Indigenous	S. Alam 820
	XVI) Tribe: **Fabeae:** Genera:02; Species:06					
90	*#Lathyrus aphaca* L.	Climber	Weed of cultivated Grass pea field (7,14)	-	Indigenous	S. Alam 1204
91	*Lathyrus oleraceus* Lam.	Climber	Cultivated farms (Entire district)	Seeds are cooked and eaten as pulses.	Exotic	S. Alam 1205
92	*Lathyrus sativus* L.	Climber	Cultivated farms (Entire district)	i) Seeds are cooked and eaten as pulses. ii) Leaves are cooked and eaten as leafy vegetables. iii) Twigs with leaves are used as fodder for livestock.	Exotic	S. Alam 1206
93	*Vicia hirsuta* (L.) Gray	Climber	Cultivated Lentil field (Entire district)	-	Indigenous	S. Alam 1207
94	*Vicia lens* (L.) Coss. & Germ.	Herb	Cultivated farms (Entire district)	Seeds are cooked and eaten as pulses.	Exotic	S. Alam 1208
95	*#Vicia sativa* L.	Herb	Cultivated fields (Gram & Lentil) (Entire district)	-	Indigenous	S. Alam 1209
	XVII) Tribe: **Genisteae:** Genus:01; Species:01					
96	*Lupinus angustifolius* L.	Herb	Planted (1)	The plant is planted in the garden for beautification.	Exotic	S. Alam 1210
	XVIII) Tribe: **Indigofereae:** Genus:01; Species:07					
97	*Indigofera cassioides* Rottler ex DC.	Shrub	Dry deciduous forests (11)	-	Indigenous	S. Alam 1233
98	*#Indigofera glabra* L.	Herb	Dry deciduous forests (2)	-	Indigenous	S. Alam 938

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
99	*#Indigofera hirsuta* L.	Shrub	Roadsides and Wastelands (1,2)	-	Indigenous	S. Alam 939
100	*Indigofera linifolia* (L.f.) Retz.	Herb	Grasslands and Roadsides (Entire district)	-	Indigenous	S. Alam 821
101	*Indigofera linnaei* Ali.	Herb	Grasslands and Wastelands (Entire district)	-	Indigenous	S. Alam 940
102	*#Indigofera prostrata* Willd.	Herb	Grasslands and Wastelands (2)	-	Indigenous & Endemic**	S. Alam 941
103	*Indigofera tinctoria* L.	Shrub	Open areas and Roadsides (Entire district)	The roots are crushed and made into paste and the same is taken with black pepper and turmeric to treat rheumatism.	Indigenous	S. Alam 725
	XIX) Tribe: **Millettieae:** Genera:05; Species:06					
104	*#Brachypterum scandens* (Roxb.) Miq.	Climber	Dry deciduous forests and Open areas (2,3)	-	Indigenous	S. Alam 726
105	*#Derris trifoliata* Lour.	Shrub	Dry deciduous forests (11)	-	Indigenous	S. Alam 251
106	*Millettia peguensis* Ali	Tree	Roadsides (1)	-	Exotic	S. Alam 202
107	*Pongamia pinnata* (L.) Pierre	Tree	Dry deciduous forests and Roadsides (Entire district)	Freshly cut bark boiled in hot water and the boiled barks are used to relief from toothache.	Indigenous	S. Alam 308
108	*Tephrosia purpurea* (L.) Pers.	Herb	Open areas and Wastelands (Entire district)	-	Indigenous	S. Alam 617
109	*Tephrosia villosa* (L.) Pers.	Herb	Open areas and Wastelands (1,2)	-	Indigenous	S. Alam 727
	XX) Tribe: **Phaseoleae:** Genera:17; Species:22; Subspecies:01; Variety:01					
110	*Butea monosperma* (Lam.) Kuntze	Tree	Dry deciduous forests and Roadsides (Entire district)	i) The bark infusion is used to reduce fever. ii) The flower buds are crushed and mixed with black pepper and taken in empty stomach to treat menorrhagia.	Indigenous	S. Alam 203
111	*Cajanus cajan* (L.) Huth	Shrub	Cultivated farms (Entire district)	i) Seeds are cooked and eaten as pulses. ii) The leaves are crushed and make into soup mixed with sugarcane juice for treating Jaundice. iii) The plant is used as hedges in agricultural fields.	Indigenous	S. Alam 1020
112	*Cajanus crassus* (Prain ex King) Maesen	Climber	Dry deciduous forests (15)	-	Indigenous	S. Alam 1211
113	*Cajanus scarabaeoides* (L.) Thouars	Climber	Dry deciduous forests and Open areas (Entire district)	Decoction of the plant twig is used in veterinary to treat cattle diarrhoea.	Indigenous	S. Alam 942
114	*#Centrosema pubescens* Benth.	Climber	Open forests (1,2,18)	-	Exotic	S. Alam 1108
115	*#Clitoria ternatea* L. var. *pleniflora* Fantz	Climber	Along roadsides; often planted (1, 14, 17)	-	Exotic	S. Alam 618
116	*Clitoria ternatea* L. var. *ternatea*	Climber	Dry deciduous forests, Roadsides, Planted (Entire district)	Root decoction is used to treat leucorrhea.	Exotic	S. Alam 619
117	*Erythrina variegata* L.	Tree	Roadsides and Open areas (1,2,4,5,11,17)	i) Decoction of the bark mixed with black pepper is taken to treat dysentery. ii) The seed paste is used for massaging the affected part of the body for treating paralysis.	Indigenous	S. Alam 204
118	*Glycine max* (L.) Merr.	Herb	Cultivated farms (2)	Seeds are cooked or roasted and eaten.	Exotic	S. Alam 943
119	*Lablab purpureus* (L.) Sweet	Climber	Cultivated (Entire district)	Green fruits are cooked and eaten as vegetables.	Indigenous	S. Alam 1021
120	*#Macroptilium atropurpureum* (DC.) Urban	Climber	Open areas and Roadsides (1)	-	Exotic	S. Alam 1109
121	*Macrotyloma uniflorum* (Lam.) Verdc.	Herb	Cultivated farms (1, 2,3,4,5,6)	Seeds are cooked and eaten as pulses.	Indigenous	S. Alam 944

	Name of taxon	Habit	Habitat & localities (Block number)	Ethnobotanical uses	Taxon status (as per POWO 2023)	Exsiccata
122	*Mucuna pruriens* (L.) DC.	Climber	Dry deciduous forests and Roadsides (2,5,14,15,18)	i) Seed decoction is used to treat irregular menstruation. ii) Decoction of leaves is used to treat cattle diarrhoea.	Indigenous	S. Alam 1022
123	*Neustanthus phaseoloides* (Roxb.) Benth.	Climber	Dry deciduous forests (2,14,15)	-	Indigenous	S. Alam 822
124	*Pachyrhizus erosus* (L.) Urb.	Herb	Cultivated farms (3,5,6)	Fleshy tubers are eaten.	Exotic	S. Alam 945
125	*Phaseolus vulgaris* L.	Herb	Cultivated farms (1,2,9)	Green fruits are cooked and eaten as vegetables.	Exotic	S. Alam 112
126	*#Rhynchosia rufescens* DC.	Shrub	Dry deciduous forests (15)	-	Indigenous	S. Alam 1212
127	*#Spatholobus parviflorus* (Roxb. ex G.Don) Kuntze	Climber	Dry deciduous forests (2,11,14,15)	-	Indigenous	S. Alam 946
128	*Teramnus labialis* (L.f.) Spreng.	Climber	Open areas and Cultivated fields (1,2,3,4)	-	Indigenous	S. Alam 947
129	*Vigna mungo* (L.) Hepper	Herb	Cultivated farms (Entire district)	Seeds are cooked and eaten as pulses.	Indigenous	S. Alam 728
130	*Vigna radiata* (L.) R. Wilczek	Herb	Cultivated farms (Entire district)	Seeds are cooked and eaten as pulses.	Indigenous	S. Alam 517
131	*Vigna trilobata* (L.) Verdc.	Herb	Open areas and Wastelands (Entire district)	-	Indigenous	S. Alam 729
132	*Vigna unguiculata* (L.) Walp. subsp. *cylindrica* (L.) Eseltine, Hendricks	Herb	Cultivated farms (Entire district)	Green fruits are cooked and eaten as vegetables.	Exotic	S. Alam 730
133	*Vigna unguiculata* (L.) Walp. subsp. *unguiculata*	Climber	Cultivated farms (Entire district)	Green fruits are cooked and eaten as vegetables.	Exotic	S. Alam 731
	XXI) Tribe: **Psoraleeae:** Genus:01; Species:01					
134	*Cullen corylifolium* (L.) Medik.	Herb	Weed of cultivated field (19)	-	Indigenous	S. Alam 1110
	XXII) Tribe: **Robinieae:** Genus:01\; Species:01					
135	*Gliricidia sepium* (Jacq.) Kunth	Tree	Open areas and Roadsides (1,2,11,17,18)	-	Exotic	S. Alam 205
	XXIII) Tribe: **Trifolieae:** Genera:03; Species:05					
136	*Medicago lupulina* L.	Herb	Weed of cultivated fields (14)	-	Indigenous	S. Alam 113
137	*Melilotus albus* Medik.	Herb	Weed of cultivated fields (1)	-	Exotic	S. Alam 1213
138	*Melilotus indicus* (L.) All.	Herb	Weed of cultivated fields (1,4)	-	Indigenous	S. Alam 1214
139	*Trigonella balansae* Boiss. & Reut.	Herb	Cultivated as leafy vegetable (1,7,8,9,10,11,12)	Leaves are cooked and eaten as leafy vegetables.	Exotic	S. Alam 1215
140	*Trigonella foenum-graecum* L.	Herb	Cultivated as leafy vegetable & spice (2,4,12,17)	i) Leaves are cooked and eaten as leafy vegetables. ii) Seeds are used as spices.	Exotic	S. Alam 1216
	XXIV) Tribe: **Sesbanieae:** Genus:01; Species:03					
141	*Sesbania bispinosa* (Jacq.) W. Wight	Shrub	Cultivated farms and Roadsides (1,2,4,13,14,16)	i) The plant is grown in the agricultural fields to enhance soil fertility. ii) Leaves are used in fishery as food for grass carp & silver carp fish and as fodder for domestic grazing animals.	Indigenous	S. Alam 948
142	*Sesbania grandiflora* (L.) Poir.	Tree	Dry deciduous forests and Roadsides (2,14,16)	i)The whole flower is mixed with gram flour, fry or cooked in oil and eaten as vegetables. ii)Flower is also used to treat hypertension. ii) Leaf extracts mixed with honey & milk is taken to improve night vision.	Exotic	S. Alam 823
143	*Sesbania sesban* (L.) Merr. var. *bicolor* (Wight & Arn.) F. W. Andrews	Tree	Roadsides and Planted (2,11,13,14)	-	Indigenous	S. Alam 1111

*—endemic to India | **—endemic to West Bengal | #—taxa not reported from Birbhum by Paul et al. (2015) and Sarkar (2017).
Blocks: 1—Bolpur-Sriniketan (BS) | 2—Ilambazar (I) | 3—Labpur (L) | 4—Nanoor (N) | 5—Mayureswar-I (M-1) | 6—Mayureswar-II (M-2) | 7—Murarai-I (Mu-1) | 8—Murarai-II (Mu-2) | 9—Nalhati-I (N-1) | 10—Nalhati-II (N-2) | 11—Rampurhat-I (R-1) | 12—Rampurhat-II (R-2) | 13—Dubrajpur (D) | 14—Khayrasole (K) | 15—Md. Bazar (M) | 16—Rajnagar (R) | 17—Sainthia (S) | 18—Suri-I (S-1) | 19—Suri-II (S-2).

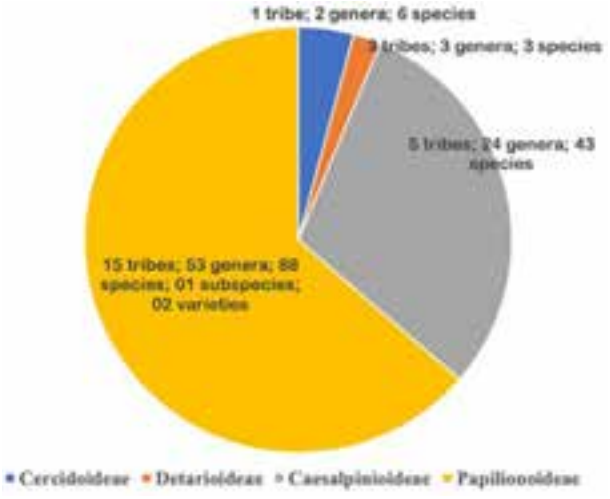

Figure 2. Subfamily wise distribution of legumes in Birbhum District (as per LPWG 2017).

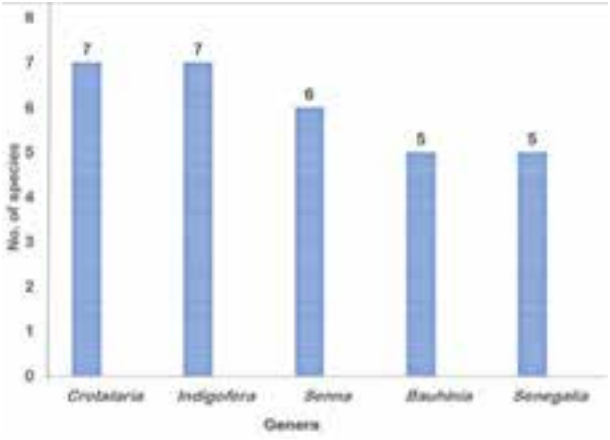

Figure 4. Top five dominant legume genera in Birbhum District.

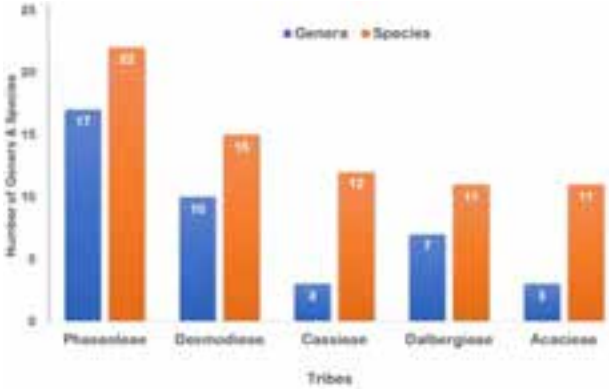

Figure 3. Top five dominant legume tribes showing number of genera and species in Birbhum District.

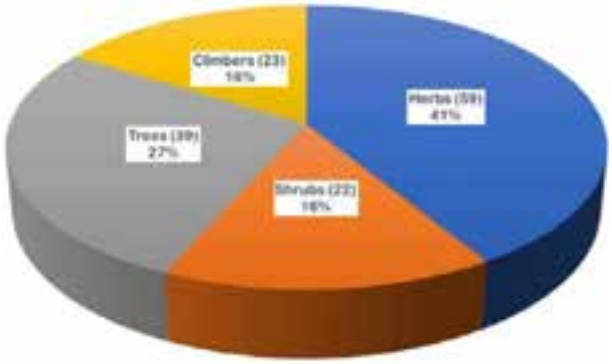

Figure 5. Percentage of various legume life forms in Birbhum District.

(7 species each)—as the dominant genera from the district. The present observation is in conformity with the findings of Paul et al. (2015) where Papilionoideae, Phaseoleae, and *Crotalaria* emerged as the most dominant subfamily, tribe and genus, respectively, which suggest the family (Fabaceae) has high adaptability and abundance throughout the state. Out of 24 tribes and 82 genera recorded from the district, nine tribes and 57 genera are represented by only a single taxon.

The *Hardwickia binata* (monotypic genus, Image 1h), three other species—*Grona brachystachya* (Image 5p), *Pterocarpus marsupium* (Image 5e) and *P. santalinus* (Image 5f)—were found to be endemic to India (Irwin & Narasimhan 2011; Sanjappa 2020) while *Indigofera prostrata* (Image 7f) was identified as an exclusive endemic species to West Bengal (Karthigeyan et al. 2022). As per the IUCN (2023) three species which are in different critical levels as 'Endangered' (*Pterocarpus santalinus*), 'Vulnerable' (*Saraca asoca*), and 'Near Threatened' (*Pterocarpus marsupium*) were documented from this district. This study recorded 32 wild legume species as new additions to the flora of Birbhum district which were not reported by Paul et al (2015) and Sarkar (2017) from the district Birbhum, viz.: *Aeschynomene americana*, *Albizia procera*, *Brachypterum scandens*, *Canavalia gladiata*, *Cassia roxburghii*, *Centrosema pubescens*, *Chamaecrista absus*, *C. mimosoides*, *Crotalaria quinquefolia*, *Dalbergia lanceolaria*, *Derris trifoliata*, *Desmodium scorpiurus*, *Grona heterocarpos*, *G. heterophylla*, *Indigofera glabra*, *I. hirsuta*, *I. prostrata*, *Lathyrus aphaca*, *Macroptilium atropurpureum*, *Mezoneuron cucullatum*, *Polhillides velutina*, *Rhynchosia rufescens*, *Senegalia intsia*, *S. megaladena*, *S. polyacantha*, *S. torta*, *Spatholobus parviflorus*, *Vachellia farnesiana*, *V. leucophloea*, *V. tomentosa*, *Vicia sativa*, and *Zornia gibbosa*. The study also recorded 18 cultivated / planted legume taxa which

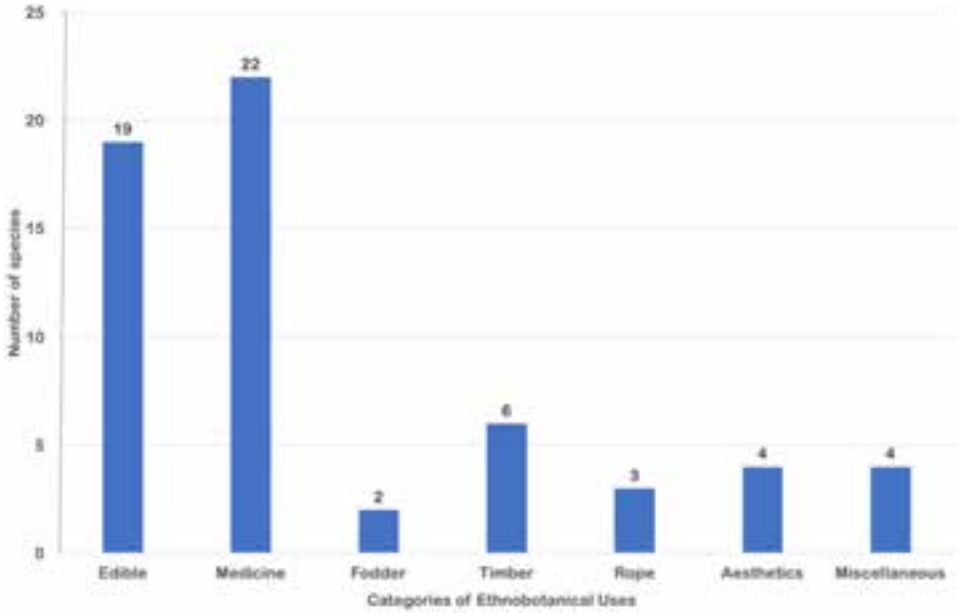

Figure 6. Different ethnobotanical usage groups.

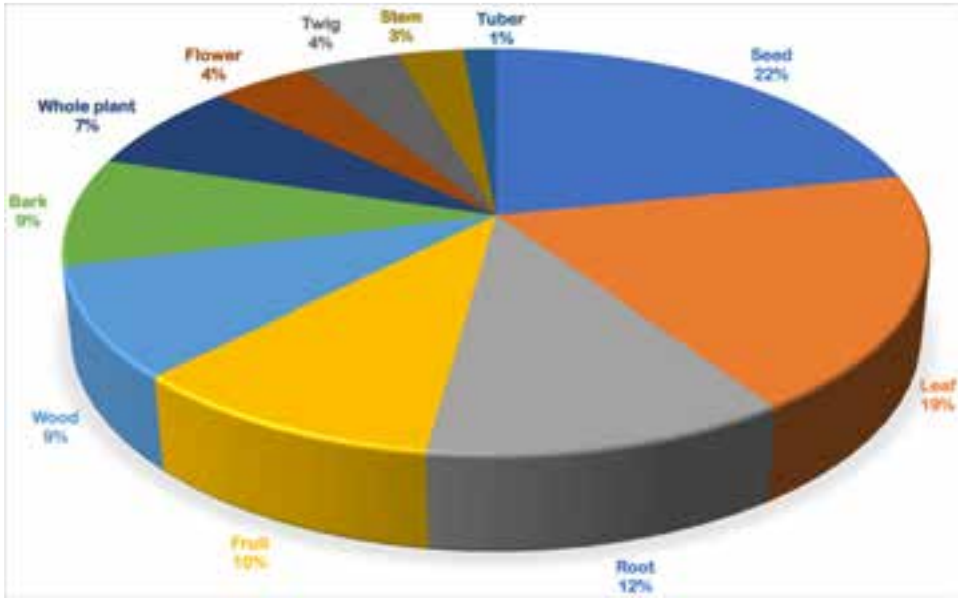

Figure 7. Different plant parts used for ethnobotany in Birbhum District.

were not reported earlier from the district, viz.: *Acacia holosericea*, *Adenanthera pavonina*, *Bauhinia acuminata*, *Bauhinia purpurea*, *B. blakeana*, *Brya ebenus*, *Calliandra haematocephala*, *Cassia javanica* ssp. *nodosa*, *Clitoria ternatea* var. *pleniflora*, *Crotalaria juncea*, *Dichrostachys cinerea*, *Hardwickia binata*, *Leucaena leucocephala*, *Parkinsonia aculeata*, *Phyllodium pulchellum*, *Prosopis juliflora*, *Pterocarpus santalinus*, and *Senna polyphylla*. In spite of the rich legume diversity, the Birbhum district hosts 49 exotic species (table 1) which represents over one-third (34%) of the total legume species in the district which have become naturalized and affect the local phytodiversity. The exotic genus *Senna* (Image 3b–g) was found to be the most dominant one with six exotic species (*Senna alata*, *S. occidentalis*, *S. polyphylla*, *S. siamea*, *S. sophera*, and *S. tora*).

The different plant parts (seeds, stem, leaves, fruits, roots, wood, bark, whole plant, flowers, twig, tuber) of 50 legume taxa (34%) under 39 genera are used for various ethnobotanical uses (Table 1), of

which 19 taxa are edible, 22 taxa have medicinal uses, two taxa (*Lathyrus sativus* and *Sesbania bispinosa*) are used as fodder, six taxa (*Acacia auriculiformis*, *Albizia* lebbeck, *Albizia saman*, *Dalbergia sissoo*, *Pterocarpus marsupium*, and *Vachellia nilotica*) are used in timber production purposes, four taxa (*Brya ebenus*, *Christia vespertilionis*, *Lupinus angustifolius*, and *Senna polyphylla*) for aesthetics, three taxa (*Crotalaria juncea*, *Pleurolobus gangeticus*, and *Phanera vahlii*) are used in making ropes and cordage, and four taxa (*Acacia auriculiformis*, *Cajanus cajan*, *Sesbania bispinosa*, and *Vachellia nilotica*) for miscellaneous purposes as shown in Figure 6. Among the plant parts used, seeds (15) taxa emerged as the most frequently utilized component followed by leaves (13), roots (08), fruits (07), wood (06), bark (06), whole plant (05), flowers (03), twig (03), stem (02) and tuber (01) as depicted in Figure 7. About 44% of the ethnobotanical plants recorded are used as medicine for treating a range of 20 common ailments. The species which are used as medicines for various treatments, viz., *Senna tora*, *Albizia lebbeck*, *Dalbergia sissoo* for cold & cough; *Adenanthera pavonina*, *Mimosa pudica* for healing wounds; *Senna occidentalis*, *Mucuna pruriens* for menstrual problems; *Guilandina bonduc*, *Crotalaria pallida* for indigestion and stomach problems; *Abrus precatorius*, *Cajanus cajan* to treat jaundice; *Cajanus scarabaeoides* & *Mucuna pruriens* for cattle diarrhoea; *Butea monosperma* (fever), *Cassia fistula* (hiccups), *Clitoria ternatea* (leucorhhea); *Erythrina variegata* for dysentery & paralysis; *Pleurolobus gangeticus* for chest pain; *Senna alata* for ringworm; *Sesbania grandiflora* for dizziness & night blindness; *Tamarindus indicus* (heat-shock); *Indigofera tinctoria* (rheumatism); *Butea monosperma* (menorrhagia); *Pongamia pinnata* for toothache; and *Abrus precatorius* for arthritis.

Fifteen species have been documented which are popularly used for food, viz., *Cajanus cajan*, *Cicer arietinum*, *Glycine max*, *Lathyrus oleraceus*, *L. sativus*, *Macrotyloma uniflorum*, *Vicia lens*, *Vigna mungo* and *V. radiata*, *Lablab purpureus*, *Pachyrhizus erosus*, *Phaseolus vulgaris*, *Vigna unguiculata*, *Trigonella balansae*, *T. foenum-graecum*. The only species *Arachis hypogaea* is used for oil seed. The study also documents four ornamental legume species cultivated for beautification in gardens, viz., *Brya ebenus*, *Christia vespertilionis*, *Lupinus angustifolius*, *Senna polyphylla*, and one legume fiber plant, *Crotalaria juncea* for making ropes and cordages.

Six species categorized as weeds in cultivated fields were identified such as *Lathyrus aphaca*, *Medicago lupulina*, *Melilotus albus*, *M. indicus*, *Vicia hirsuta*, and *V. sativa*. Furthermore, species like *Crotalaria prostrata*, *Indigofera linifolia*, and *I. linnaei* were noted for their ability to retain moisture, forming a dense mat on the soil surface, which aids in water conservation.

CONCLUSION

It is revealed from the present investigation on the family Fabaceae that in the Birbhum District 143 taxa are recorded, which indicates 36% of the total legume taxa reported in West Bengal. Amongst the total taxa (143), 50 additional taxa (including 32 wild and 18 cultivated/ planted taxa) were documented that are not reported from the district by earlier workers (Paul et al. 2015; Sarkar 2017). Also, the taxon *Cassia roxburghii* has been reported for the first time as a new addition to the flora of West Bengal (Alam & Lokho 2019). Apart from legume rich diversity, the district is a habitat for a few Indian endemic species, viz., *Hardwickia binata*, *Grona brachystachya, Pterocarpus marsupium, P. santalinus* (Irwin & Narasimhan 2011; Sanjappa 2020), and one exclusive species *Indigofera prostrata* endemic to the West Bengal State (Karthigeyan et al. 2022). The presence of exotic legumes species (34%) in the district requires the importance of monitoring and managing non-native species to prevent potential ecological disruptions. Management strategies to control the weedy legumes are essential to safeguard agricultural productivity. There are a few species recorded which fall in a different category as per IUCN (2023) and require immediate attention for conservation, viz., *Pterocarpus santalinus* (Endangered), *P. marsupium* (Near Threatened). The local people (mostly tribals) use about 50 legume taxa for multiple ethnobotanical uses such as food, and folk medicine on a daily basis indicating the direct dependence on the natural resources for their livelihood. Therefore, the sustainable management of the resources found in the district is paramount for preservation and conservation of the rich diversity of the legume taxa. Further research is required in medicinal plants for scientific validation and potential biochemical constituents in various plants for drug discovery to treat various diseases. The comprehensive legume data will be beneficial to the local people, students, teachers, forest officials and policy makers to enable them to study, utilize and in the management of legumes in a sustainable manner.

Image 1. a—*Bauhinia acuminata* L. | b—*Bauhinia purpurea* L.; |c—*Bauhinia tomentosa* L. | d—*Bauhinia variegata* L. | e—*Bauhinia ´ blakeana* Dunn | f—*Phanera vahlii* (Wight & Arn.) Benth. | g—*Tamarindus indica* L. | h) *Hardwickia binata* Roxb. | i—*Saraca asoca* (Roxb.) de Wilde | j—*Acacia auriculiformis* A.Cunn. ex Benth. | k—*Acacia holosericea* A.Cunn. ex G.Don | l—*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb. | m—*Senegalia intsia* (L.) Maslin, Seigler & Ebinger | n—*Senegalia megaladena* (Desv.) Maslin, Seigler & Ebinger | o—*Senegalia polyacantha* (Willd.) Seigler & Ebinger | p—*Senegalia torta* (Roxb.) Maslin, Seigler & Ebinger. © Shamim Alam.

Image 2. a—*Vachellia farnesiana* (L.) Wight & Arn. | b—*Vachellia leucophloea* (Roxb.) Maslin, Seigler & Ebinger | c—*Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. | d—*Vachellia tomentosa* (Rottler) Maslin, Seigler & Ebinger | e—*Caesalpinia pulcherrima* (L.) Sw. | f—*Delonix regia* (Bojer) Raf. | g—*Guilandina bonduc* L. | h—*Mezoneuron cucullatum* (Roxb.) Wight & Arn. | i—*Moullava digyna* (Rottler) Gagnon & G.P.Lewis | j—*Parkinsonia aculeata* L. | k—*Peltophorum pterocarpum* (DC.) Baker ex K.Heyne | l—*Cassia fistula* L. | m—*Cassia javanica* L. ssp. *nodosa* (Buch.-Ham. ex Roxb.) K.Larsen & S.S.Larsen | n—*Cassia roxburghii* DC. | o—*Chamaecrista absus* (L.) H.S.Irwin & Barneby | p—*Chamaecrista mimosoides* (L.) Greene. © Shamim Alam.

Image 3. a—***Chamaecrista pumila*** (Lam.) K. Larsen | b—***Senna alata*** (L.) Roxb. | c—***Senna occidentalis*** (L.) Link | d—***Senna polyphylla*** (Jacq.) H.S. Irwin & Barneby | e—***Senna siamea*** (Lam.) H.S. Irwin & Barneby | f—***Senna sophera*** (L.) Roxb. | g—***Senna tora*** (L.) Roxb. | h—***Albizia lebbeck*** (L.) Benth. | i—***Albizia procera*** (Roxb.) Benth. | j—***Calliandra haematocephala*** Hassk. | k—***Pithecellobium dulce*** (Roxb.) Benth. | l—***Samanea saman*** (Jacq.) Merr. | m—***Adenanthera pavonina*** L. | n—***Dichrostachys cinerea*** (L.) Wight & Arn. | o—***Leucaena leucocephala*** (Lam.) de Wit | p—***Mimosa pudica*** L. © Shamim Alam.

Image 4. a—***Mimosa rubicaulis*** **subsp.** ***himalayana*** **(Gamble—H.Ohashi | b—*Neptunia oleracea* Lour. | c—*Prosopis juliflora* (Sw.) DC. | d—*Xylia xylocarpa* (Roxb.) Taub. | e—*Abrus precatorius* L. | f—*Cicer arietinum* L. | g—*Crotalaria juncea* L. | h—*Crotalaria pallida* Aiton | i—*Crotalaria prostrata* Rottl. | j—*Crotalaria quinquefolia* L. | k—*Crotalaria retusa* L. | l—*Crotalaria spectabilis* Roth | m—*Crotalaria verrucosa* L. | n—*Aeschynomene americana* L. | o—*Aeschynomene aspera* L. | p—*Aeschynomene indica* L. © Shamim Alam.

Image 5. a—*Arachis hypogaea* L. | b—*Brya ebenus* DC. | c—*Dalbergia lanceolaria* L.f. | d—*Dalbergia sissoo* Roxb. | e—*Pterocarpus marsupium* Roxb. | f—*Pterocarpus santalinus* L.f. | g—*Smithia sensitiva* Aiton, | h—*Zornia gibbosa* Span. | i—*Alysicarpus bupleurifolius* (L.) DC. | j—*Alysicarpus monilifer* (L.) DC. | k—*Alysicarpus vaginalis* (L.) DC. var. *nummulariifolia* (DC.) Miq. | l—*Alysicarpus vaginalis* (L.) DC. var. *vaginalis* | m—*Christia vespertilionis* (L.f.) Bakh.f. | n—*Codariocalyx motorius* (Houtt.) H. Ohashi | o—*Desmodium scorpiurus* (Sw.) Desv. | p—*Grona brachystachya* (Graham ex. Benth.) H. Ohashi & K. Ohashi. © Shamim Alam.

Image 6. a—*Grona heterocarpos* (L.) H. Ohashi & K. Ohashi | b—*Grona heterophylla* (Willd.) H. Ohashi & K. Ohashi | c—*Grona triflora* (L.) H. Ohashi & K. Ohashi | d—*Phyllodium pulchellum* (L.) Desv. | e—*Pleurolobus gangeticus* (L.) J.St.-Hil. | f—*Polhillides velutina* (Willd.) H. Ohashi & K. Ohashi | g—*Pseudarthria viscida* (L.) Wight& Arn. | h—*Uraria lagopodioides* (L.) Desv. | i—*Canavalia gladiata* (Jacq.) DC. | j—*Lathyrus aphaca* L. | k—*Lathyrus oleraceus* Lam. | l—*Lathyrus sativus* L. | m—*Vicia hirsuta* (L.) Gray | n—*Vicia lens* (L.) Coss. & Germ. | o—*Vicia sativa* L. | p—*Lupinus angustifolius* L. © Shamim Alam.

Image 7. a—*Indigofera cassioides* Rottler ex DC. | b—*Indigofera glabra* L. | c—*Indigofera hirsuta* L. | d—*Indigofera linifolia* (L.f.) Retz. | e—*Indigofera linnaei* Ali. | f—*Indigofera prostrata* Willd. | g—*Indigofera tinctoria* L. | h—*Brachypterum scandens* (Roxb.) Miq. | i—*Derris trifoliata* Lour. | j—*Millettia peguensis* Ali | k—*Pongamia pinnata* (L.) Pierre | l—*Tephrosia purpurea* (L.) Pers. | m—*Tephrosia villosa* (L.) Pers. | n—*Butea monosperma* (Lam.) Taub. | o—*Cajanus cajan* (L.) Huth | p—*Cajanus crassus* (Prain ex King) Maesen. © Shamim Alam.

Image 8. a—*Cajanus scarabaeoides* (L.) Thouars | b—*Centrosema pubescens* Benth.;c—*Clitoria ternatea* L. var. *pleniflora* Fantz. | d—*Clitoria ternatea* L. var. *ternatea* | e—*Erythrina variegata* L. | f—*Glycine max* (L.) Merr. | g—*Lablab purpureus* (L.) Sweet | h—*Macroptilium atropurpureum* (DC.) Urb. | i—*Macrotyloma uniflorum* (Lam.) Verdc. | j—*Mucuna pruriens* (L.) DC. | k—*Neustanthus phaseoloides* Benth. | l—*Pachyrhizus erosus* (L.) Urb. | m—*Phaseolus vulgaris* L. | n—*Rhynchosia rufescens* (Willd.) DC. | o—*Spatholobus parviflorus* (Roxb. ex DC.) Kuntze | p—*Teramnus labialis* (L.f.) Spreng. © Shamim Alam.

Image 9. a—*Vigna mungo* (L.) Hepper | b—*Vigna radiata* (L.) R. Wilczek | c—*Vigna trilobata* (L.) Verdc. | d—*Vigna unguiculata* (L.) Verdc. subsp. *cylindrica* (L.) Eseltine | e—*Vigna unguiculata* (L.) Verdc. subsp. *unguiculata* | f—*Cullen corylifolium* (L.) Medik. | g—*Gliricidia sepium* (Jacq.) Kunth ex Walp. | h—*Medicago lupulina* L. | i—*Melilotus albus* Medik. | j—*Melilotus indicus* (L.) All. | k—*Trigonella balansae* Boiss. & Reut. | l—*Trigonella foenum-graecum* L. | m—*Sesbania bispinosa* (Jacq.) W. Wight | n—*Sesbania grandiflora* (L.) Poir. | o—*Sesbania sesban* (L.) Merr. var. *bicolor* (Wight & Arn.) F.W. Andrews. © Shamim Alam.

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ARTICLE

Floristic diversity of mangroves and mangrove associate species of Kali River Estuary, Karwar, Karnataka, India

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Abstract: This study assessed the mangrove flora of the Kali River estuary, Uttara Kannada district, Karnataka. Fourteen true mangrove species belonging to eight families and 11 genera were documented from four locations: Devbagh, Mavinhole, Kalimatha Island, and Halgejoog. The mangrove species show a discontinuous distribution pattern in the Kali River estuary. The highest IVI in true mangroves was recorded for *Avicennia officinalis* at Devbagh, *Acanthus ilicifolius* at Mavinhole, *Sonneratia caseolaris* (after *Oryza coarctata*) at Kalimatha Island, and *S. caseolaris* (after *Derris trifoliata*) at Halgejoog. Of the four sites, Devbagh has the highest Shannon-Wiener diversity index, and with regard to species composition, Devbagh and Kalimatha Island are the most similar sites. Kalimatha island has the most well-preserved mangrove community.

Keywords: Floristic diversity, Kalimatha Island, Kali mangroves, phytosociology, vegetation analysis.

Abbreviations: A/F Ratio—Abundance to Frequency Ratio | GBH—Girth at Breast Height | IVI—Importance Value Index | L1—Location 1: Devbagh | L2—Location 2: Mavinhole | L3—Location 3: Kalimatha Island | L4—Location 4: Halgejoog.

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INTRODUCTION

Mangroves are unique plant communities found in sheltered shores, estuarial inter-tidal zones, tidal creeks, backwaters, lagoons, mudflats, and marshes of the tropical and sub-tropical areas of the world. Mainly found in areas between latitude 24° N and 38° S (India State of Forest Report 2019), evergreen trees and shrubs chiefly make up the vegetational components of the mangrove ecosystem. They have adapted to grow in hostile conditions such as high salinity, recurring inundation by tidal saltwater, high temperature & wind speeds, and anaerobic soils. Mangrove species can be obligate halophytes, euryhalines, or stenohalines.

Mangroves provide a broad range of ecosystem services, including protecting coastline against erosion, storms and cyclones, serving as a natural carbon sink, and providing breeding grounds and nurseries for fish and prawns. This fragile ecosystem is in a seriously threatened state due to natural and anthropogenic causes. Standing at the brink of degradation, the mangroves are in need of urgent protecting and safeguarding. It is of grave importance that all the components of every ecosystem on earth, along with its interactions, are preserved. This conservation of the health of the ecosystems is imperative, not only for the sake of nature itself but also to ensure the survival of the present life and of the generations to come. This is because the human race heavily depends on the services (all the four types – provisioning, regulating, supporting, and cultural services) that the ecosystem so freely provides.

A global plan has to be made and executed in order to conserve not only a few species, but the whole mangrove ecosystem. Global mangrove mappings and biodiversity documentations are crucial for they define the mangrove limits, show an estimation of the carbon stores (Ximenes 2015), serve as an essential source of information about the biodiversity of the area and its biomass and describe the ecosystem as a whole. These mappings can also sometimes be used to determine the extent of the degradation or alteration of the mangrove communities. They serve as a guide for conservation efforts and hence policymaking for the same.

Chandran et al. (2012) studied the mangroves of Gangavali, Aghanashini estuaries, and Sharavathi-Badgani estuarine complex. Ramachandra et. al. (2013) estimated the total economic value of the ecosystem benefits provided by the mangroves of Venktapur, Sharavathi, Aghanishini, Gangavali, and Kali River estuaries. The study shows how the estuarine ecosystems contribute to the sustenance of the Uttara Kannada district's economy. The present study aims to understand the vegetation structure and estimate the floral diversity of the mangrove forests of the Kali River estuary at Karwar, Uttara Kannada district, Karnataka.

MATERIALS AND METHODS

Study Area

The current study was undertaken in the mangrove forests belonging to Karwar's Kali River estuary (74.1876°N, 14.8836°E) in Uttara Kannada district, Karnataka. Four locations were chosen to represent the floral diversity in the mangrove species varying with the salinity of the Kalli River estuary: Devbagh, Mavinhole, Kalimatha Island, and Halgejoog (Image 1). Except for the Kalimatha Island, which belongs to the Karwar Range of the Karwar Sub-Division, all the locations belong to the Gopshitta Range of Karwar Sub-Division, Canara Circle of the Karnataka State Forest Department.

1. Devbagh: located at the creek mouth (14.8476^0N and 74.1211^0E), at the junction of the creek and the river Kali. This water is 'euhaline' (salinity levels > 30.0ppt). The mangrove cover in the area is 40.07 ha of the total 102 ha belonging to the Devbagh region.

2. Mavinhole: located in a creek of the river Kali (14.8677^0N and 74.1219^0E), at 2.5 km from the mouth of the river. The water is 'polyhaline' (with salinity levels in the range of 18.0–30.0 ppt). The mangroves occupy 23.8 ha of the total 30 ha belonging to the Mavinhole region.

3. Kalimatha Island: located 3.2 km away from the river-mouth (14.8420^0N and 74.1428^0E), the water around the island is 'polyhaline' (with salinity levels in the range of 18.0–30.0 ppt). There is a patch of coconut trees and other cultivable plants at the center and at the periphery of this 8.5 ha island sits a 7 ha mangrove belt.

4. Halgejoog: located 10.5 km away from the mouth of the river (14.8818^0N and 74.1974^0E), the river water here is 'mesohaline' (with salinity levels in the range of 5.0–18.0 ppt). The mangroves here occupy an area of 91.13 ha.

Sampling and data collection

Nested quadrat method was used to gather primary data from the chosen study area. The quadrats sizes for trees, shrubs, and herbs were 31.62 × 31.62 m (approx. 0.1 ha), 3 × 3 m, and 1 × 1 m, respectively. On the confirmation of the presence of the mangroves in the area and their accessibility, random plots were selected for the study. Species accumulation curves

Image 1. Map showing the location of the four study areas.

were plotted, and 5 quadrats were sampled at each of the four locations.

The true mangrove and the mangrove associate species were identified and enumerated in all the chosen plots. The girth of all trees (> 15 cm) was measured at a height of 1.37 m above the ground level (GBH). The plots for shrubs and herbs were nested inside the plot for trees.

The phytosociology and the diversity indices for true mangroves and the associate mangroves were then estimated using this data.

The field data was gathered in various sessions in March 2021, during the low tides.

Species Identification

The plant specimens of true mangroves and mangrove associates were collected for identification purposes. Standard books and research papers on mangroves (Banerjee et al. 1989; Rao & Suresh 2001; Chandran et al. 2012) were consulted for the verification of the names of the species after their photographs were taken.

Species Composition and Importance Value

The plant species at the study plots of each location were identified and enumerated. The data collected from the field was used to analyze the distribution pattern of mangroves and their population structure by establishing a quantitative relationship among the plant species.

Relative frequency, relative density, relative dominance, abundance, abundance to frequency ratio, and Importance Value Index (IVI) were calculated in the application 'Microsoft Excel 2019', using the standard phytosociological methods (Curtis & McIntosh 1951). IVI was calculated as the sum of relative frequency, relative dominance, and relative density (Vijayan et al. 2015),

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which a species occurs}}{\text{The total number of quadrats sampled}} \times 100 \quad \text{(Eq. 1)}$$

$$\text{Density} = \text{Number of individuals / ha} \quad \text{(Eq. 2)}$$

$$\text{Dominance} = \frac{GBH}{4\pi} \quad \text{(Eq. 3)}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occurs}} \quad \text{(Eq. 4)}$$

$$\text{Abundance/ Frequency (A/F) Ratio} = \frac{\text{Abundance of a species}}{\text{Frequency (in \%) of the species}} \quad \text{(Eq. 5)}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100 \quad \text{(Eq. 6)}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Total number of individuals of a species}}{\text{Total number of individuals of all species}} \times 100 \quad \text{(Eq. 7)}$$

$$\text{Relative Dominance (\%)} = \frac{\text{The dominance of a species}}{\text{The dominance of all species}} \times 100 \quad \text{(Eq. 8)}$$

$$\text{IVI} = \text{Relative Frequency} + \text{Relative Density} + \text{Relative Dominance} \quad \text{(Eq. 9)}$$

Table 1. Occurrence of true mangroves and mangrove associates at the four locations.

Mangroves			Locations			
Family	Species	Life form	L – I	L – II	L – III	L – IV
True Mangroves						
Acanthaceae	*Acanthus ilicifolius* L.	S	+	+	+	+
	Avicennia marina (Forssk.) Vierh.	T	+	+	+	-
	Avicennia officinalis L.	T	+	+	+	-
Combretaceae	*Lumnitzera racemosa* Willd.	T	+	+	-	-
Euphorbiaceae	*Excoecaria agallocha* L.	T	+	+	+	+
Lythraceae	*Sonneratia alba* Sm.	T	+	-	+	-
	Sonneratia caseolaris Engl.	T	+	-	+	+
Poaceae	*Oryza coarctata* Roxb.	H	-	-	+	+
Primulaceae	*Aegiceras corniculatum* (L.) Blanco	S	-	+	+	-
Pteridaceae	*Acrostichum aureum* L.	H	-	+	-	+
Rhizophoraceae	*Bruguiera cylindrica* Blume	T	-	-	+	-
	Kandelia candel Druce	T	-	+	+	+
	Rhizophora apiculata Blume	T	-	+	+	+
Rhizophoraceae	*Rhizophora mucronata* Poir.	T	-	+	+	-
Mangrove Associates						
Bignoniaceae	*Dolichandrone spathacea* (L.f.) Baillon ex Schumann	T	-	-	-	+
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br.	C	+	-	-	+
Fabaceae	*Acacia auriculiformis* A.Cunn. ex Benth.	T	-	+	-	-
	Caesalpinia crista L.	C	+	+	+	+
	Derris trifoliata Lour.	C	+	+	+	+
Lamiaceae	*Premna corymbosa* Rottler & Willd.	S	-	+	-	-
	Volkameria inermis L.	S	+	+	+	-
Lauraceae	*Cassytha filiformis* L.	C	+	+	+	+
Malvaceae	*Thespesia populnea* Sol. ex Corrêa	T	+	-	+	-

+—Presence | -—Absence | S—Shrub | T—Tree | H—Herb | C—Creeper/Climber

Species Diversity

Two of the three main components of diversity—α-diversity and β-diversity were calculated. For α-diversity, three measures of diversity – evenness, richness, and heterogeneity were calculated to analyse the diversity in the chosen locations based on the data collected. Cluster analysis was carried out to calculate β-diversity.

To determine the species evenness, Pielou's equitability index (J) and Buzas-Gibson's evenness index (E) were calculated; for species richness, Margalef's index (d) was calculated; for species diversity or heterogeneity, Shannon-Weiner index (H') and Simpson's diversity index (1-D) were calculated. These were calculated using the software 'PAST (PAleontological STatistics) Version 4.03' (Hammer et al. 2001). Further, the similarity in the species composition among the four locations was compared by the method of cluster analysis on the presence/absence transform data, using the software 'BioDiversity Professional Version 2.0'.

RESULTS

Species Composition

A total of 14 true mangrove species from eight families and 11 genera, and nine mangrove associate species belonging to six families and nine genera were found in the quadrats chosen for the present study.

Other true mangrove (*Bruguiera gymnorhiza* (L.) Lam. (Family: Rhizophoraceae)) and mangrove associate species (*Ixora concinna* R.Br. ex Hook.f. (Family: Rubiaceae), *Casuarina equisetifolia* L. (Family: Casuarinaceae), *Sesuvium portulacastrum* (L.) L. (Family: Aizoaceae), *Salvadora persica* L. (Family: Salvadoraceae), *Pongamia pinnata* (L.) Pierre (Family: Fabaceae), *Terminalia catappa* L. (Family: Combretaceae)) were also observed in the vicinity, but outside of the study plots.

The highest number of species (true mangroves and mangrove associates) of the four locations was observed at the Kalimatha Island (Location 3), with 17 species—12 true mangroves and five mangrove associates, followed by Mavinhole (Location 2), with 16 species—10 true mangroves and six mangrove associates. At Devbagh (Location 1), 13 species—seven true mangroves and six mangrove associates were observed, while at Halgejoog (Location 4), it was 12 species—seven true mangroves and five mangrove associates.

Acanthus ilicifolius and *Excoecaria agallocha* occurred at all the four locations, *Avicennia marina* and *Avicennia officinalis* occurred at locations 1, 2, and 3;

Table 2. Phytosociological characters of mangroves at Devbagh.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	40	5.71	40	1.34	5.74	0.007	10	0.25	7.06
Acrostichum aureum	0	0	0	0	0	0	0	0	0
Aegiceras corniculatum	0	0	0	0	0	0	0	0	0
Avicennia marina	40	5.71	84	2.82	6781.19	8.26	21	0.52	16.80
Avicennia officinalis	100	14.29	360	12.08	26126.16	31.82	36	0.36	58.19
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	80	11.43	112	3.76	3657.38	4.46	14	0.18	19.64
Kandelia candel	0	0	0	0	0	0	0	0	0
Lumnitzera racemosa	40	5.71	6	0.20	206.90	0.25	1.5	0.04	6.17
Oryza coarctata	0	0	0	0	0	0	0	0	0
Rhizophora apiculata	0	0	0	0	0	0	0	0	0
Rhizophora mucronata	0	0	0	0	0	0	0	0	0
Sonneratia alba	40	5.71	166	5.57	17330.78	21.11	41.5	1.04	32.40
Sonneratia caseolaris	100	14.29	366	12.28	24677.61	30.06	36.6	0.37	56.63
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	40	5.71	340	11.41	646.23	0.79	85	2.12	17.91
Cassytha filiformis	40	5.71	24	0.81	1.51	0.002	6	0.15	6.52
Derris trifoliata	40	5.71	52	1.74	264.65	0.32	13	0.32	7.78
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	40	5.71	110	3.69	43.20	0.05	27.5	0.69	9.46
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	60	8.57	40	1.34	1536.00	1.87	6.67	0.11	11.78
Volkameria inermis	40	5.71	1280	42.95	814.87	0.99	320	8	49.66
Total	700	100	2980	100	82092.23	100	618.77		300

Sonneratia caseolaris occurred at locations 1, 3, and 4; *Kandelia candel* and *Rhizophora apiculata* were found at locations 2, 3, and 4; *Lumnitzera racemosa* was observed at locations 1 and 2; *Sonneratia alba* occurred at locations 1 and 3; *Rhizophora mucronata* was found at locations 2 and 3, while *Bruguiera cylindrica* was observed only at location 3. *Caesalpinia crista*, *Cassytha filiformis*, and *Derris trifoliata* were the most widespread mangrove associates. They were found distributed at all the four locations (Table 1).

The floral composition that was observed at the four locations is as follows:

Location 1 – Devbagh: *A. officinalis* and *S. caseolaris* were present in all the sample plots and were observed to have good growth. *A. ilicifolius, A. marina*, *L. racemosa*, and *S. alba* were found only in two sample plots; *S. alba* was found in plenty in the samples studied near the sea. The shrubby vegetation was sparse at best. This could probably be due to the lack of huge areas of deposited sediments that do not float away with the water because of the daily low- and high-tide phenomena. Vast expanses of mangroves were destroyed due to the inundation caused by heavy floods that occurred in 2019.

Location 2 – Mavinhole: *R. mucronata* occurred in all the sample plots at the location. There was a good amount of shrubby vegetation in some plots.

Location 3 – Kalimatha Island: *Oryza coarctata* was observed in newly forming mudflats in some plots (and in the adjacent areas) at the location. In some plots, a very good growth of *S. alba* was observed, and so was the case of *S. caseolaris* in some other plots. A good amount of species richness was observed at the location.

Location 4 – Halgejoog: *K. candel* and *S. caseolaris* were found in all the study stations of the location; but the plots were mostly dominated by shrubby and ground vegetation. A large number of mangrove associates were also observed adjacent to the study plots.

Table 3. Phytosociological characters of mangroves at Mavinhole.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	80	9.30	9746	74.37	1256.41	0.80	1218.5	15.23	84.47
Acrostichum aureum	40	4.65	44	0.34	6.22	0.004	11	0.28	4.99
Aegiceras corniculatum	60	6.98	1832	13.98	54331.54	34.52	305.33	5.09	55.48
Avicennia marina	40	4.65	62	0.47	4600.45	2.92	15.5	0.39	8.05
Avicennia officinalis	40	4.65	6	0.05	820.28	0.52	1.5	0.04	5.22
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	60	6.98	238	1.82	7620.12	4.84	39.67	0.66	13.63
Kandelia candel	60	6.98	330	2.52	72111.05	45.82	55	0.92	55.31
Lumnitzera racemosa	40	4.65	10	0.08	602.88	0.38	2.5	0.06	5.11
Oryza coarctata	0	0	0	0	0	0	0	0	0
Rhizophora apiculata	40	4.65	126	0.96	3193.13	2.03	31.5	0.79	7.64
Rhizophora mucronata	100	11.63	318	2.43	10860.88	6.90	31.8	0.32	20.96
Sonneratia alba	0	0	0	0	0	0	0	0	0
Sonneratia caseolaris	0	0	0	0	0	0	0	0	0
Acacia auriculiformis	40	4.65	24	0.18	1294.01	0.82	6	0.15	5.66
Caesalpinia crista	60	6.98	76	0.58	171.91	0.11	12.67	0.21	7.67
Cassytha filiformis	40	4.65	28	0.21	2.75	0.002	7	0.18	4.87
Derris trifoliata	60	6.98	62	0.47	298.26	0.19	10.33	0.17	7.64
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	0	0	0	0	0	0	0	0	0
Premna corymbosa	40	4.65	16	0.12	99.47	0.06	4	0.1	4.84
Thespesia populnea	0	0	0	0	0	0	0	0	0
Volkameria inermis	60	6.98	186	1.42	118.41	0.08	31	0.52	8.47
Total	860	100	13104	100	157387.77	100	1783.05		300

Vegetation Structure and Importance Value

Location 1 – Devbagh: Frequency (%) was the highest for *S. caseolaris* and *A. officinalis* (100%); density was the highest for *S. caseolaris* (a total of 366 stems in the study plots, i.e., 732 stems/ha and a relative density of 12.28%) and *Volkameria inermis* (1560 stems/ha and a relative density of 42.95%). Relative dominance was the highest for *A. officinalis* (31.82%). Abundance and A/F ratio were the highest for *S. alba* (abundance—41.5 | A/F ratio—1.05) and *V. inermis* (abundance—320 | A/F ratio 8). *A. officinalis* had the highest Importance Value Index—58.19 (Table 2).

Location 2 – Mavinhole: Frequency (%) was the highest for *R. mucronata* (100%); density was the highest for *A. ilicifolius* (a total of 9746 stems in the study plots, i.e., 19492 stems/ha and a relative density of 74.37%), *Aegiceras corniculatum* (3764 stems/ha and a relative density of 13.98%), *K. candel* (660 stems/ha and a relative density of 2.52%), and *R. mucronata* (636 stems/ha and a relative density of 2.43%). Relative dominance was the highest for *K. candel* (45.82%) and *A. corniculatum* (34.52%). Abundance was the highest for *A. ilicifolius* (abundance—1218.5) and *E. agallocha* (abundance—39.67). A/F ratio was the highest for *A. ilicifolius* (15.93) and *K. candel* (0.92). *A. ilicifolius* had the highest Importance Value Index—84.47 (Table 3).

Location 3 – Kalimatha Island: Frequency (%) was the highest for *A. corniculatum, A. officinalis, B. cylindrica,* and *R. apiculata* (80%); density was the highest for *S. caseolaris* (a total of 454 stems in the study plots, i.e., 908 stems/ha and a relative density of 9.33%) after *O. coarctata* (a grass species with a total of 5520 stems/ha and a relative density of 56.70%). Relative dominance was the highest for *S. caseolaris* (41.38%). Abundance and A/F ratio were the highest for *O. coarctata* (abundance—460, A/F ratio—7.67) and *S. caseolaris* (abundance—75.67, A/F ratio—1.26). *S. caseolaris* had the highest Importance Value Index—56.96 at location

Table 4. Phytosociological characters of mangroves at Kalimatha Island.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	60	6.25	260	5.34	41.38	0.03	43.33	0.72	11.62
Acrostichum aureum	0	0	0	0	0	0	0	0	0
Aegiceras corniculatum	80	8.33	172	3.53	4613.58	3.59	21.5	0.27	15.46
Avicennia marina	40	4.17	12	0.25	2429.26	1.89	3	0.08	6.31
Avicennia officinalis	80	8.33	188	3.86	42784.91	33.32	23.5	0.29	45.52
Bruguiera cylindrica	80	8.33	136	2.79	4645.89	3.62	17	0.21	14.75
Excoecaria agallocha	60	6.25	54	1.11	1612.88	1.26	9	0.15	8.62
Kandelia candel	40	4.17	70	1.44	2195.54	1.71	17.5	0.44	7.32
Lumnitzera racemosa	0	0	0	0	0	0	0	0	0
Oryza coarctata	60	6.25	2760	56.70	1083.85	0.844	460	7.67	63.79
Rhizophora apiculata	80	8.33	38	0.78	915.38	0.71	4.75	0.06	9.83
Rhizophora mucronata	60	6.25	96	1.97	2652.00	2.07	16	0.27	10.29
Sonneratia alba	40	4.17	148	3.04	10811.63	8.42	37	0.92	15.66
Sonneratia caseolaris	60	6.25	454	9.33	53129.58	41.38	75.67	1.26	56.96
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	40	4.17	46	0.94	122.11	0.095	11.5	0.29	5.20
Cassytha filiformis	40	4.17	16	0.33	1.01	0.001	4	0.1	4.50
Derris trifoliata	60	6.25	42	0.86	225.79	0.18	7	0.12	7.29
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	0	0	0	0	0	0	0	0	0
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	40	4.17	16	0.33	900.18	0.70	4	0.1	5.20
Volkameria inermis	40	4.17	360	7.36	229.18	0.18	90	2.25	11.74
Total	960	100	4868	100	128394.16	100	844.75		300

3 (Kalimatha Island), after *O. coarctata* (63.79) (**Table 4**).

Location 4 – Halgejoog: Frequency (%) was the highest for *A. ilicifolius, Acrostichum aureum, K. candel*, and *S. caseolaris* (100%); density was the highest for *A. aureum* (a mangrove fern). Relative dominance was the highest for *S. caseolaris* (48.27%). Abundance was the highest for *A. aureum* (506) and *S. caseolaris* (9.6). A/F ratio was the highest for *O. coarctata* (11.62) and *R. apiculata* (0.12). *D. trifoliata* had the highest Importance Value Index—67.25, followed by S. caseolaris (61.11) (Table 5).

Species Diversity

α-diversity

Species richness, species evenness, and species heterogeneity were calculated for the four locations using various diversity indices (Table 6).

According to Margalef's index (d), the Kalimatha Island (location 3) had the highest species richness (with a Margalef's index value of 2.052) of the four locations. The Margalef's index values were 1.642, 1.706, 2.052, and 1.233 for locations 1, 2, 3, and 4, respectively.

Both the indices to calculate species evenness—Pielou's evenness index (J) and Buzas-Gibson's evenness (E) measure indicate to Devbagh (location 1) having the highest species evenness (with Pielou's index value of 0.7282 and Buzas-Gibson's index value of 0.498) of all the four locations. Pielou's index of species richness gives a measure of the degree of community structuring, and ranges from 0–1. A higher value indicates a lesser variation of the species abundance within a community, and this means that all the species occur in relatively similar proportions.

Pielou's index values were 0.7282, 0.3609, 0.602, and 0.6525 for the locations 1, 2, 3, and 4, respectively. Buzas-Gibson's index values were 0.498, 0.17, 0.3238, and 0.4217 for the locations 1, 2, 3, and 4, respectively.

For the calculation of species heterogeneity of

Table 5. Phytosociological characters of mangroves at Halgejoog.

Species	Frequency (in)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	100	12.20	3240	21.57	623.95	1.51	324	3.24	35.27
Acrostichum aureum	100	12.20	5060	33.68	715.34	1.73	506	5.06	47.61
Aegiceras corniculatum	0	0	0	0	0	0	0	0	0
Avicennia marina	0	0	0	0	0	0	0	0	0
Avicennia officinalis	0	0	0	0	0	0	0	0	0
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	60	7.32	12	0.08	467.36	1.13	2	0.03	8.53
Kandelia candel	100	12.20	24	0.16	954.85	2.31	2.4	0.02	14.67
Lumnitzera racemosa	0	0	0	0	0	0	0	0	0
Oryza coarctata	40	4.88	1860	12.38	730.42	1.77	465	11.62	19.03
Rhizophora apiculata	40	4.88	20	0.13	454.78	1.10	5	0.12	6.11
Rhizophora mucronata	0	0	0	0	0	0	0	0	0
Sonneratia alba	0	0	0	0	0	0	0	0	0
Sonneratia caseolaris	100	12.20	96	0.64	19937.82	48.27	9.6	0.1	61.11
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	80	9.76	1060	7.06	1665.04	4.03	132.5	1.66	20.84
Cassytha filiformis	40	4.88	46	0.31	2.89	0.007	11.5	0.29	5.19
Derris trifoliata	80	9.76	3380	22.50	14454.55	35.00	422.5	5.28	67.25
Dolichandrone spathacea	40	4.88	24	0.16	1218.73	2.95	6	0.15	7.99
Ipomoea pes-caprae	40	4.88	200	1.33	78.54	0.19	50	1.25	6.40
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	0	0	0	0	0	0	0	0	0
Volkameria inermis	0	0	0	0	0	0	0	0	0
Total	820	100	15022	100	41304.27	100	1936.5		300

Table 6. Diversity indices of the four locations.

Diversity indices	Location 1	Location 2	Location 3	Location 4
(i) Species richness				
Margalef's index (d)	1.642	1.706	2.052	1.233
(ii) Species evenness				
Pielou's index (J)	0.7282	0.3609	0.602	0.6525
Buzas-Gibson's index (E)	0.498	0.17	0.3238	0.4217
(iii) Species diversity				
Shannon-Wiener's index (H')	1.868	1.001	1.706	1.621
Simpson's index (1-D)	0.7654	0.428	0.6561	0.7688

the study sites, Shannon-Wiener's diversity index (H') and Simpson's diversity index (1 - D) were calculated. Shannon-Wiener's diversity index values were 1.868, 1.001, 1.706, and 1.621 for location 1, 2, 3, and 4, respectively. Simpson's diversity index values were 0.7654, 0.428, 0.6561, and 0.7688 for locations 1, 2, 3, and 4, respectively. According to Shannon-Wiener's diversity index, Devbagh (location 1) had the highest species heterogeneity or diversity (with the index value of 1.868) of the four locations. But the Simpson's diversity index values of the four locations showed that location 4 (Halgejoog) was the most diverse one, with an index value of 0.7688, while Devbagh had the index value of 0.7654.

Shannon-Wiener's diversity index is a Type I index, i.e., it is most sensitive to the changes in the rare species of the community sample, while Simpson's diversity index is a Type II index, which means that it is most sensitive to the changes in the more abundant species of the community sample (Peet 1974).

The calculated diversity indices indicate to Devbagh having the highest diversity of the four locations with the diversity being sensitive to the less-abundant species of the community sample, and Halgejoog having

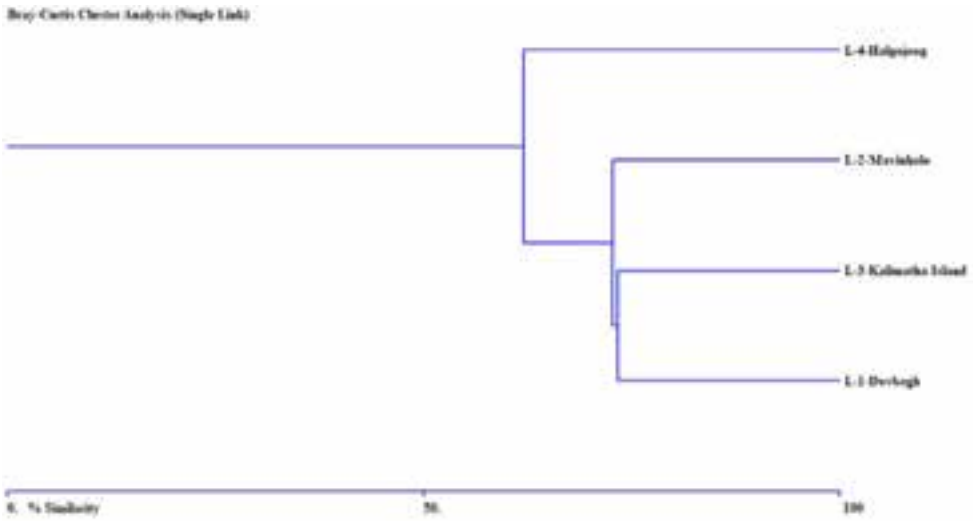

Figure 1. Dendrogram of the species composition at the four locations based on presence/absence transform data by way of single-link Bray-Curtis cluster analysis.

the highest diversity with the diversity being sensitive to the common or more abundant species at the location. This would imply that Devbagh was more diverse due to the presence of less-abundant species, while Halgejoog was more diverse due to the dominance of the common species at the location. This can be supported by the fact that the index values of both measures – species richness and species evenness, of Devbagh are higher as compared to those of Halgejoog. The index value for Margalef's species richness of Halgejoog (1.233) is much lesser than that of Devbagh (1.642), while there is a lesser difference between the index values of the measure of species evenness of the two locations – the Pielou's species evenness index value of Devbagh is 0.7282, and that of Halgejoog is 0.6525. Similarly, the Buzas-Gibson's species evenness index value of Devbagh is 0.498, while that of Halgejoog is 0.4217. This means that the species abundance at both Devbagh and Halgejoog was almost similar, but Devbagh was more species-rich, i.e., there were more less-abundant species at Devbagh than there were at Halgejoog.

β-diversity

Based on the presence/absence transform data of the species, the similarity index was calculated, and the dendrogram (Figure 1) briefs it based on the Bray-Curtis Cluster Analysis (Single-Link).

Locations 1 (Devbagh) and 3 (Kalimatha Island) were most similar to each other (73.33% similarity), while location 2 (Mavinhole) is 72.73% similar to this cluster. Location 4 (Halgejoog) matched the least with the rest of the locations, with a similarity of 62.07%.

DISCUSSIONS

Of the four locations studied, Kalimatha Island had the highest number of species (17)—12 true mangroves and five mangrove associates. Devbagh had the highest species evenness of the four locations and is also the most diverse concerning the less-abundant species, and second-most diverse when common species are emphasized. Halgejoog had the highest species diversity from Simpson's diversity indices (0.7688), i.e., diversity with respect to common species. Kalimatha Island and Devbagh are the most similar locations regarding the species composition. Tree density was the highest at Mavinhole (2,505 trees/ha).

Although plantation activities have been taken up at all the four locations, the study shows that, out of Devbagh, Mavinhole, Kalimatha Island, and Halgejoog, Kalimatha Island has the best-preserved mangrove community as it has the highest number of true mangroves (12) and the least number of mangrove associates (five). Halgejoog is located well inland compared to the other three sites and shows mostly shrubby vegetation, despite having seven true mangrove and five mangrove associate species. Devbagh, located at the mouth of the river, has the maximum number of mangrove associate (six) and the least number of true mangroves species (seven), which seems to be so because of frequent floods and long-term inundations. Non-native species like *Acacia auriculiformis* was observed in the study plots at Mavinhole, which could hamper the growth of native biodiversity of the area. Anthropogenic interference – both positive (like plantation activities, and other

measures for conservation) and negative (pollution, and fishing), was observed at all the sites.

The Karwar mangrove forests can be classified as scattered patches since the mangrove species, at all the sites, showed a discontinuous distribution pattern.

The studied mangrove forests create a very fragile ecosystem as they depend on unique ecological conditions like salinity, depth of water, specific substrate, and any alteration triggers to these conditions may lead to invasion of other associate species resulting in risks to the true mangrove species in the future.

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ARTICLE

Reproductive biology of *Senna spectabilis* (DC.) H.S.Irwin & Barneby (Fabaceae) - an invasive tree species in the tropical forests of the Western Ghats, India

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Abstract: *Senna spectabilis* (DC.) H.S.Irwin & Barneby is an invasive tree species native to tropical America and is commonly found in the forest areas of Wayanad Wildlife Sanctuary. Its aggressive growth rate and ability to quickly cover up open and degraded lands in forest ecosystems make it challenging to control its spread. Reproductive studies of *S. spectabilis* and its pollen-ovule ratio indicate this species is cross-pollinating. The species is self-compatible, owing to the simultaneous occurrence of xenogamy, geitonogamy and autogamy. This reproductive strategy helps the taxon to colonise degraded areas and invade the forest ecosystem. The anthesis is diurnal and sometimes asynchronous. Peak insect visitors were observed from 0900 h to 1230 h, with the major visitor being *Tetragonula iridipennis*. *Xylocopa violaceae* was also a regular visitor along with resident Formicidae members, such as *Oecophylla smaragdina* and *Myrmicaria brunnae*. They feed on the floral parts, like tender petals and sepals. The reproductive syndrome of this plant favours maximum fertilization.

Keywords: Breeding, Fabaceae, forest, invasive, reproduction, Wayanad,

Malayalam: ഉഷ്ണമേഖല അമേരിക്കൻ പ്രദേശങ്ങളിലെ സ്വദേശി ആയ സെന്ന സ്പെക്ടാബിലിസ്, ഒരു അധിനിവേശ മരം എന്ന നിലയിൽ വയനാട് വന്യജീവി സങ്കേതത്തിൽ സർവ്വ സാധാരണമായി ഇപ്പോൾ കണ്ടുവരുന്നു. അവയുടെ അതിതീവ്രമായ വളർച്ചാനിരക്കിനുള്ള ശേഷി മൂലം വനത്തിലുള്ളിലെ തുറസ്സായ ഇടങ്ങളിലും, ദുർബ്ബലമായ താഴ്ന്ന പ്രദേശങ്ങൾ ഉൾപ്പെട്ട ആവാസവ്യവസ്ഥകളിലും വളരെ പെട്ടെന്ന് വളർന്ന് ഇത്തരം പ്രദേശങ്ങൾ മൂടിവയ്ക്കാൻ ഉതകുന്ന തരത്തിലുള്ള ശേഷിയും, ഇവയുടെ വളർച്ച നിയന്ത്രണങ്ങൾക്ക് വലിയ വെല്ലുവിളി ഉയർത്തി നിൽക്കുന്നു. പ്രത്യുത്പാദന പഠനങ്ങളും, അവയുടെ പുഷ്പങ്ങളിലെ പരാഗരേണുക്കളും അണ്ഡവും തമ്മിലുള്ള അനുപാതവും പരിഗണിക്കുമ്പോൾ, സെന്നാ സ്പെക്ടബിലിസ് ഒരു പരപരാഗണം നടത്തുന്ന സസ്യമാണ് എന്ന് വ്യക്ത മാകുന്നു. ഒരേ സമയം സ്വപരാഗണവും, ഗൈറ്റനോഗാമിയും സിനോഗമിയും നടക്കുന്ന കാരണത്താൽ തന്നെ സെന്നാ സ്പെക്ടബിലിസ് ഒരു സ്വയം പൊരുത്തപ്പെടുന്ന (സെൽഫ് കോമ്പാറ്റബിൾ) സസ്യജാതി ആയി കരുതാം. ഇത്തരം പ്രത്യുത്പാദന തന്ത്രങ്ങൾ ഈ സസ്യ ജാതിയെ കാട്ടിലെ ദുർബ്ബലമായ ആവാസവ്യവസ്ഥകളിലേക്ക് പെട്ടെന്ന് അധിനിവേശം നടത്തുന്നതിന് സഹായിക്കുന്നു. പുഷ്പങ്ങളിലെ കേസരങ്ങൾ പൂർണ വളർച്ച പ്രാപിച്ച്, ആന്ദർപാളികൾ പൊട്ടി പരാഗരേണുക്കൾ വിതരണത്തിന് തയ്യാറാവുന്ന ആന്തസിസ് എന്ന പ്രക്രിയ സെന്നയിൽ നടക്കുന്നതു പകൽ സമയങ്ങളിൽ ആണ്. പലപ്പോഴും അത് ഒരുപോലെ അല്ല. പ്രാണികൾ സെന്നയുടെ പുഷ്പത്തി ലേക്ക് വരുന്നത് കൂടുതലായി നിരീക്ഷിയ്ക്കപെട്ടതു് രാവിലെ 9 മണി മുതൽ 12 മണി വരെയാണ്. പ്രധാനമായും ടെട്രഗോണലൂ ഇരിഡിപെന്നിസ്, സൈലോകോപ്പ വയോലെസിയേ തുടങ്ങിയവ ആണ് തുടർച്ചയായി പുഷ്പത്തിൽ വന്നിരുന്ന പരാഗികൾ. ഇവ കൂടാതെ സ്ഥിരമായി പുഷ്പത്തിൽ ഇരിക്കുന്ന ഫോർമിസിഡെ വർഗ്ഗത്തിൽ പെട്ട ഈസോഫില്ല സ്മരാഗ്ദിന, മിർമികേറിയ ബ്രൂണെ തുടങ്ങിയ പ്രാണികളെയും പഠനത്തിൽ കണ്ടെത്തി. ഇവ പുഷ്പത്തിൻ്റെ ഇളം ഭാഗങ്ങൾ ആയ ദളങ്ങൾ വിദളങ്ങൾ എന്നിവ ആഹാരമാക്കുന്നു. ഈ സസ്യജാതിയുടെ വ്യത്യസ്തങ്ങളായ പ്രത്യുത്പാദന പ്രവൃത്തികൾ ഇവയ്ക്ക് പരമാവധി ബിജസങ്കലനത്തിന് ഉള്ള സാഹചര്യങ്ങൾ ഒരുക്കുന്നു.

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Author contributions: All authors equally contributed in fieldwork, travel and data collection. MK and SCV did data compilation and analysis under the supervision of HTK. MK led the writing with inputs from SCV and HTK. All authors equally contributed to proofreading; and have read and approved the final file.

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INTRODUCTION

Exotic species must reproduce successfully in new areas to establish self-replacing populations. Therefore, reproductive characteristics and reproductive success are crucial factors in the invasion of plants. Biological invasions are considered the second largest threat to the environment, next to habitat destruction. According to Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services IPBES (2019), one-fifth of Earth's surface, including global biodiversity hotspots, is under biological invasion risk. Richardson et al. (2014) studied tree invasions, their patterns and processes and discussed the challenges facing researchers and managers. Tree invasions are being studied from different perspectives due to their increased importance in recent decades as more species are becoming invasive and larger areas of land are being invaded, resulting in larger impacts and increasing complexity of management challenges (Richardson & Rejmánek 2011; Rejmánek & Richardson 2013).

Senna spectabilis (DC.) H.S.Irwin & Barneby is an invasive tree in the forest areas of Wayanad Wildlife Sanctuary, part of the Western Ghats, India. It has an aggressive growth rate and the ability to quickly occupy open and degraded forest areas. Furthermore, *S. spectabilis* has a trait of suppressing the regeneration of native species due to allelopathic effect, which can increase their extinction risks. *S. spectabilis* spreads aggressively in disturbed and open forests, vacant spaces, parks, riverbanks, and plantations but not in closed canopies (Irwin & Barneby 1982), which is typical of most invasive plant species. Invasive plants are exotic species introduced in new areas that reproduce and disperse efficiently to the extent that they spread rapidly. Some of the plant traits related to seedling emergence, growth form, growth rate, breeding system, dispersal, and environmental tolerance are important in predicting whether a species will become invasive (Thuiller et al. 2006; Kleunen & Johnson 2007; Pysek & Richardson 2007). Seed production is essential for the establishment of self-sustaining populations and the subsequent naturalization of introduced species. However, seed production relies on the pollination ecology and breeding system of the plants introduced, and the environmental conditions of the recipient area (Richardson et al. 2000). Thus, floral traits linked to the functioning of the flower and dependence on pollinators, as well as pollinator attraction, will determine the final reproductive success of the plant. Field surveys on the occurrence of *S. spectabilis* showed that in areas it has invaded, particularly forest areas, this species is markedly abundant and out-competes other plants. It has significantly reduced overall species abundance and diversity and has impacted forest ecosystems and the natural reversion of vegetation in degraded lands.

This study aimed to find out the reproductive characteristics, including pollination mechanisms and breeding systems, of *S. spectabilis*. Identifying the reproductive traits alone cannot control the invasion but understanding the ecology of *S. spectabilis* in introduced areas is important in controlling the spread. We, therefore, examined the reproductive biology of *S. spectabilis,* by studying its: (i) floral biology through the description of floral morphology, the pattern of production and concentration of nectar, and stigmatic receptivity periods, (ii) pollination system and foraging behaviour of visitors, (iii) breeding system through hand pollination experiments, and (iv) reproductive success estimated as the proportion of the total number of fruits over the total number of flowers. These observations analyse the factors that aid the rapid spreading of *S. spectabilis* and may help develop eradication strategies for this species in forest ecosystems.

MATERIALS AND METHODS

Study Species

Senna spectabilis (Fabaceae: Caesalpinioideae), according to Irwin & Barneby (1982) it is commonly seen in the region of northeastern Brazil, where it is known as *Cassia*. It occurs naturally from southwestern Mexico to southern tropical America. It has been widely introduced and naturalized in many tropical countries (https://powo.science.kew.org/). Wayanad Wildlife Sanctuary is one of the aggressive growth habitats of *S. spectabilis,* which is considered invasive. It is a medium to large-sized tree growing up to 60 feet high, but is often much smaller. This species is extremely fast-growing, flowers, and sets seeds profusely. In India, it was introduced as an ornamental plant in the botanical gardens and is distributed in Mysuru in Karnataka, Wayanad in Kerala, Rishikha in Sikkim, Coimbatore and Sathyamangalam in Tamil Nadu, and Howrah in West Bengal. This species is reported in the forest areas of Sathyamangalam, suburban areas of Coimbatore and Wayanad Wildlife Sanctuary (Satyanarayana & Gnanasekaran 2013) and has been confirmed to have a high potential to flourish rapidly and produce numerous viable seeds. The plant, which was first introduced to Wayanad Wildlife Sanctuary in the early 1980s, has invaded approximately

23% of the sanctuary's total area in 40 years (Anoop et al. 2021).

Study Sites

Reproductive studies were conducted at the model site established at Muthanga Forests, Wayanad Wildlife Sanctuary. It is contiguous to the protected areas of Nagarhole National Park and Bandipur Tiger Reserve of Karnataka on the north-east and Mudumalai Wildlife Sanctuary of Tamil Nadu on the south-east and is located at 11.5777–11.9701 ^{0}N and 75.9896–76.4364 ^{0}E. Wayanad Wildlife Sanctuary has an area of 344.44 km^2. The biodiversity-rich sanctuary is an integral part of the Nilgiri Biosphere Reserve. Other study sites are Meppadi and Kalpetta forest ranges of South Wayanad Territorial Forest Division of Kerala, India.

Data Collection

The plant species for the study was selected after carrying out a field study in Wayanad. Field investigations and experiments were conducted from September 2019 to January 2020 and from October 2020 to January 2022. Following a preliminary field study of the flowering seasons of the selected species, regular field studies were carried out to collect information and data on the reproductive aspects. The functional events of individual flowers, sexual status, floral rewards and their details, breeding system, flower visitors and their behaviour and pollination role, natural fruit and seed output rates, and duration of fruit maturation were carefully observed, and seed dispersal aspects were examined. Floral structural and functional aspects were studied, as per the methods of Raju & Reddi (1994), Raju & Rao (2004), and Dafni et al. (2005).

Flower Morphology

The details of flower morphology, such as flower sex, shape, size, colour, odour, sepals, petals, stamens and ovary, as well as the position of stamens were described. The morphology and dimensions of the inflorescence were studied from the fresh inflorescence as well as those fixed in formalin-aceto-alcohol under a microscope. The order of wilting or dropping off of floral parts was recorded. These details of the selected plant species were provided due to inadequate and confusing taxonomic descriptions.

Pollen-Ovule Ratio

The pollen-ovule ratio was determined by dividing the average number of pollen grains per flower by the number of ovules per flower. The value thus obtained was taken as the pollen-ovule ratio (Cruden 1977).

Nectar Characters

The presence of nectar was determined by observing the mature buds and open flowers. When the nectar secreted was found to be in a measurable quantity, the volume of nectar from 10 flowers of 10 trees were determined. Then the average volume of nectar per flower was determined and expressed in µl, following Dafni et al. (2005). The flowers used for this purpose were bagged at the mature bud stage, opened after anthesis, and the nectar was squeezed into micropipettes for measuring the volume of nectar. Nectar sugar concentration was determined using a handheld sugar refractometer.

Stigma Receptivity

The stigma receptivity was observed visually and by the H_2O_2 (Hydrogen peroxide) test. In the visual method, the stigma's physical state (wet/dry) and the unfolding of its lobes were considered to record the commencement of receptivity, withering of the lobes was taken as loss of receptivity. The stigma receptivity period was recorded using the H_2O_2 test (Dafni et al. 2005). This test is widely followed, although it does not indicate the exact location of the receptive area. In this study, the period of slow release of bubbles from the surface of the stigma following the application of H_2O_2 was taken as stigma receptivity.

Anther Dehiscence

Anthesis was initially recorded by observing markedly mature buds in the field. Later, the observations were repeated three to four times on different days to provide an accurate anthesis schedule for this species. Similarly, the mature buds were followed to record the time of anther dehiscence. It is confirmed by observing the anthers using a 10x hand lens.

Breeding Systems

In *S. spectabilis*, mature flower buds of some inflorescences on different individuals were tagged and enclosed in paper bags. A fixed number of flowers from different inflorescences were bagged or tagged and followed further to study whether the pollination is vector-dependent and to understand the flower abortion rate. Another set of flowers was used for experiments on apomixis, self-pollination, and cross-pollination, such as geitonogamy and xenogamy, to collect data for understanding the breeding behaviour. All these categories of flower pollination were followed for the

fruit set. If the fruit set was present, the percentage of the fruit set was calculated for each mode.

Plant-Pollinator Interaction

Flower visitors were also observed concerning their mode of approach, landing, probing behaviour, forage collected, and contact with sex organs of flowers to effect pollination, and inter-tree foraging activity. Foraging visits made by major pollinators were recorded on selected inflorescences.

Pollen Viability

The viability of pollen at the time of dehiscence was tested using 1% acetocarmine, considering stained grains as viable and shrivelled grains as non-viable (Radford et al. 1974; Koshy & Jee 2001). The viable pollen in the 40x microscopic field was counted and expressed as a percentage of the total. In vitro germination of pollen was tested in five different germination media. Fresh mature anthers were collected from the field at anthesis, and pollen grains were carefully dusted on cavity slides containing germination media. One hour after inoculation, the number of pollen grains germinated, and the number of grains per field of view, were recorded. Pollen grains were considered to have germinated when the pollen tube length was greater than the diameter of the pollen grain (Tuinstra & Wedel 2000). Pollen diameter and tube length were observed under an image analyzer (Leica Q 500 MC) at 40 x magnifications.

RESULTS

Floral Biology

The phenological observations have indicated that the peak flowering of *S. spectabilis* typically commences in September and extends until December. The inflorescence takes the form of a raceme, either terminal or axillary, featuring corymbose panicles that are approximately 10–15 cm in length. Each panicle contains 120–140 flowers, with peduncles measuring 2–3 cm in length and pedicels also measuring 2–3 cm in length. The bracts are narrowly ovate or lanceolate with an acute or sub-acuminate apex, and are caducous. The plant possesses five sepals, which are unequal in size and reflexed. The outer two sepals are green and ovate, measuring about 5.5 x 3 mm, with a concave shape and pubescent surface. The inner three sepals are petaloid, rotund or ovoid in shape, measuring 9–10 x 10–13 mm, with inconspicuous veins and a pubescent surface. The plant also has five unequal petals, which are ovoid in shape and measure 2–2.5 cm in length. The petals have a short claw at the base and a smooth margin. There are two types of stamens present: seven fertile stamens and three sterile stamens or staminodes. The fertile stamens are equal in size and have a glabrous surface, with filaments measuring approximately 3 mm in length and anthers measuring approximately 5 mm in length. The anthers are biporose at the apex and reflexed.

The anther is dehisced by apical slits, which open or close according to ambient humidity. The sterile stamens, or staminodes, are each 4 mm long, glabrous, and deeply cordate at both ends. The ovary is curved, 2 mm long, style up to 2.3 cm long, glabrous, stigma fringed with cilia. Style is bent downwards. The sickle-shaped pistil projects into the fertile stamens. The average number of pollen grains per anther is 6580 ± 5.20, which has moderate viability. The pods are pendulous, 17–25 x 1–1.50 cm long, shortly stipitate, linear-cylindric, 100–108 seeded, nearly terete, turgid, septate, and dehiscing along one margin. Seeds are orbicular, 4–6 x 3–5 mm,

Table 1. Observations on floral characters of *Senna spectabilis*.

Floral Characters	Observations
Flowering period	September to December
Flower colour	Rich yellow to Dark-veined
Odour	Present
Nectar	Present
No. of primary branch	16 ± 1.73
No. of inflorescence/branch	2262.75 ± 527.74
No. of flowers/inflorescence	120–140
Sepals/ flower	5
Petals/ flower	5
No. of anthers/ flower	7 fertile stamens, 3 sterile staminodes
No. of pollen grains /anther	6580 ± 5.20
No. of ovules/ flower	80–120
Pollen/ ovule ratio	59.81
Length of stigma ± style (in cm)	2.35 ± 0.19
Length of ovary (in cm)	0.2
Anthesis time	0600–0900 h
Anther dehiscence time	0800–1200 h
Nectar sugar concentration (%)	4.11 ± 0.79
Pollen type	Tri-colporate
Pollen size	35.05 ± 2.19 µm
Stigma type	Above anther level
Fruit setting / inflorescence	10.55 ± 0.95
No. of seeds / pod	108.91 ± 9.69

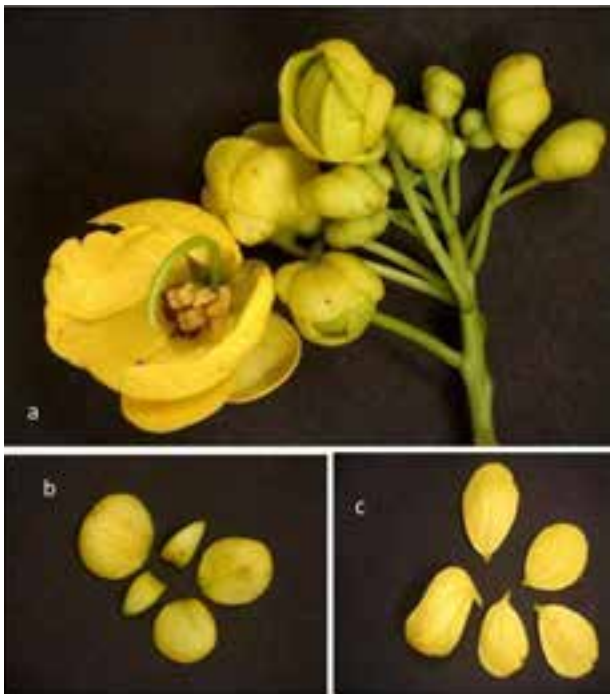

Image 1. Floral morphology of *Senna spectabilis*: a—inflorescence | b—sepals | c—petals. © K. Muraleekrishnan.

brown, and rugulose. Floral morphology observations are detailed in Table 1. The dimensions of the floral parts of *S. spectabilis* are given in Image 1.

Anthesis and Pollination

The duration of anthesis was from 0600 h to 0900 h, and anther dehiscence started at 0800 h and continued up to 1200 h. The stigma became receptive at 0800 h. The anthesis process is diurnal and sometimes asynchronous, which means some flowers are completely open by 1000 h, while some flowers start opening early. The flowers remain open until the next day, probably due to increasing temperature favoring the anthesis. The anthesis exhibited two days of positive stigmatic receptivity under this condition. The flowers open partially on the first day. Then they gradually open fully and expose the sexual whorls for visitors. A fluid-like substance in the basal portion of the flower and tender floral parts of newly opened flowers were used for sugar concentration, and the mean nectar sugar concentration is 4.11 ± 0.79 brix. No distinct nectaries or extra floral nectaries were found. According to Marazzi (2013) extra floral nectar was absent in the case of *S. spectabilis* var. *excelsa*. The peak arrival time of insect visitors was observed from 0900 h to 1230 h.

Dammar Bee is a major visitor to *S. spectabilis* while Violet Carpenter Bee is a regular visitor. Some Formicidae

Table 2. List of Flower foragers on *Senna spectabilis*.

	Scientific name	Common name	Visiting status
1.	*Tetragonula iridipennis* Smith	Dammar Bee	Regular
2.	*Xylocopa violaceae*.	Violet carpenter bee	Regular
3.	*Amata huebneri* Boisdual	Wasp Moth	Occasional
4.	*Bocana manifestalis* Walker	Moth	Occasional
5.	*Camponotus mitis* Smith	Carpenter Ant	Regular
6.	*Myrmicaria brunnea* Saunders	Hunchback Ant	Resident
7.	*Oecophylla smaragdina* Fabricius	Weaver Ant	Resident
8.	*Tapinoma melanocephalum* Fabricius	Ghost Ant	Occasional
9.	*Borbo cinnara* Wallace	Rice Swift	Occasional
10.	*Musca domestica* L.	Housefly	Occasional
11.	*Halyomorpha halys* Stal	Stink Bug	Occasional
12.	*Coptosoma* Laporte	-	Occasional

members, like Weaver Ant and Large Myrmicine ant, are residents of the flowers of this species. They feed on the floral parts, like the tender petals and sepals, even during night hours. Rice Swift is an occasional visitor. Other visitors, such as Stink Bugs and Wasp Moths, came to consume the sap from tender pedicels and branches. The list of flower visitors is recorded (Table 2, Image 2). The Indian Stingless Bee, a major visitor, starts its nectar-foraging activity, from 0800 h to 1230 h, and resumes forging from 1600 h to 1730 h. The Violet Carpenter Bee species foraged during 1000 h to 1130 h. Dammar Bee, a very frequent visitor, only visited open flowers. This foraging behaviour is thought to be boosting the chances of cross-pollination.

Breeding Systems

Studies carried out on artificial breeding experiments and observations of natural and open pollination showed that 20% of fruits were set in crossing experiments such as hand-geitonogamy, while 25% were set in hand-xenogamy and 20% of fruits in autogamy. The natural and open pollination from our tagged flowers set 30% of fruits (Table 3). The fruit set per inflorescence in open pollination is 10.55 ± 0.96. The number of flowers per inflorescence is 114 ± 4.27. After observing 20 trees and their tagged uniform inflorescence, 10% of fruits were found to be finally maturing following the abortion of immature flowers, immature fruits and unripe fruits. The examination of futile percentage also demonstrates that 13.58% of opened flowers were lost, while 90.84% represents the final ripened pod futile percentage (Table 4). Despite these findings, the remaining 10% of

Image 2. Some of the floral visitors of *Senna spectabilis*: a—Formicidae | b—Dammar Bee | c—Housefly | d—Wasp Moth | e—Stink bug | f—Coptosoma. © K. Muraleekrishnan.

Table 3. Modes of breeding pattern in *Senna spectabilis*.

	Treatments	n	No. of flowers		Fruit set (%)
			Pollinated	Set fruit	
1.	Autogamy	20	8	4	20
2.	Geitonogamy	20	11	4	20
3.	Xenogamy	20	9	5	25
4.	Apomixis	20	-	-	0
5.	Open	20	16	6	30

Table 4. Flower and fruit set per inflorescence.

Tree no.	Flower			Fruit-pod		
	Bud	Young	Opened	Bud	Young	Opened
1	140	124	120	76	24	12
2	138	137	121	68	16	15
3	139	128	114	59	17	10
4	132	130	116	72	20	13
5	128	119	114	60	28	12
Mean	135.40	127.60	117	57.40	21	12.40
Futile (%)		5.70	13.58	57.60	84.49	90.84

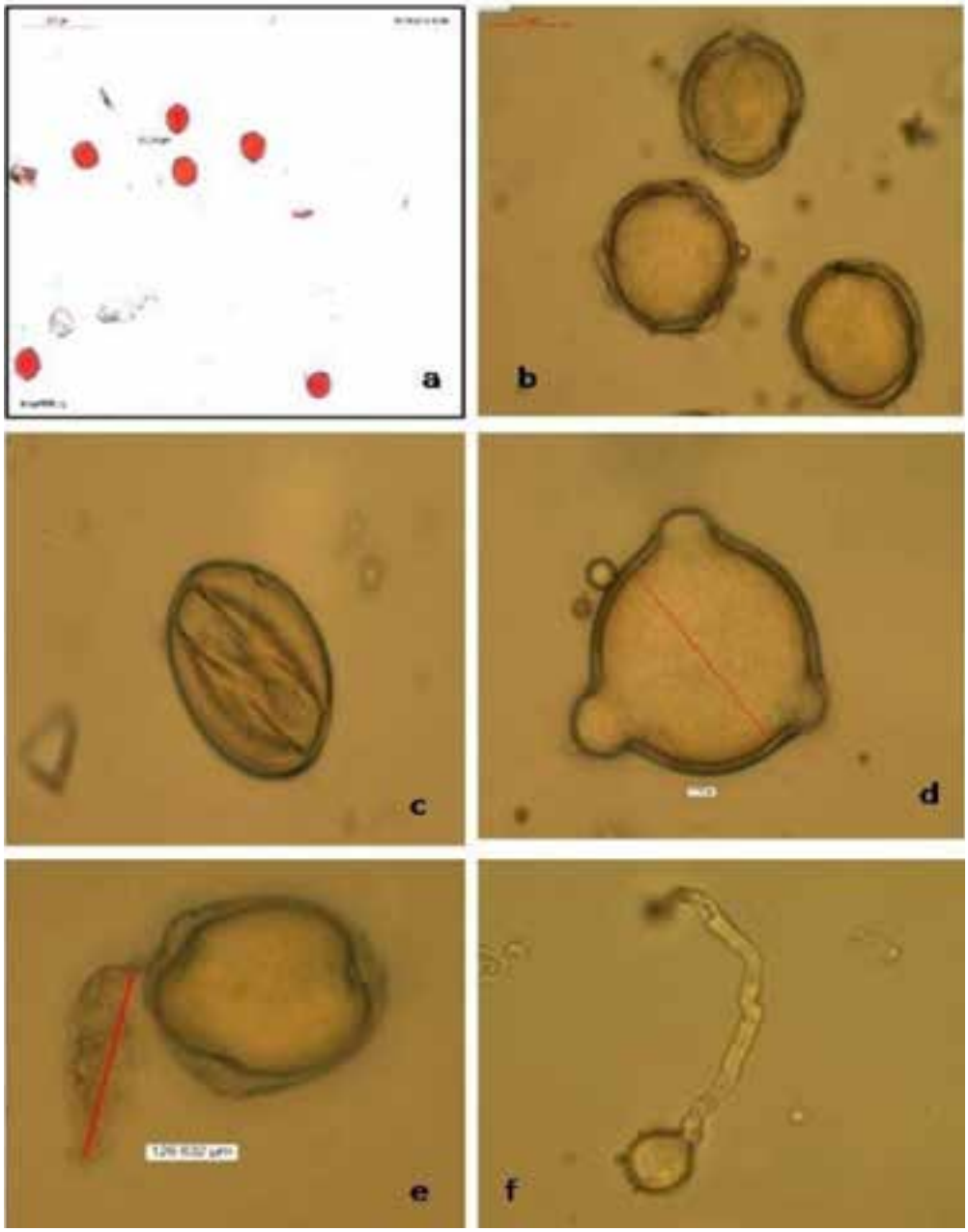

Image 3. Stages of pollen germination: a—Viable pollen (stained red in acetocarmine) | b–d—Pollen germination | e,f—Pollen tube development. © K. Muraleekrishnan.

Table 5. Composition of the pollen germination media.

Composition	1	2	3	4	5	6	7	8	9
Sucrose (g)	10	10	10	0	10	5	5	5	5
Boric acid (g)	0.01	0.01	0	0.01	0	0.01	0.01	0	0
Calcium nitrate (g)	0.03	0	0.03	0.03	0	0.03	0	0.03	0
Distilled water (ml)	100	100	100	100	100	100	100	100	100
Germination %	100	91	72	32	64	75	71	54	44
Duration (min)	20	20	20	30	20	20	20	20	20

Table 6. Nectar sugar concentration in *Senna spectabilis*.

Time of testing	0530	0600	0700	0800	0900	1000	1100	1200	1400
Brix %	3.02± 0.14	3.30± 0.57	3.58± 0.40	4.32± 0.34	4.90 ± 0.26	5.00 ± 0.12	5.10 ± 0.17	4.38± 0.57	3.42± 0.86

ripened pods proved sufficient for additional dispersal mechanisms and the successful invasion of this particular tree species. The results of the breeding system indicated that the flowers are self-compatible and self-pollinating, and they also facilitate cross-pollination. Being an out-crosser and a self-pollinating species, *S. spectabilis* has different ways to reproduce in this invasion area.

Pollen Viability

Fresh pollen grains of *S. spectabilis* show 30% viability when stained with acetocarmine (1%). In vitro germination was found to be 32–100 % when the pollen grains dusted in different media were observed under the microscope after 20 min. (Table 5; Image 4). The highest germination was obtained in medium 1 (100%). The lowest germination was obtained in medium IV (32%) which does not contain sucrose.

DISCUSSION

Information on floral characters and pollination systems is important in the breeding system, especially in the case of *Senna spectabilis* which poses a major threat and has a negative impact on the structure and diversity of the forest and its ecosystem. In order to manage this species in the invaded forest areas, observation of reproductive biology is very important. The diurnal anthesis period of this species is characterized by the simultaneous presence of flowers and flower buds at various stages of development on the same inflorescence, as observed in *Sesbania virgata* (Cav.) Pers. Additionally, an extended duration of flower opening has been observed to promote pollinator activity throughout the day (Souza et al. 2016). In the case of *S. spectabilis*, the flowers remain open until the following day, which may facilitate cross-pollination by providing a continuous supply of pollen as a resource for flower visitors across different plants and flowers.

The flowers of the Fabaceae family possess specific and highly efficient pollination mechanisms that rely on various biotic vectors, including bees and birds (Rasmussen 2013). The present study has identified the Dammar Bee, a widespread species in India, and the Violet Carpenter Bee, as the primary pollen vectors. These species have been confirmed as pollinators based on their pollen load and their role in seed setting (Rasmussen 2013).

Research findings indicate that *Senna* pollen-collecting bees employ a technique of extracting pollen by vibrating the middle “feeding” stamens, which they firmly grasp with their legs (Marazzi & Endress 2008). In their investigation into the diversity and evolution of a trait associated with ant-plant interactions involving extra floral nectaries in Senna (Leguminosae), Marazzi et al. (2013) deliberately excluded *S. spectabilis* from their study due to the absence of ants in the vicinity of its floral buds or leaves. However, extensive field observations revealed the presence of abundant Formicidae species, which were observed to be permanent residents of these flowers and actively feeding on delicate floral components. These ants displayed both diurnal and nocturnal activities. Additionally, a moth species, *Bocana manifestalis*, was observed on the flowers during the night.

This species has poricidal dehiscence of anthers, minute terminal stigmas and curved styles. Pollens are released when anthers are vibrated by the bees (Buchmann 1974). These floral features showed that this species has buzz pollination syndrome. According to Almeida et al. (2015), *S. spectabilis* is listed as an Enantiostylous type of species. They classified Cassiinae species into seven types based on morph distribution among plants and grouped species with different flower morphologies and diverse reproductive strategies of these types.

Senna spectabilis belongs to Type 5, which is classified as the Amiciella group. The model species for this group is *Chamaecrista amiciella*. The characteristic pattern of these species involves the deposition of pollen grains on the dorsal portion of the pollinator after they have passed through all the extensions of a modified, tube-shaped petal (Almeida et al. 2013). The pollen produced by the pollination anthers is deposited opposite the stigma. The Amiciella type is considered the second most complex, as it exhibits similar mechanisms to the Ramosa type (Type 7), with the exception of the use of a group of petals (only one petal fulfills this role). This type is unique to *Chamaecrista* and *Senna* species. In the case of *S. spectabilis*, the pollen grains are deposited on both the dorsal and ventral sides as a result of the body-washing behavior of a dammer bee. The number of pollen grains is higher on the ventral side. Pollen serves as the most sought-after floral reward, providing vital nutrition for many insects, particularly Apidae, beetles, flies, thrips, springtails, as well as some orthopteroids and butterflies (Anderson 1996). Pollen is highly nutritious and contains essential and quasi-essential amino acids (Haydak 1970). In the case of *S. spectabilis*, pollen is also the primary reward due to the low concentration of nectar sugar and the absence of proper nectar secretion in this flower (Table 6).

Tamnet et al. (2011) studied on optimization of the preservation of pollen grain germination of *S. spectabilis*. For the study, they selected this invasive tree species, which is a large species of bee flora facing extinction threat in the Adamawa region of northern Cameroon. They claimed to have conducted the study to help beekeepers. They tested in vitro germination and storage of pollen. The results reveal that its pollen germinates preferentially up to 38.36% in Brewbaker medium enriched with the optimal concentration of 25% sucrose. Pollen was stored at 10°C and 20°C and germinated at length during 22 weeks of storage.

In vitro germination was found to be good in the present study, and 32 to 100% germination was found in different media, which is also proven in the experiments (Image 3). During field observations for pollinator interactions, the Indian Honey Bee *Apis cerana indica* was always found to be hovering around the flowers of *S. spectabilis* and visiting only the associate plants, but it never made a single visit to *S. spectabilis* flowers. Further observations and research experiments are required to find out the reason behind it, as this could be due to a lack of sufficient forage or the presence of any repellent factors. It also possesses a self-pollination mechanism. Autogamy is a reproductive characteristic of invasive and pioneer species that occupy clearings and forest edges (Williamson 1996; Holsinger 2000). Here, the case of *S. spectabilis* occurred in areas similar to clearings, such as massive bamboo flowering in open areas, other open areas of deciduous forest patches and the edges of Vayal ecosystems. In breeding experiments, 25–20% of fruit sets occurred, and autogamy also accounted for 20% of fruit sets. It reveals that *S. spectabilis* possesses a mixed reproductive system composed of cross-pollination and autogamy. This system is probably related to its success as an invasive species, which helps it spread and colonise new habitats.

Baker & Baker (1979) observed that maintaining a particular balance between self-compatibility and cross-pollination is beneficial to weeds. The author states that once a seed is dispersed to a distant place, the formation of a new population will depend on the self-pollination capacity of the species. *S. spectabilis* is autogamous and an out-crosser, which appears to be a good strategy when combined with its ability to invade degraded lands such as open forest areas. Several invasive plants have been described as self-compatible in the introduced ranges (Rambuda & Johnson 2004; Kleunen & Johnson 2007; Stout 2007; Rodger et al. 2010; Hao et al. 2011), and this has been proposed as an advantage for successful invasion (Williamson & Fitter 1996; Pannel & Barret 1998).

Invasive species generally have a high sexual reproductive capacity, the ability to reproduce asexually, the capability to grow rapidly from seed to sexual maturity, great dispersal and colonization efficiency, a high tolerance to environmental heterogeneity and disturbances, a high adaptation to environmental stress, and a greater competitive capacity than native species (Sakai et al. 2001; Vila & Weiner 2004; Werner & Zahner 2009). As an invasive tree species in forest areas of Wayanad Wildlife Sanctuary, forest officials and locals try to eradicate this species by cutting the tree. However, the tree re-sprouts profusely. During a period of five years, this tree was observed to have grown more

branches after re-sprouting, while each branch produced flowers vigorously in three years. Re-sprouting ability is a positive reflection of its invasiveness.

Research conducted on invasive Australian Acacias by Milton & Hall (1981) elucidated that this species possesses various reproductive characteristics that potentially contribute to their invasiveness. These traits include extensive and enduring floral displays, pollination syndromes that cater to a wide range of pollinators, early production of a substantial quantity of long-living and highly viable seeds, leading to the formation of extensive seed banks, adaptations for seed dispersal, and mass germination. These findings were also observed in *S. spectabilis*, which displayed comparable behavior and responses. The study revealed that the high rate of seed production in *S. spectabilis* can be attributed to various factors, including the pollen viability and vigour of the pollen tube, the timing of anther dehiscence and stigma receptivity, the presence of multiple pollinators, and adequate pollen rewards. The pods of *S. spectabilis* were observed to contain an average of 108.91 ± 09.69 seeds. Notably, the plant exhibited no sexual incompatibility or pollination difficulties. The reproductive syndrome of *S. spectabilis* is conducive to achieving maximum fertilization.

CONCLUSION

Reproductive studies of *Senna spectabilis* and its pollen-ovule ratio indicate that this species is a cross-pollinating species. This species is self-compatible, as xenogamy, geitonogamy and autogamy are observed in field experiments. This reproductive strategy helps the tree colonise degraded areas and invade the forest ecosystem. Reproductive successes of this species also depend on its production of large amounts of flowers during its peak phenophase. Flowers, pollen grains, fruit set—everything facilitates the invasive nature of this tree.

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COMMUNICATION

Diversity and status of butterfly fauna at Kurukshetra University campus, Haryana, India

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Abstract: Campuses of educational institutions in India serve as important reservoirs for different faunal components, including ecologically sensitive species like butterflies. To record the diversity, status, and occurrence of butterfly fauna in Kurukshetra University Campus, Haryana, a year-long survey was done from July 2021 to June 2022. A total of 710 individuals of butterflies belonging to 39 species, 32 genera, and five families were recorded. Nymphalidae represented the highest diversity with 13 species followed by Lycaenidae (11 species), Pieridae (10 species), Papilionidae (3 species), and Hesperiidae (2 species). The number of individuals encountered was maximum in family Pieridae (n = 158) while the minimum was in family Hesperiidae (n = 4). Species richness, abundance, and diversity differed significantly ($P < 0.05$) across the different seasons. Species richness was recorded to be the highest in summer season (35 species) followed by monsoon, post monsoon, and winter. Among the recorded species, one species, i.e., Common Baron *Euthelia aconthea* is protected under Schedule II of the Wildlife (Protection) Amendment Act (2022). The findings of the present study support the importance of the higher educational institution campuses in providing valuable habitat and resources for butterflies.

Keywords: Abundance, community composition, conservation, cluster analysis, ecosystem, Nymphalidae, Peridae, Pollard Walk, seasonal variation, species richness.

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Author contributions: PK conceived and designed the study as well as wrote the final draft of the manuscript. VG performed the field surveys, analysed the data and prepared rough draft of the manuscript. Both authors read and approved the final manuscript.

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INTRODUCTION

Being ecologically sensitive insects, butterflies respond to the disturbances in their habitat including changes in the microclimate, temperature, sun radiation, and the availability of host plants by changing their ovi-positioning site, flight patterns, and egg laying rates (Aneesh et al. 2013; Chowdhury et al. 2023).

Due to their species richness, abundance, diverse ecological needs, and dependency on various plants for nectaring and larva development butterflies serve as the umbrella species in nature conservation (New 1997). The protection of butterflies in a region indirectly leads to the protection of a number of plants, trees, and other flora, therefore, research on their population ecology offers crucial insights on the status of other taxa in a particular terrestrial ecosystem (Weber et al. 2008). India being one of the 12 mega biodiversity countries of the world, harbours 1,800 species of butterflies including both endemic as well as globally threatened species (Harisha & Hosetti 2021). However, in the state of Haryana, only scanty information is available and most of it is from protected areas and the butterfly diversity in urban, rural, and various other habitats of Haryana still remains unexplored. Uniyal & Bhargav (2007) documented 24 species of butterflies belonging to four families from Bir Shikargah Wildlife Sanctuary. Sethy & Ray (2010) recorded 35 species of butterflies under 24 genera and five families from Kalesar Wildlife Sanctuary.

Since both adult butterflies and caterpillars are reliant on plants for leaf, nectar, and pollen as a source of food, therefore, their distribution is largely dependent on the presence of the host plants (Majumder et al. 2012)). The anthropogenic pressure such as habitat degradation due to construction activities, excessive use of pesticides and weedicides, removal of nectar, and host plants are some of the major threats to the butterfly fauna in India (Narayana et al. 2017). To comprehend the impact of anthropocentric development on the integrity and sustainability of ecosystems, studies on species diversity in various ecosystems are of utmost importance (Harsh 2014). The educational institutions being endowed with natural flora and a wide range of seasonal flowering plants and favourable environmental conditions can provide flourishing habitat to butterfly populations. Despite their common occurrence, little is known about the butterfly assemblages in educational institutions in India and particularly in Haryana. Information on species composition and seasonal assemblages of butterflies in a particular habitat is essential to understand the habitat conditions to design suitable conservation and management strategies. In this context, the present study is an attempt to document the diversity of butterfly fauna in the Kurukshetra University campus.

MATERIAL AND METHODS

Study area

Kurukshetra University (29.969^{0}N, 76.878^{0}E) is located in district Kurukshetra of Haryana state at an altitude of 206 m (Figure 1A). Spread over an area of about 179 ha, the university campus is a conglomerate of a variety of habitats including undisturbed areas with endemic plants and canopies of tall trees, afforestation zone, grasses, plain lush green lawns, gardens of fruit trees, bushes, and varied natural habitat covering over 40 acres of the area. The prominent shrubs of the campus include *Cassia javanica*, *Murraya exotica*, *Bougainvillea* sp., *Hibiscus rosa*, *Zizyphus jujuba*, *Zizyphus nummularia*, *Jasminium* sp., *Lantana camara*, *Jasminum* sp., and *Amaranthus spinosus*. This mosaic of habitats in the university campus provides a broad niche to the butterfly fauna. The study area experiences subtropical climate, having three major seasons: rainy (July–September), a cool dry (October–February), and the hot dry season (March–June). Temperature is as high as 45° C in summer and as low as 3° C during the winter whereas, annual rainfall of the area ranges from 582–808 mm.

METHODS

The butterfly surveys were conducted at fortnightly intervals from July 2021 to June 2022 in the university campus. Pollard Walk method was adopted to record the butterfly species (Pollard 1977). Fixed transect routes ranging between 500 m–1 km were established and followed for surveying the entire campus. The butterfly species were observed at 2.5 m on both sides of the transects by moving at a slow and steady pace. Butterflies were counted directly, aided by a pair of field binoculars (Nikon 10 x 50) during the peak hours of activity 0700–1100 h or 1400–1600 h. Field visits were carried out only on days with suitable weather conditions (i.e., in absence of rain and strong wind). In addition to regular surveys, opportunistic observations of butterflies at other times were also recorded to prepare a comprehensive checklist of the study area.

Whenever possible photographs of butterflies were taken with a digital camera (Nikon D5200) from

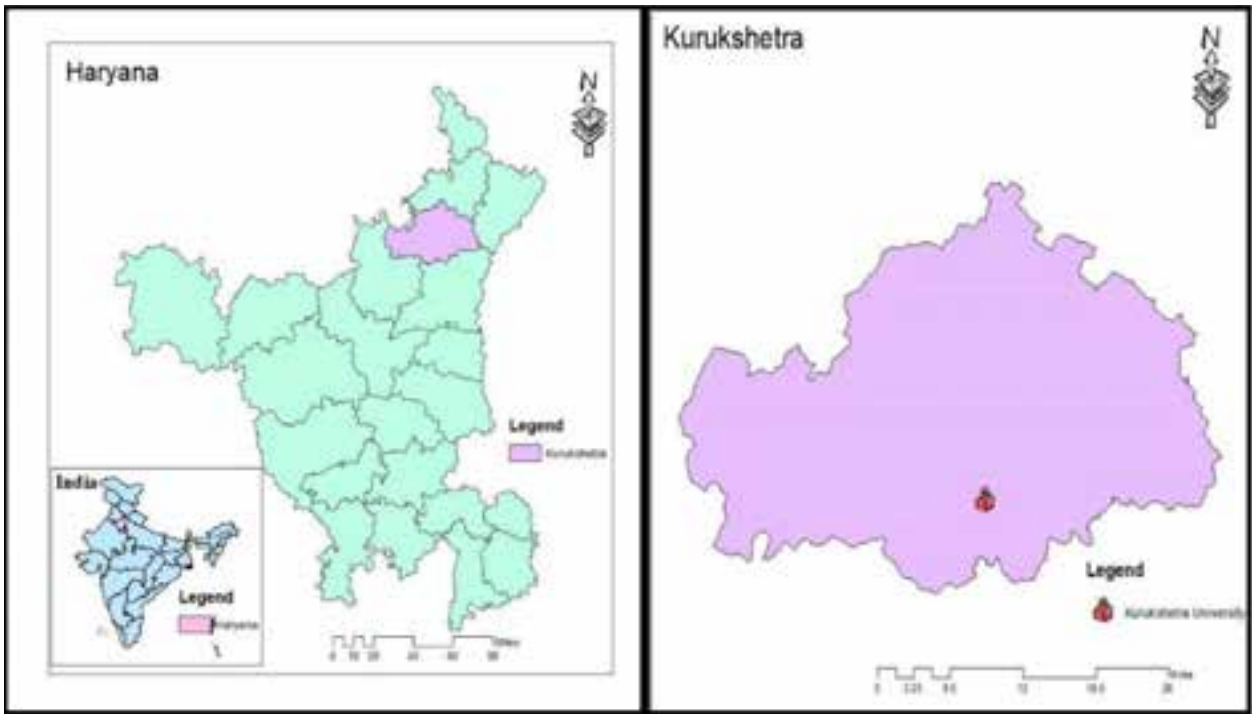

Figure 1. The location of study area.

different angles to obtain sufficient pictures for accurate identification of species. Only visual documentation was done and no specimen was collected. Butterflies were identified with the help of standard field guide (Smetacek 2017). The names (common and scientific names) and taxonomic position (family and sub family) of recorded butterfly species were accorded following Bhakare & Ogale (2018). We also assigned a local status to each recorded species based on the frequency of sightings following Samanta et al. (2017) as abundant (A)—sighted on 75–100 % of survey days; common (C)— sighted on 50–74.99 % of survey days; occasional (O)—sighted on 25–49.99 % of survey days; and rare (R)—sighted on less than 25% of survey days. For analysis of seasonal variations in species richness of butterfly assemblages, we pooled the recorded field data corresponding to four seasons, i.e., summer (March–May), monsoon (June–August), post-monsoon (September–November), and winter (December–February).

Species richness was calculated as total number of butterfly species observed in the study area. To test whether the sampling efforts were enough to detect all the butterfly species that occurred in the study area, a species accumulation curve was produced, by plotting the cumulative number of species recorded against the sampling efforts. Species similarity between any two seasons was measured by using Jaccard's similarity index as (Cj) = a / (a + b + c) where a is the number of species common to both the seasons, b is the number of species unique to the first season and c is the number of species unique to the second season. A cluster analysis was performed using Jaccard's similarity measure and a paired group method (UPGMA) by PAST version 3.26 software. Shannon-Wiener's diversity and species evenness indices of butterfly species were also estimated using PAST version 3.26 software. Differences in the various diversity indices among the different seasons were compared using one-way analysis of variance (ANOVA) with Tukey HSD test at 5% level of significance (SPSS 24.0 version). The conservation status of the recorded butterfly species was assessed according to the Wildlife (Protection) Amendment Act (2022).

RESULTS

A total of 710 individuals of butterflies belonging to 39 species, 32 genera, and five families were recorded during the study period (Table 1, Image 1–24). A checklist of the recorded butterfly fauna with their common and scientific names, season of occurrence, local abundance status, and activity are presented in Table 1. Nymphalidae was found to be the most diverse family comprising 13 species (34%) followed by

Table 1. List of butterfly species recorded from campus of Kurukshetra University, Kurukshetra, Haryana, India.

	Common name	Scientific name	Season				Local status	Activity observed
			S	M	PM	W		
Family: Nymphalidae Subfamily: Nymphalinae								
1.	Peacock Pansy	*Junonia almana*	12	3	2	6	Abundant	Basking
2.	Blue Pansy	*Junonia orithya*	5	4	5	5	Common	Basking, sucking nectar
3.	Chocolate Pansy	*Junonia iphita*	5	3	1	1	Common	Basking
4.	Common Castor	*Ariadne merione*	2	3	2	1	Common	Basking
5.	Great Eggfly	*Hypolimnas bolina*	2		2	1	Occasional	Basking
6.	Painted Lady	*Vanessa cardui*	11	9	0	0	Common	Basking, sucking nectar
7.	Common Leopard	*Phalanta phalantha*	2	3	2	1	Occasional	Basking
Subfamily: Danainae								
8.	Plain Tiger	*Danaus chrysippus*	7	6	8	0	Abundant	Basking, sucking nectar, mud puddling
9.	Striped Tiger*	*Danaus genutia*	2	1	1	0	Occasional	Resting, sucking nectar
Subfamily: Satyrinae								
10.	Common Palmfly	*Elymnias hypermnestra*	3	0	0	0	Rare	Resting
11.	Dark Evening Brown	*Melanitis phedima*	0	0	1	1	Occasional	Resting
Subfamily: Limenitidinae								
12.	Common Baron	*Euthalia aconthea*	2	2	1	1	Common	Basking
13.	Common Sailer	*Neptis hylas*	2	1	1	1	Occasional	Resting, basking, mud puddling
Family: Pieridae Subfamily: Pierinae								
14.	Indian Cabbage White	*Pieris canidia*	26	0	3	6	Abundant	Resting, basking, sucking nectar
15.	Large Cabbage White	*Pieris brassicae*	10	0	0	12	Abundant	Resting, basking, sucking nectar
16.	Yellow Orange Tip	*Ixias pyrene*	4	1	1	1	Common	Resting, sucking nectar
17.	Common Gull	*Cepora nerissa*	10	3	2	3	Occasional	Basking
18.	Pioneer	*Belenois aurota*	15	5	5	7	Abundant	Basking, resting, patrolling.
Subfamily: Coliadinae								
19.	Common Grass Yellow	*Eurema hecabe*	8	4	10	8	Abundant	Mud puddling
20.	Small Grass Yellow	*Eurema brigitta*	3	4	2	2	Abundant	Mud puddling, resting, sucking nectar.
21.	Common Emigrant	*Catopsilia pomona*	13	4	6	6	Abundant	Mud puddling, resting, sucking nectar, patrolling
22.	Mottled Emigrant	*Catopsilia pyranthe*	4	4	2	3	Abundant	Mud puddling, resting, sucking nectar, patrolling
23.	Dark Clouded Yellow	*Colias feldii*	8	0	0	0	Occasional	Resting, sucking nectar
Family: Lycanidae Subfamily: Polyommatinae								
24.	Pale Grass Blue	*Pseudozizeeria maha*	13	24	12	4	Abundant	Resting, basking, patrolling
25.	Lesser Grass Blue	*Zizina otis*	20	18	17	10	Abundant	Resting, basking, patrolling, mating.
26.	Dark Grass Blue	*Zizeeria karsandra*	39	45	23	0	Common	Resting, basking
27.	Zebra Blue	*Leptotes plinius*	4	4	6	0	Occasional	Resting, basking
28.	Pea Blue*	*Lampidesboeticus*	4	6	0	0	Rare	Resting, basking
29.	Gram Blue*	*Euchrysops cnejus*	6	5	3	0	Common	Resting, basking, patrolling
30.	Striped Pierrot	*Tarucus nara*	2	2	1	0	Occasional	Resting, basking
31.	Red Pierrot	*Talicada nyseus*	2	2	4	0	Occasional	Resting

32.	Black Spotted Grass Jewel	*Freyeria putli*	3	4	5	0	Occasional	Resting
33.	Plain Cupid	*Chilades pandava*	6	5	3	0	Occasional	Resting
Subfamily: Theclinae								
34.	Common Silverline	*Spindasis vulcanus*	4	1	1	1	Occasional	Resting
Family:Papilionidae Subfamily: Papilioninae								
35.	Common Jay	*Graphium doson*	9	5	4	0	Abundant	Mud puddling, sucking nectar
36.	Lime Swallowtail	*Papilio demoleus*	7	7	3	3	Abundant	Resting, basking, sucking nectar
37.	Common Mormon	*Papilio polytes*	8	4	5	0	Abundant	Nectar sucking, mud puddling.
Family: Hesperiidae Subfamily: Hesperiinae								
38.	Small Branded Swift	*Pelopidas mathias*	0	3	2	1	Occasional	Resting, sucking nectar
39.	Common Banded Awl	*Hasora chromus*	0	0	2	1	Occasional	Resting

S—Summer | M—Monsoon | PM—Post monsoon | W—Winter.

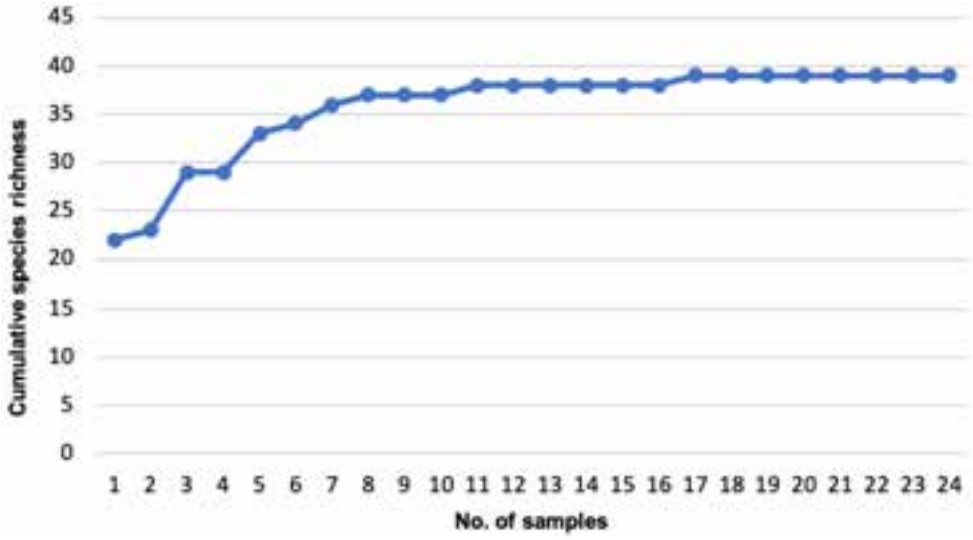

Figure 2. Species accumulation curve of butterflies recorded in Kurukshetra University campus.

Lycaenidae (11, 29%), Pieridae (10, 26%), Papilionidae (3, 8%), and Hesperiidae (2, 3%). In terms of the number of individuals sighted, family Lycanidae was the most abundant (308 individuals) followed by Pieridae (205), Nymphalidae (133), Papilionidae (55), and Hesperiidae (09).

The most diverse genus was *Junonia* represented by three species whereas five genera (*Danaus*, *Pieris*, *Catopsilia, Eurema*, and *Papilio*) were represented by two species each and the remaining 26 genera were represented in the study area with a single species each. The ratio of species to genus of recorded butterfly fauna was estimated to be 1.21 (Figure 2).

The species accumulation curve based on observed species richness in the university campus showed that the richness initially was lesser, then increased gradually and later on approached to an asymptote. It reached stable values of 38 species after the 11th sampling while the observed curve stabilized at 39 species after the 17th sampling (Figure 2). Monthly variations in species richness of butterfly in the study area are depicted in Figure 3. A bi-annual peak in species richness was recorded during the study period, first in the month of October (25 species) and second in the month of April (33 species). Maximum species richness of butterfly fauna (n = 35) was recorded in summer followed by post monsoon (n = 33), monsoon (n = 32), and winter season (n = 22). Species richness of butterflies differed significantly across the four seasons in the study area ($F = 15.098$, $P < 0.05$, Table 3). Average species richness

Table 2. Species richness, abundance, species diversity and species evenness of butterfly fauna in university campus of Kurukshetra.

Season	Diversity indices (Mean ± S.E)			
	Species richness	Population abundance	Species diversity	Species evenness
Summer	29.66±1.76[a]	93.66±8.35[a]	3.16±0.80[a]	0.75±0.67
Monsoon	21.34±1.20[b]	64.66±4.91[b]	2.80±0.94[b]	0.75±0.25
Post monsoon	21.00±3.0[bc]	50.00±4.93[bc]	2.80±0.14[bc]	0.76±0.06
Winter	11.67±0.66[d]	28.33±5.89[d]	2.25±0.14[d]	0.83±0.06
F value	15.098	19.653	9.863	0.413
P value	0.001	0.000	0.005	0.749

Significant differences were found at 5% level of significance. Results in a column under various indices followed by different letters indicate significant differences among different seasons at P <0.05. Results in a column followed by same letters indicate non-significant differences among different seasons at P >0.05 (one-way ANOVA and Tukey's HSD post-hoc test.

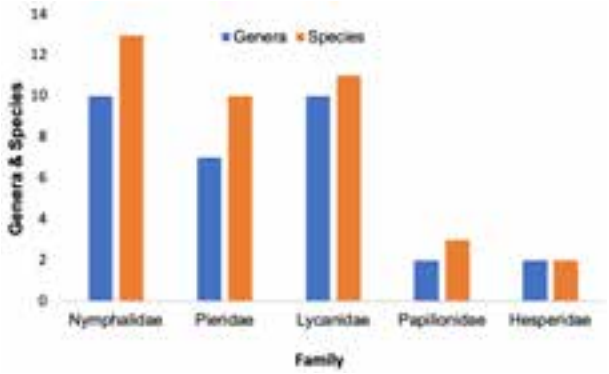

Figure 3. Distribution of genera and species in different families of butterflies in the study area.

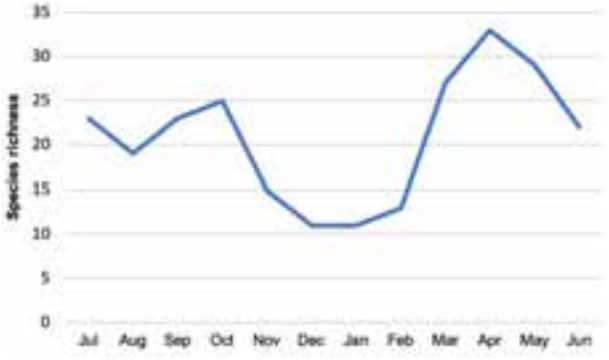

Figure 4. Monthly variations in overall species richness of butterflies in Kurukshetra University Campus.

in summer (29.66±1.76) was significantly higher than that of the remaining three seasons (Tukey's HSD test, all P <0.05). Population abundance of butterfly fauna also varied significantly among all the four seasons (F = 22.98, P <0.05). Mean population abundance was highest in summer (46.83±2.74), and lowest in winter (14.16±2.88). The species diversity of butterflies varied significantly among the seasons (F = 9.863, P <0.05). However, species diversity of summer (3.16±0.80) did not differ significantly (P >0.05) than that of monsoon (2.80±0.94), and post monsoon (2.80±0.14). The species evenness was found to be almost similar across all the seasons (Table 2).

As far as seasonal distribution of butterfly families is concerned, four families (Nymphalidae, Peridae, Lycanidae, and Papilionidae) were recorded in all four seasons whereas family Hesperidae was encountered only during three seasons (monsoon, post monsoon, and winter) (Table 3).

Of the total detected species, 16 species were recorded across all four seasons whereas the remaining 23 species were recorded only during certain seasons (Table 1). Jaccard's similarity index was calculated from the record of occurrence of the butterfly species across the four seasons (Table 4). Monsoon & post monsoon season and monsoon & summer showed the maximum similarity in species composition of butterfly community (0.81), while species similarity was found to be minimum between monsoon and winter season (0.46). Detailed cluster analysis paired (UPGMA) of Jaccard's similarity index of each season showed that butterfly communities harboured by summer, monsoon and post monsoon were fairly distinct from winter (Figure 5).

Assessment of local abundance status revealed that 14 species were abundant, eight species were common, 14 species were occasional, and two species (Common Palmfly *Elymnias hypermnestra* and Pea Blue *Lampides boeticus*) were rare in the study area (Table 1). Two species namely, Common Baron *Euthalia aconthea* and Common Silverline *Spindasis vulcanus* were found to be very static and the rest of species were very active and swift in their recorded seasons in the study area. Among

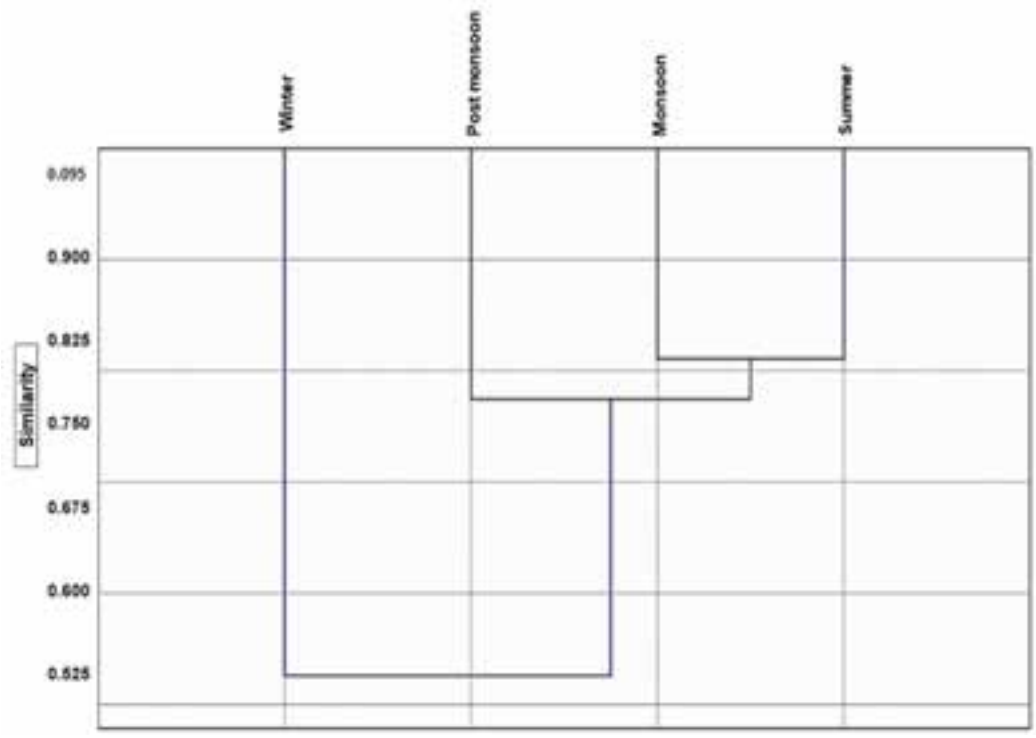

Figure 5. Cluster analysis based on Jaccard's similarity index using unweighted pair group method with arithmetic mean (UPGMA) showing similarity of butterfly species composition in different season.

Table 3. Seasonal distribution of butterfly families in the study area.

Family	Species richness					Abundance				
	S	M	PM	W	Overall species richness	S	M	PM	W	Total
Nymphalidae	11	9	11	9	13	53	32	29	19	133
Lycaenidae	11	11	9	2	11	103	116	75	14	308
Pieridae	10	7	8	9	10	101	25	31	48	205
Papilionidae	3	3	3	1	3	24	16	12	3	55
Hesperidae	0	2	2	1	2	0	5	3	1	9
Total	35	32	33	22	39	281	194	150	85	710

S—Summer | M—Monsoon | PM—Post monsoon | W—Winter.

the recorded butterfly fauna Common Baron *Euthelia aconthea* was found to be protected under Schedule II of the Wildlife (Protection) Amendment Act, 2022.

DISCUSSION

The observed richness of butterfly fauna is comparable with reports of earlier studies carried out on the campuses of educational institutions in some adjoining eco-regions. For instance, Pathania et al. (2018) reported 33 species of butterflies belonging to 24 genera and five families from Punjab Agricultural University Campus, Ludhiana, Punjab. Singh et al. (2016) recorded a total of 23 butterfly species belonging to five families and 18 genera from Khalsa College Amritsar, Punjab.

Nymphalidae is the most dominant family of butterflies in India (Kunte 2000). In the present study area also, Nymphalidae emerged as the most diverse family. Members of the family Nymphalidae are dominant in the tropical region because of their polyphagous nature

Image 1–12. 1—Great Eggfly *Hypolimnas bolina* | 2—Grass Jewel *Freyeria putli* | 3—Common Silverline *Spindasis vulcanus* | 4—Common Castor *Ariadne merione* | 5—Common Grass Yellow *Eurema hecabe* | 6—Common Baron *Euthalia aconthea* | 7—Yellow Orange Tip *Ixias pyrene* | 8—Common Palmfly *Elymnias hypermnestra* | 9—Blue Pansy *Junonia orithya* | 10—Zebra Blue *Leptotes plinius* | Image 11—Gram Blue *Euchrysops cnejus* | 12—Striped Pierrot *Tarucus nara*. © Vidisha Gupta.

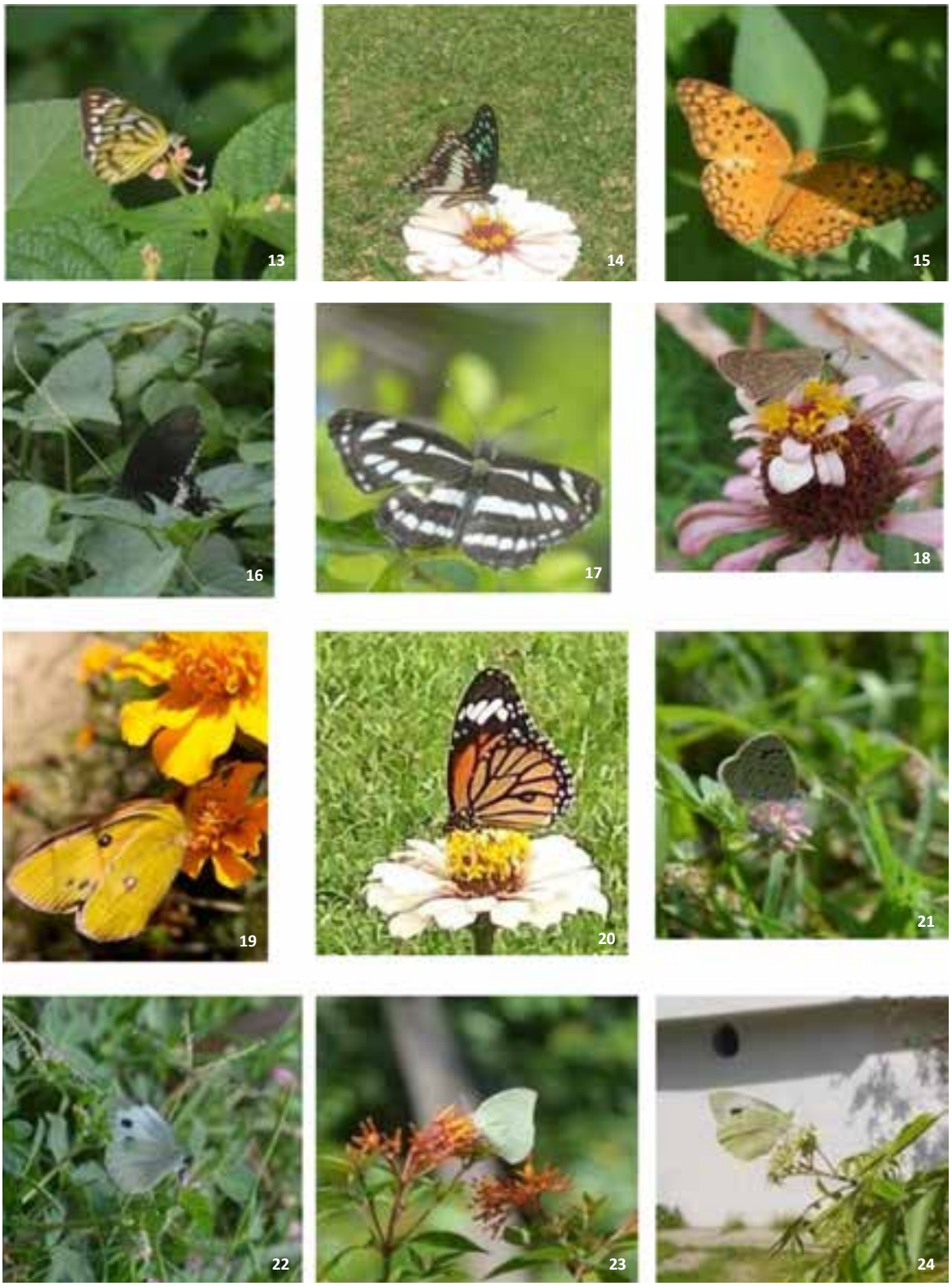

Image 13–24. 13—Common Gull *Cepora nerissa* | 14—Common Jay *Graphium doson* | 15—Common Leopard *Phalanta phalantha* | 16—Common Mormon *Papilio polytes* | 17—Common Sailor *Neptis hyla* | 18—Small Branded Swift *Pelopidas mathias* | 19—Dark Clouded Yellow *Colias feldii* | 20—Striped Tiger *Danaus genutia* | 21—Dark Grass Blue *Zizeeria karsandra* | 22—Indian Cabbage White *Pieris canidia* | 23—Lemon Emigrant *Catopsilia pomona* | 24—Large Cabbage White *Pieris brassicae*. © Vidisha Gupta.

Table 4. Jaccard's similarity index (Cj) of butterfly species between seasons in the study area.

	Summer	Monsoon	Post monsoon
Summer			
Monsoon	0.81		
Post monsoon	0.74	0.81	
Winter	0.5	0.46	0.56

and active flight that helps them survive in various habitats. The attributed reasons for the variation in butterfly diversity might be the climatic and ecological conditions such as ambient temperature, light intensity, precipitation, humidity, presence of natural enemies, availability of a number of host plants and vegetation cover of herbs, shrubs, and trees for nectaring & egg laying (Sharmila et al. 2020; Sharma & Sharma 2021). The results of the present study are consistent with the previous records that Nymphalidae is the most common family in the campuses of educational institutions in different parts of the India (Deb et al. 2015).

In terms of individuals recorded Lycanidae was abundant in the study area with an occurrence of 308 individuals. The species richness, abundance and diversity of butterfly fauna varied significantly ($P < 0.05$) across the four seasons. Two peaks of species richness in the study area, one in the post monsoon season with an occurrence of 32 species and an additional peak during the summer season with 35 species were recorded. These results are consistent with the observation of Gupta et al. (2019) who recorded a bi-annual peak of species richness in butterfly assemblages in a sub-tropical urban landscape of Delhi. The tropical insect communities tend to remain stable throughout the year and the seasonal peaks are not well defined as in the case of subtropical insect communities (Gupta et al. 2019). This seasonal variation in butterfly species in the communities reveals that the diversity of butterflies in the study area (in sub-tropical regions) could be different from the tropics due to marked dry and wet seasons and greater climatic variability such as temperature, photoperiod, precipitation, and humidity.

The seasonal distribution of butterfly fauna in the study area revealed that families Nymphalidae and Lycanidae were equally dominant in summer whereas, in winter Nymphalidae and Pieridae showed equal dominance. In monsoon again Lycaenidae was observed as the most dominant family, however, in winter it showed a sharp decline. The months of December and January witnessed the minimum species richness (11 species) at an average lowest temperature of 12.7° C. Because of the lower temperature and ectothermic nature of the butterflies, they prefer to undergo diapause. As far as Pieridae is concerned it showed a decline in monsoon and escalated again in winter. Whereas Papilionidae showed equal distribution in summer, monsoon, and post monsoon and declined in winter. However, a record of Hesperiidae was only made in monsoon, post monsoon, and winter season but not in summer season. The attributed reason for the absence of the latter in summer season might be the non-availability of specific host /nectar plants and the low dispersal ability due to its shade loving nature.

Among the recorded 39 species, one species is protected under the Schedule II of Wildlife (Protection) Amendment Act, 2022. The results of the current study underscore the importance of institutional campuses in the urban landscapes as a preferred habitat for butterflies. However, habitat alterations due to developmental activities, use of pesticides, herbicides, and insecticides in gardens, plucking of flowers, cutting of host plants, litter deposition are some of the threat factors prevailing in the campus which could affect the population of the butterflies.

CONCLUSION

The present primary study on the butterfly fauna of Kurukshetra University campus provides a baseline data for future studies, emphasizing the temporal pattern in the butterfly community. If the landscaping is carefully planned in the university campus and campus gardens are well maintained with lush green grasses and floral beds with a variety of seasonal plants, plantation of a wide range of nectaring & larval host plants along roadside pavements, establishment of a butterfly park, conservation of habitats with a high cover of natural & semi natural vegetations, minimal use of herbicides and insecticides, and reduced anthropogenic stress these measures can help in increasing the diversity of butterfly fauna in the university campus as well as at the local biodiversity level. Long term monitoring programmes should be carried out to manage and conserve the butterfly diversity of the university campuses. Under the current scenario of habitat fragmentation and degradation in urban areas of the country, the results of the present study underline the importance of institutional campuses in the urban landscapes as a preferred habitat for butterflies and other associated floral and faunal components.

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COMMUNICATION

First report of *Lutevula hortensia* (Distant) (Heteroptera: Reduviidae: Emesinae) from India

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Abstract: An emesine bug, *Lutevula hortensia* (Distant), is recorded from India for the first time; type locality of this species is Sri Lanka and it was recently collected from Vellore, Tamil Nadu, in southern India. This is a rediscovery of the species after more than 50 years. Digital images of the species are presented along with comments on recent classification of Emesinae.

Keywords: Assassin bug, *Guithera*, Leistarchini, *Luteva*, *Proguithera*, thread-legged bug.

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Author contributions: VAI—noted and photographed this bug in live condition, collected / preserved this as specimen and reviewed manuscript. HVG—identified the bug, prepared phtographs of morphology and wrote first draft.

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INTRODUCTION

The subfamily Emesinae Amyot & Serville, 1843 that includes so called 'thread-legged assassin bugs', is one of the most remarkable and species rich subfamilies in the family Reduviidae, as is evident from the list in Catalogue of Reduviidae by Maldonado Capriles (1990). There are six tribes, about 90 genera, and 950 species of Emesinae (Wygodzinsky 1966; Schuh & Weirauch 2020) but new species continue to be discovered all over the globe. Further, as is discussed below, Standring et al. (2023) have considerably revised the classification that was proposed by Wygodzinsky (1966), some of the original tribes have been merged, new tribes added and former subfamily Saicinae is treated as tribe under Emesinae. Obviously, the number of genera and species, now under Emesinae, has also increased.

A single female emesine bug, collected from Vellore (Tamil Nadu, India) when attracted to light, was identified as *Guithera hortensia* Distant, 1906 based on Wygodzinsky (1966) and redescription given by Distant (1910). The original description given by Distant (1906) was also checked. Distant (1910) had synonymized *Lutevula lutea* Breddin, 1909 with *G. hortensia,* a synonymy that was later accepted by Wygodzinsky (1966) who subsequently treated *Lutevula* as a subgenus of *Guithera* and mentioned the species as *Guithera* (*Lutevula*) *hortensia.*

Villiers (1970), while describing new species of Emesinae from caves of Sri Lanka, rediscovered this species from Istripura cave near Hanguranketa (now Hanguranketha) and resurrected *Lutevula* as a genus on the basis of length of fore tarsus and wing venation.

Wygodzinsky (1966) had recognized three subgenera under *Guithera* (namely, *Guithera* Distant, 1906; *Proguithera* Wygodzinsky, 1966; & *Lutevula* Breddin, 1909) but, according to Rédei (2004), all three are treated as valid genera now and of these *Guithera* and *Lutevula* are closer to each other and form *Guithera-Lutevula* group. Recent keys to this group also identify our specimen as *Lutevula hortensia* (see Rédei 2004; Ishikawa & Naka 2016; Chen et al. 2021). In addition, we had a chance to compare our specimen with the images of the type (preserved at Natural History Museum, London), prepared by Dr. Zhuo Chen (China) and this further confirmed the identity of our specimen.

Distant (1906) defined the genus *Guithera* with *Luteva feana* Distant, 1903 as type species (see Distant 1903a,b for original description of *L. feana*) and described two new species from Sri Lanka, namely, *G. hortensia* and *G. nubifera*. The same two species and the characters of the genus *Guithera* were redescribed in Distant (1910). Of these species, *G. nubifera* is now treated as *Stenorhamphus nubiferus* (Distant) under Collartidini (see Wygodzinsky 1966). Distant did not give any illustration of *G. hortensia*, neither in original description nor in subsequent redescription. However, Breddin (1909) had given detailed description of his species *L. lutea* with a drawing of anterior half of body in lateral view – a drawing that matches with image of our specimen given here (see Image 2B). Villiers (1970), who reported the species again, also did not redescribe or illustrate it. Wygodzinsky (1966) illustrated habitus, male genitalia and a few other details of this species, based on holotype of *L. lutea* Breddin, deposited in Deutsches Entomologisches Institut (Müncheberg, Germany).

As the species has been adequately described by Distant (1906, 1910), and a detailed diagnosis of the genus has been given by Wygodzinsky (1966), the purpose of this note is to provide digital images and a brief redescription. It is true that Dispons (1970) listed *Lutevula* as a distinct genus (then under the tribe Orthungini Villiers, 1948 which is now treated as synonym of Leistarchini) but it was Villiers (1970) who categorically stated that *Lutevula* should not be treated as a subgenus of *Guithera* but must be resurrected as a valid genus.

Taxonomy

Heteroptera, Reduviidae, Emesinae, Leistarchini:

Genus *Lutevula* Breddin, 1909 (type species *Lutevula lutea* Breddin); (Distant 1910: 176 as synonym of *Guithera*); (Wygodzinsky 1966: 128 as subgenus of *Guithera*); (Dispons 1970: 220 tabulated); (Maldonado Capriles 1990: 101 Catalogued); (Rédei 2004: 308); (Ishikawa & Naka 2016: 188); (Chen et al. 2021: 355)

Lutevula hortensia

Guithera hortensia Distant (1906: 364); Distant (1910: 177).

Lutevula lutea Breddin: (1909: 303). Synonymized by Distant (1910: 177)

Guithera (Lutevula) hortensia: Wygodzinsky (1966: 127,128)

Lutevula hortensia**:** Villiers (1970: 325); Maldonado Capriles (1990: 103).

Lutevula hortensia**:** Rédei (2004: 314 in key)

Lutevula hortensia**:** Ishikawa & Naka (2016: 191 in key)

Lutevula hortensia**:** Chen et al. (2021: 362 in key)

MATERIALS AND METHODS

Methods of study, photography and measurement follow earlier work (Ranade & Ghate 2023).

Material examined: one female, attracted to light. The specimen was photographed and collected from the campus of the Christian Medical College, Bagayam, Vellore, Tamil Nadu (Latitude 12.876186 and Longitude 79.130975) INDIA; collector Dr. Vijay Anand Ismavel; date: 6.x.2023.

Measurements (in mm): Total length—8 | dorsally head length—1.15 | head width including eyes—0.75 | interocular width—0.40 | laterally anteocular length—0.50 | postocular—0.18 | eye diameter—0.42 | antenna total length—11.50 | I antennomere—5 | II—3 | III+ IV—3.5 | labium I visible segment— 0.9, II—0.75, III—1.25 | pronotum dorso-median total length—1.45 | anterior lobe—0.63 | posterior lobe—0.83 | pronotal width at humerus—1.30 | width at anterior angles—1.0 | forewing length—5.25 | fore leg coxa—2.0 | femur—3.0 | tibia—1.4 | tarsus—1.1 | mid leg coxa—0.5 | femur—5.5 | tibia—8.0 | tarsus + claw—0.3 | hind leg coxa—0.5 | femur—7.5 | tibia—11.5 | tarsus+claw—0.3 | abdomen—3.5

Brief redescription of female

Medium sized thread-legged bug. Overall colour brown, some parts dark brown to blackish. Head brown, eyes black, labium with visible first two segments light brown while third segment dark brown laterally; antennae with first two antennomeres dark brown while third and fourth pale, with indistinct boundary between them. Anterior lobe of pronotum pale brown dorsally as well as ventrally; posterior lobe dark brown to black dorsally in posterior one third part; scutellum blackish; narrow basal part of forewing and nearly half of posterior part fuscous, in-between area pale. Fore legs brown, tibia and tarsus darker than femur; mid and hind legs almost uniformly pale brown. Abdomen partly fuscous to dark brown in posterior half, especially laterally, remaining part brown, as illustrated here with live and preserved bug (Image 1A–D). All body covered with fine, yellowish, adpressed setae which are slightly denser on ventral side, especially genital region.

Head fusiform, clypeus elevated, anteocular narrowed anteriad and longer than postocular, postocular region semi-globose dorsally as well as ventrally; transverse dorsal sulcus or interocular furrow indistinct, shallow, situated near posterior border of eye; eyes large, vertically elliptical. Antennae inserted at anterior end of head, longer than body, first antennomere longest, first and second antennomeres thicker than remaining two antennomeres. Labium straight, moderately thick, bent under head, first two visible segments subequal, third visible longest (Image 2A).

Pronotum saddle like, nearly covering mesonotum except for small basal region, with deep transverse depression marking anterior and posterior lobes; anterior lobe convex dorsally, somewhat smooth and shining, with distinct median longitudinal sulcus, slightly shorter than posterior lobe when measured dorso-medially; posterior lobe dull, rugulose punctate, especially in posterior dark area, with one small, rounded bulging or nodule on each side laterally, just behind transverse depression (Image 2B, C). Prosternum depressed, flattish, its posterior margin rounded; meso- and metasternum slightly gibbous, with carina in between, this carina partly extends behind on to metasternum (Image 2D).

Forewings broad, just passing tip of abdomen (Image 2G). Hind wings very transparent, venation very difficult to discern except under very weak light.

Fore legs stout, fore coxa slightly shorter than femur, femur with usual anteroventral and posteroventral series of spiniferous setae as well as one accessory discal row of short black denticles (Image 2E,F). Tibia and tarsus together shorter than femur; tarsus one segmented, claw tiny. Mid and hind legs typical of emesine bugs, very slender and long, hind femora passing abdominal apex.

Abdomen as broad as thorax at base, broadened in middle but slightly narrowed in genital region. Female genitalia not dissected; in situ view of genitalia in postero-ventral aspect is shown here (Image 2H). Various parts, such as tergite 9, gonocoxae 8 (gcx 8), gonapophysis (gap 8), proctiger (pr) and sternum are labelled; syngonapophysis and other boundaries are not clear due to small size and setae.

DISCUSSION

Emesinae are an interesting group of reduviids that are receiving attention in recent years. In a monograph on Emesinae, Wygodzinsky (1966) recognized six tribes: Collartidini Wygodzinsky, 1966; Leistarchini Stål, 1862; Deliastini Villiers, 1949; Metapterini Stål, 1874, Emesini Amyot & Serville, 1843, and Ploiariolini, Van Duzee, 1916. Very recently, Standring et al. (2023) treated the subfamilies Saicinae Stål, 1859 and Visayanocorinae Miller, 1952 as tribes under Emesinae, based on

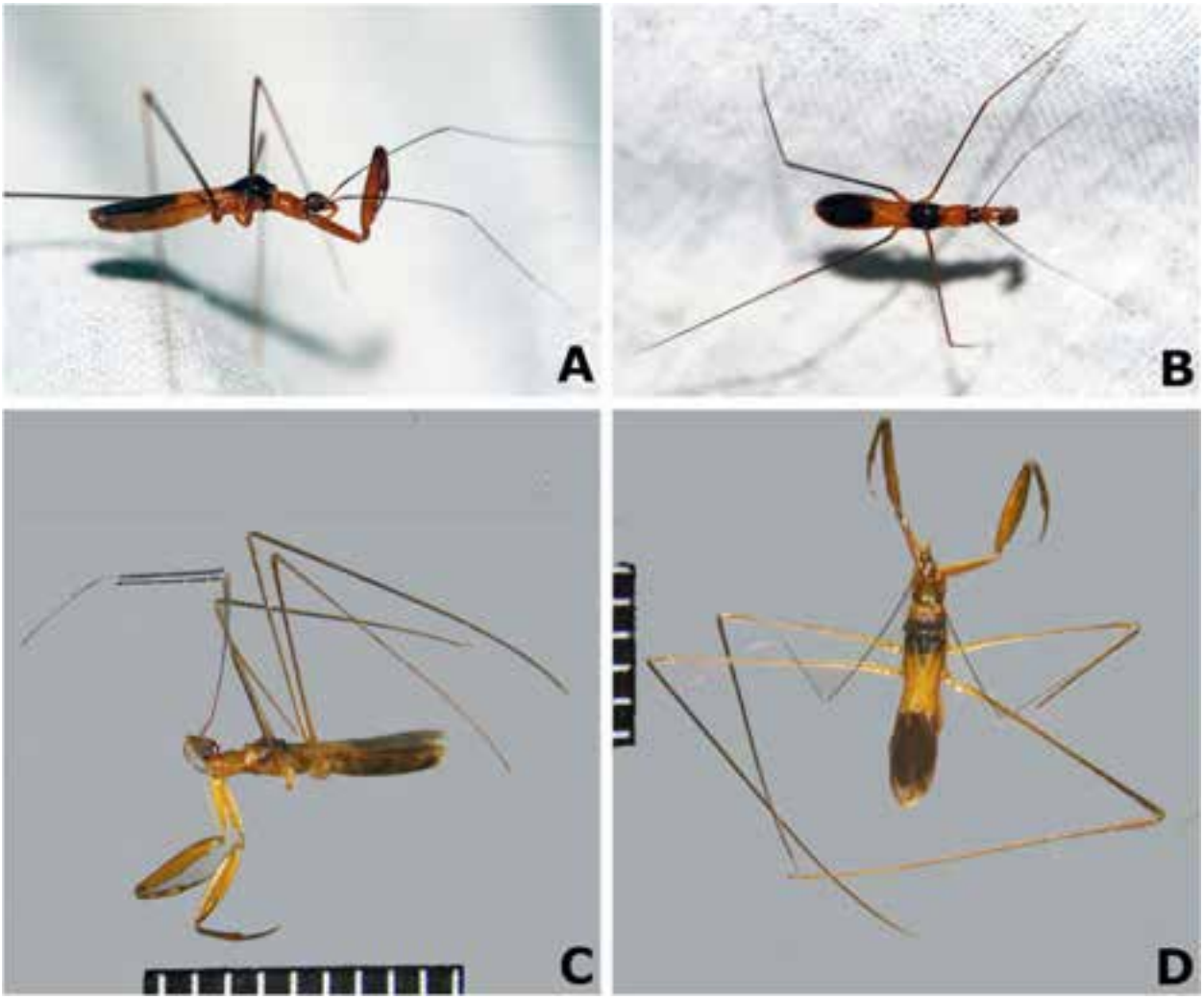

Image 1. *Lutevula hortensia* Distant, female habitus: A & B—lateral and dorsal view of live bug, respectively| C & D—lateral and dorsal view respectively, of preserved specimen. Scale: mm scale. © A & B—Vijay Anand Ismavel | C & D—H.V. Ghate.

extensive work on morphology as well as some marker genes. This so called "Emesine Complex" now is said to include over 1,000 species and the currently recognized tribes under Emesinae are: Collartidini Wygodzinsky, Leistarchini Stål, Visayanocorini Miller, Emesini Amyot & Serville, Oncerotrachelini Standring et al., 2023 and Saicini Stål. Former tribes like Metapterini and Ploiariolini are now treated as synonyms under Emesini. Deliastini were already treated as a junior synonym of Metapterini (see Castro-Huertas et al. 2020; Standring et al. 2023).

As mentioned above, based on comparison of images, our specimen matches exactly with the type and with original description, so there is no doubt about the identity of our specimen. All recent keys cited above also lead to the same species. The nodule or small bulging laterally on posterior lobe of pronotum is also seen in *Guithera feana, Proguithera kiinugama* Ishikawa & Naka, 2016 and *Proguithera caspersi* Chen, Li & Cai, 2021 (see Wygodzinsky 1966; Ishikawa & Naka 2016; Chen et al. 2021). Only the forewing venation was illustrated by Wygodzinsky (1966) for this species and it is also identical, as shown here (see Image 2G). Hindwing is very transparent but its venation, studied under subdued light, appears to be the same as that of *Proguithera caspersi*, as illustrated by Chen et al. (2021). Forewing venation, as illustrated for two species of *Proguithera* (Ishikawa & Naka 2016; Chen et al. 2021), is also not significantly different from that of *L. hortensia*. Female genitalia of *L. hortensia* in situ are similar to that described for *Proguithera drescheri* Wygodzinsky, 1966 (see Wygodzinsky 1966).

Since *Guithera*, *Proguithera*, and *Lutevula* are closely related genera (see Rédei 2004; Ishikawa & Naka 2016;

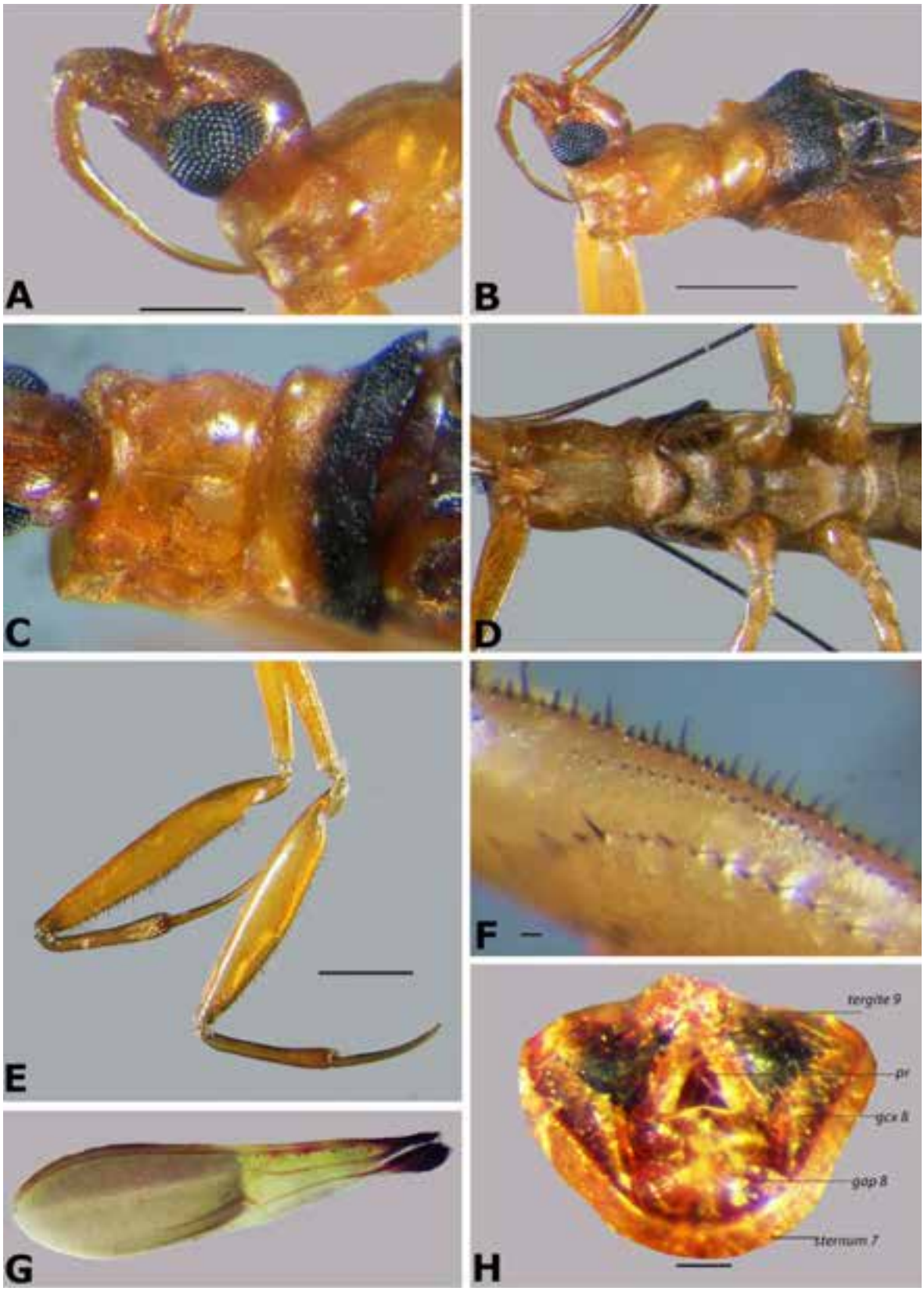

Image 2. ***Lutevula hortensia*** **Distant, female structure: A—head, lateral view, scale bar 0.5 mm | B—head with pronotum, lateral view, scale bar 1 mm | C—pronotum, dorsal view | D—thorax, ventral view | E—fore leg femur, tibia and tarsus, scale bar 1mm | F—fore femur ventral view, scale bar 0.1 mm | G—fore wing, actual size 5.25 mm | H—female terminalia in postero-ventral aspect, scale bar 0.25 mm. Abbreviations: gcx 8 = gonocoxite 8 | gap 8 = gonapophysis 8 | pr = proctiger. © H.V. Ghate.**

Chen et al. 2021), we are providing a list of all known species under these three genera. There are just six species described in about 120 years. The differences in these three genera are very small and characters of the genera not well-defined (see Ishikawa & Naka 2016); for these reasons we feel that Wygodzinsky (1966) was perhaps right in treating these all as subgenera of *Guithera*; additional work involving molecular data is essential to find out their true phylogenetic relationship.

The species *Lutevula hortensia* has not been reported again, for more than 50 years, since the record by Villiers (1970), even from Sri Lanka. For this reason, its presence in India is an interesting find as well as the first report of this genus / species from India.

The earlier checklists of Reduviidae of India (Ambrose 2006; Mukherjee et al. 2020) do not record *Lutevula hortensia* as a species found in India; Ambrose (2006) erroneously lists the species as a synonym under *G. feana*. It must also be noted here that, although the other species *G. feana* is listed by Ambrose (2006) and Mukherjee et al. (2020) as found in India, no definite locality name or reference is provided so it is uncertain if *G. feana* is present within the present Indian territory, as there is no authentic report with details / images of the specimen/s. Thus *L. hortensia* is possibly the only species, from among these three closely related genera, that is so far recorded from India.

It is interesting that *L. hortensia*, another Sri Lankan species, is collected from India after a prolonged gap. Although Sri Lankan faunal elements are regularly noted from India subsequently, for example recent record of an Emesinae bug *Gardena melinarthrum* Dohrn, 1860 from India as well as from Sri Lanka after a long gap (see Hiremath et al. 2022; Ranasinghe & Ghate 2022), lack of surveys and lack of expertise is probably the main reason for delays in recording such occurrences. Emesinae from India are being explored in recent years, as mentioned earlier (Ghate et al. 2019, 2021), and there are still many species that need attention. There are at least four more emsines that will be soon added to the Indian fauna and the list of Indian Emesinae will be updated (H.V. Ghate personal, unpub. data).

List of species under *Guithera*, *Lutevula*, and *Proguithera*

(recent keys are available, as cited above, hence not repeated here)

1. Guithera feana (Distant, 1903) (type locality: MYANMAR : Bhamo)

2. Lutevula hortensia (Distant, 1906) (type locality: SRI LANKA: Peradeniya)

3. Proguithera drescheri Wygodzinsky, 1966 (type locality: INDONESIA: Java, Dreangar, Tangkoeban Prahoe)

4. Proguithera inexpectata Rédei, 2004 (type locality: AFGHANISTAN: Nuristan)

5. Proguithera kiinugama Ishikawa & Naka, 2016 (type locality: JAPAN: The Ryukyus, Ishigaki-jima Is.)

6. Proguithera caspersi Chen, Li & Cai, 2021 (type locality: CHINA, Hainan, Baisha)

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COMMUNICATION

Diversity of mosses (Bryophyta) in Pangi valley (Himachal Pradesh, India): an unexplored domain of northwestern Himalaya

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Abstract: Diversity of mosses of a unique and unexplored geographical location in Himalaya, the Pangi valley in Himachal Pradesh, India is investigated. A total of 49 moss species belonging to 21 families have been recorded, including *Hedwigia emodica*, the detail on the type specimen of which is uncertain and *Encalypta vulgaris*, a rare moss in the Himalaya. In addition, 13 moss species are new records for Himachal Pradesh. The dominant mosses of the surveyed area are *Philonotis* and *Grimmia*, where the latter is frequently found on basic, barren boulders in sunny positions. Among the recorded moss species, 35 are terrestrial, six aquatic, and eight epiphytes. The findings will be useful for forest policies and management of bryophytes conservation in areas which have extreme climatic conditions.

Keywords: Bryophytes, ecosystem, growth forms, hotspots, indicator, macroclimate, patch size, population, richness, taxa.

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Author detail and **Author contribution:** AD is a PhD research scholar. He is currently working on biosystematics aspects of bryophytes. KS and RKS are associate professors and have expertise in bryophyte taxonomy and ecology, respectively. PLU is a senior professor. He has an expertise in biosystematics of bryophytes, pteridophytes, and gymnosperms. All the authors were involved in field trips and moss species collections. AD and PLU confirmed the identity of the specimens. AD photographed the slides sections, wrote the initial draft of the manuscript. KS and RKS were involved in data compilation. PLU edited the entire manuscript and finalized the draft.

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INTRODUCTION

The Himalayan region constitutes one of the biodiversity hotspots of India, which comprises different kinds of forests and ecosystems in the northwestern Himalaya such as tropical, sub-tropical, temperate, sub-alpine, and alpine forests (Hajra & Rao 1990). The environmental factors such as topography, soil, climate, and geographical location influence the diversity of vegetation in forest ecosystem in the Himalaya (Arora 1995). The biodiversity and productivity in a forest are the two most important attributes, which are associated with the proper functioning of a forest ecosystem in the Himalaya (Haq et al. 2021). Any kind of ecological disturbances in the Himalaya can also affect the global climate by bringing changes in the precipitation and temperature (Khan et al. 2012) and hence affect the vegetation. Therefore, the Himalaya are an excellent zone to study about the biogeographical and ecological patterns of vegetation (Körner 2000) and of course to evaluate the diversity and community composition.

The bryophytes constitute a major part of Himalayan flora. The northwestern (NW) Himalaya comprises an enormous bryophyte diversity and composition. Various authors (Chopra & Kumar 1981; Tewari & Pant 1994; Nath et al. 2008; Alam 2013; Sahu & Asthana 2014) have done preliminary studies on the bryoflora of the NW Himalaya. However, there are still many unexplored domains in the Himalayan region which need to be investigated thoroughly so that the bryophyte species diversity and their role can be assessed. The Pangi valley in Chamba district of Himachal Pradesh (India) is one such unexplored part of the NW Himalaya. The area majorly consists of bare granite rocks and experiences harsh winters and cold summers.

The objective of the present study was to assess the moss species diversity in Pangi valley. The study will be helpful in modelling the species-habitat relationship, comparing the species diversity in the disturbed and non-disturbed sites to make better planning for conservation strategies.

MATERIALS AND METHODS

The mosses were collected from the Pangi valley, Himachal Pradesh (India), located at an average elevation of 2,287 m (32.8883^{0}N, 76.4211^{0}E and 32.9266^{0}N, 76.4619^{0}E; Image 1), in the month of June 2022. The area is dominated by conifers which remains dry during most of the year due to little precipitation and a higher snowfall period. The samples were placed in separate bags and the GPS data, their substrate, along with growth forms were noted down. The samples were carefully observed under the microscope (Olympus CX21*i*) and separated from each other to have the pure samples of the species. The mosses were identified based on their growth forms and micromorphological characters along with the help of relevant literatures (Gangulee 1969–1980; Chopra 1975; Anderson 2007). The mosses are classified following Goffinet et al. (2008). Voucher specimens are deposited at the Herbarium DUH, University of Delhi (India).

RESULTS

In the present study, a total of 49 taxa of mosses under 21 families were recorded. Most of the mosses belong to families Pottiaceae, Bartramiaceae, Grimmiaceae, Amblystegiaceae, and Bryaceae. The genera such as *Grimmia* Hedw. and *Philonotis* Brid. were found to be the most dominant in the surveyed area with the maximum number of species. Species of *Grimmia* were found growing on basic and barren substrates in sunny positions in isolated patches. Some populations were encountered on basic sandstone near the river Chenab. The plants survived the winter well under snow and produced high numbers of sporophytes in spring. *Encalypta* Hedw. and *Hedwigia* P.Beauv., represented by few populations, are rare in the area. The record of *Hedwigia emodica* Hampe ex Müll.Hal. is the interesting one. Species of *Philonotis* were found to occur on soil or rock along the banks of streams, rivers in spring and waterfall areas, often in the open. Here, the authors also recorded extended distribution of 13 taxa for Himachal Pradesh (Table 1).

DISCUSSION

The bryodiversity of Himachal Pradesh has been studied or reviewed by various authors (Lal 2005; Singh & Singh 2008; Singh & Singh 2010; Dandotiya et al. 2011; Alam 2013; Pande et al. 2017; Kumar et al. 2022). These investigations provided several new records and interesting findings. However, in terms of moss richness and diversity, there are still many under-explored regions in Himachal Pradesh which require frequent and comprehensive field visits.

The climatic condition of the valley allows the development of mosses that are adapted to these

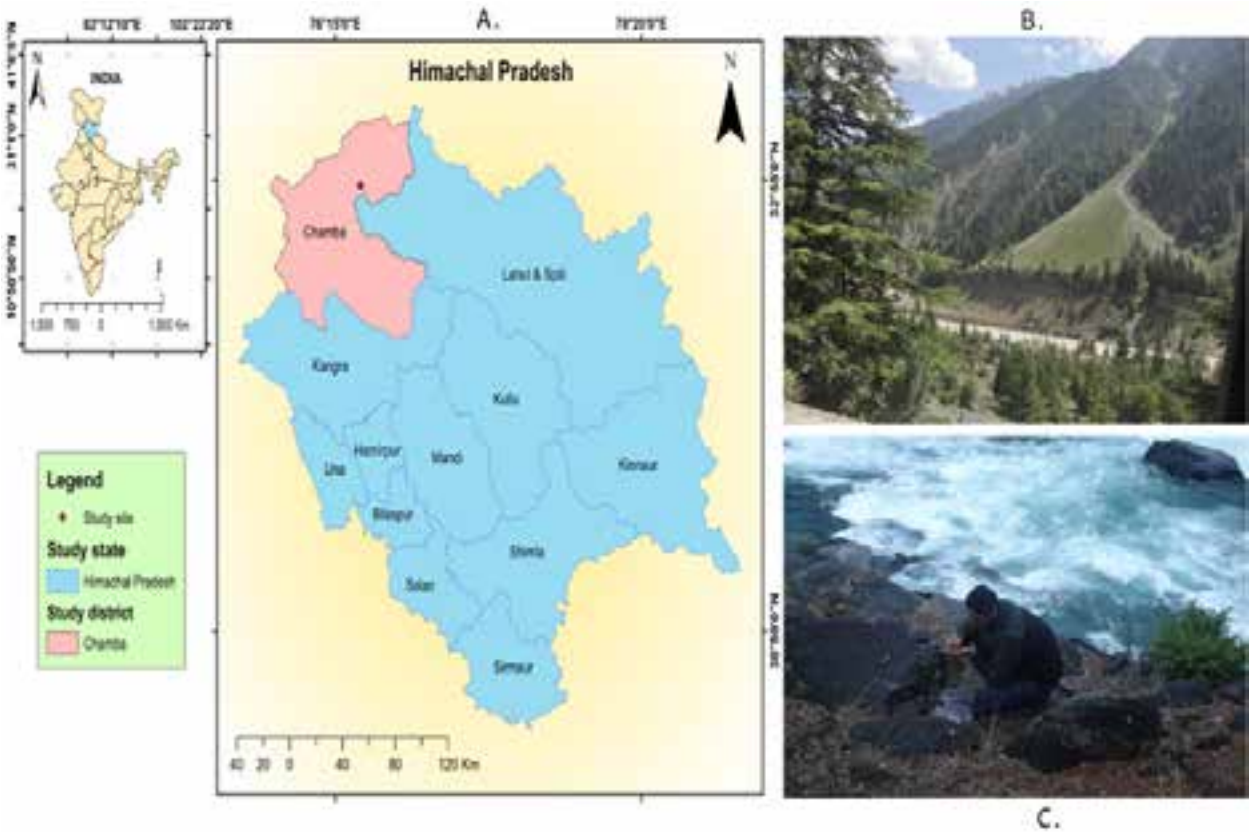

Image 1. A—Map showing the study area | B—Landscape view of the study site | C—Moss collection during study | © Anshul Dhyani & Kumar Shantanu.

climatic extremities. Several adaptive features such as the presence of long hyaline tip and compact growth in Grimmiaceae, presence of chlorophyllose cells in between the hyalocyst cells in Leucobryaceae, and the thick-coarsely papillated, small quadrate surface cells in Pottiaceae (Scott 1982) help these mosses to store water and prevent its loss, enabling these mosses to thrive in harsh and extreme climatic conditions (Image 2 & 3). Other features such as the lanceolate leaves to minimize water loss and optimize light absorption in Grimmiaceae also help in surviving the extreme conditions. In addition, the wax coating on the leaves of Polytrichaceae members prevent them from water loss as well as extreme sunlight and is considered an adaptation. In the family Pottiaceae, several species show leaf curling in response to change in humidity, which is also recognised as an adaptation factor to extreme conditions as well (Geissler 1982). The mat, cushion, turf, weft, and many such forms are also known as adaptation states to the climate. It is interesting to mention that, in *Ptychostomum pseudotriquetrum* (Hedw.) J.R.Spence & H.P.Ramsay ex Holyoak & N.Pedersen, there is production of UV-B absorbing anthocyanin pigments that check the physiological activities of the moss under extreme cold or desiccation (Dunn & Robinson 2006; Glime 2017).

A total of six species of *Encalypta* are known to occur in the northwestern Himalayan region of India, with *E. vulgaris* the only species reported from Spiti valley and Kangra in Himachal Pradesh previously (Chopra 1975). We found only few small patches of *E. vulgaris* in the studied area and one patch with a length of ca. 15 cm. which showed relatively less abundance as compared to the other reported moss taxa. The genus *Encalypta* seems to require a specific habitat condition, i.e., restricted to limestones particularly found growing in the microsites such as on exposed dry rock crevices and on ledges wedged among stones. The genus is easily distinguished by its large plate-like red perigonia which was established in the large patches along with the other herbaceous plants. Moreover, it harbours many small aquatic animals.

Only three species of *Hedwigia* have been reported from the Himalaya, viz., *H. ciliata* (Hedw.) Boucher, *H. stellata* Hedenäs, and *H. emodica* (Dalton et al. 2013). The major distinguishing characters of *H. emodica* from other species of its relatives are the presence

Table 1. Table showing the list of reported bryophyte taxa along with new records, growth form, patch size and families (Classification follows Goffinet et al. 2008).

Taxon	Substratum	Moss patch size	Growth form	Family	Voucher number
1. *Anacolia menziesii* (Turner) Paris†	Rock	Small	Open tuft	Bartramiaceae	DUH15324
2. *Anoectangium stracheyanum* Mitt.	Rock	Small	Dense tuft	Pottiaceae	DUH15325
3. *Brachythecium kamounense* (Harv.) A.Jaeger	Soil, Rock	Small	Mat	Brachytheciaceae	DUH15415
4. *Bryoerythrophyllum recurvirostrum* (Hedw.) P.C.Chen	Rock	Medium	Tuft	Pottiaceae	DUH15326
5. *Bryum argenteum* Hedw.	Open soil	Small	Mat	Bryaceae	DUH15291
6. *B. kashmirense* Broth.	Rock	Small	Thin mat, Julaceous	Bryaceae	DUH15327
7. *Chionoloma tenuirostre* (Hook. & Taylor) M.Alonso, M.J.Cano & J.A.Jiménez	Wet rocks	Small	Tuft	Pottiaceae	DUH15328
8. *Cratoneuron filicinum* (Hedw.) Spruce	Near waterfall	Small	Tuft	Amblystegiaceae	DUH15239
9. *Cynodontium polycarpon* (Hedw.) Schimp. †	Open rock	Small	Tuft	Dicranaceae	DUH15330
10. *Didymodon hastatus* (Mitt.) R.H.Zander	Calcium rock	Small	Tuft	Pottiaceae	DUH15331
11. *Encalypta vulgaris* Hedw.	Rock	Large	Cushion	Encalyptaceae	DUH15332
12. *Entodon luteonitens* Renauld & Cardot†	Forest floor	Small	Tuft	Entodontaceae	DUH15333
13. *Fissidens grandifrons* Brid.	Waterfall	Small	Mat/ Tuft	Fissidentaceae	DUH15335
14. *F. taxifolius* Hedw.	Dry Soil	Small	Tuft	Fissidentaceae	DUH15336
15. *Grimmia donniana* Sm.	Rock	Small	Cushion	Grimmiaceae	DUH15337
16. *G. elongata* Kaulf. †	Rock	Small	Cushion	Grimmiaceae	DUH15338
17. *G. funalis* (Schwägr.) Bruch & Schimp.	Calcium wet rock	Medium	Cushion	Grimmiaceae	DUH15306
18. *G. fuscolutea* Hook.	Rock	Medium	Cushion, mat	Grimmiaceae	DUH15339
19. *Haplocladium schimperi* Thér.	Tree base, Rock	Small	Mat	Leskeaceae	DUH15292
20. *Hedwigia emodica* Hampe ex Müll. Hal. †	Tree bark	Small	Tuft	Burseraceae	DUH15340
21. *Hygroamblystegium tenax* (Hedw.) Jenn.	Rock and Walls	Small	Tuft	Pottiaceae	DUH15341
22. *Hymentostylium recurvirostrum* (Hedw.) Dixon	Rock	Medium	Tuft/ Cushion	Pottiaceae	DUH15342
23. *Hypnum cupressiforme* (Hedw.)	Forest floor	Small	Mat	Hypnaceae	DUH15343
24. *Lescuraea incurvata* (Hedw.) E.Lawton	Dry Rocks	Small	Mat	Leskeaceae	DUH15344
25. *Leucodon secundus* (Harv.) Mitt.	Tree bark	Medium	Tuft	Leucodontaceae	DUH15424
26. *L. sinensis* Thér.†	Tree bark	Medium	Tuft/ Mat	Leucodontaceae	DUH15345
27. *Lewinskya speciosa* (Nees) F. Lara, Garilleti & Goffinet†	Tree branches	Small	Tuft	Orthotrichaceae	DUH15346
28. *Orthotrichum erubescens* Müll. Hal. †	Tree branches	Medium	Cushion	Orthotrichaceae	DUH15347
29. *Oxyrrhynchium hians* (Hedw.) Loeske	Waterfall	Medium	Tuft	Brachytheciaceae	DUH15348
30. *Palustriella decipiens* (De Not.) Ochyra†	Waterfall	Small	Tuft	Amblystegiaceae	DUH15349
31. *Philonotis bartramioides* (Griff.) D.G.Griffin & W.R.Buck	Calcium wet rock	Large	Tuft/ Cushion	Bartramiaceae	DUH15350
32. *P. leptocarpa* (Mitt.) †	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15352
33. *P. mollis* (Dozy & Molk.) Mitt. †	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15353
34. *P. roylei* (Hook.f.) Mitt.	Calcium wet rock	Medium	Tuft/ Cushion	Bartramiaceae	DUH15354
35. *P. turneriana* (Schwägr.) Mitt.	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15355
36. *Plagiothecium cavifolium* (Brid.) Z.Iwats.	Tree base	Small	Mat	Plagiotheciaceae	DUH15314
37. *Pseudoleskeopsis zippelii* (Dozy & Molk.) Broth. †	Rock	Small	Mat	Leskeaceae	DUH15356
38. *Ptychomitrium tortula* (Harv.) A.Jaeger	Tree bark	Small	Tuft	Ptychomitriaceae	DUH15316

Taxon	Substratum	Moss patch size	Growth form	Family	Voucher number
39. *Ptychostomum pseudotriquetrum* (Hedw.) J.R.Spence & H.P.Ramsay ex Holyoak & N.Pedersen	Open Rock	Medium	Tuft	Bryaceae	DUH15357
40. *Reimersia inconspicua* (Griff.) P.C.Chen	Rock, Soil	Small	Tuft	Pottiaceae	DUH15358
41. *Rhynchostegium planiusculum* (Mitt.) A.Jaeger	Forest floor	Small	Tuft	Brachytheciaceae	DUH15359
42. *R. riparioides* (Hedw.) Cardot	Waterfall	Small	Tuft	Brachytheciaceae	DUH15360
43. *Rosulabryum capillare* (Hedw.) J.R.Spence	Open soil	Small	Tuft	Bryaceae	DUH15361
44. *Sarmentypnum exannulatum* (Schimp.) Hedenäs	Near waterfall	Small	Mat/ Cushion	Calliergonaceae	DUH15362
45. *Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr.	Open dry soil	Small	Tuft	Pottiaceae	DUH15365
46. *Symphysodontella tortifolia* Dixon†	Rock	Small	Tuft	Pterobryaceae	DUH15363
47. *Syrrhopodon armatus* (Schwägr.)	Soil	Medium	Tuft	Calymperaceae	DUH15317
48. *Thuidium assimile* (Mitt.) A.Jaeger	Forest floor	Medium	Tuft	Thuidiaceae	DUH15364
49. *Tortella tortuosa* (Schrad. ex Hedw.) Limpr.	Dry rocks	Small	Tuft	Pottiaceae	DUH15366

†—New records to Himachal Pradesh | Moss Patch Size: Small = 0–3 cm, Medium = 3–8 cm, Large = < 8 cm

Image 2. Section photographs of some recorded mosses: a—*Sarmentypnum exannulatum* | b—*Encalypta vulgaris* | c—*Entodon luteonitens* | d—*Oxyrrhynchium hians* | e—*Grimmia fuscolutea* | f—*G. funalis* | g—*G. donniana*, h. *Fissidens taxifolius* | i—*Haplocladium schimperi* | j—*Hedwigia emodica* | k—*Hypnum cupressiforme* | l—*Leucodon sinensis* | m—*Orthotrichum griffithii* | n—*Rhynchostegium planiusculum* | o—*Syntrichia ruralis* | p—*Ptychostomum pseudotriquetrum*. © Anshul Dhyani.

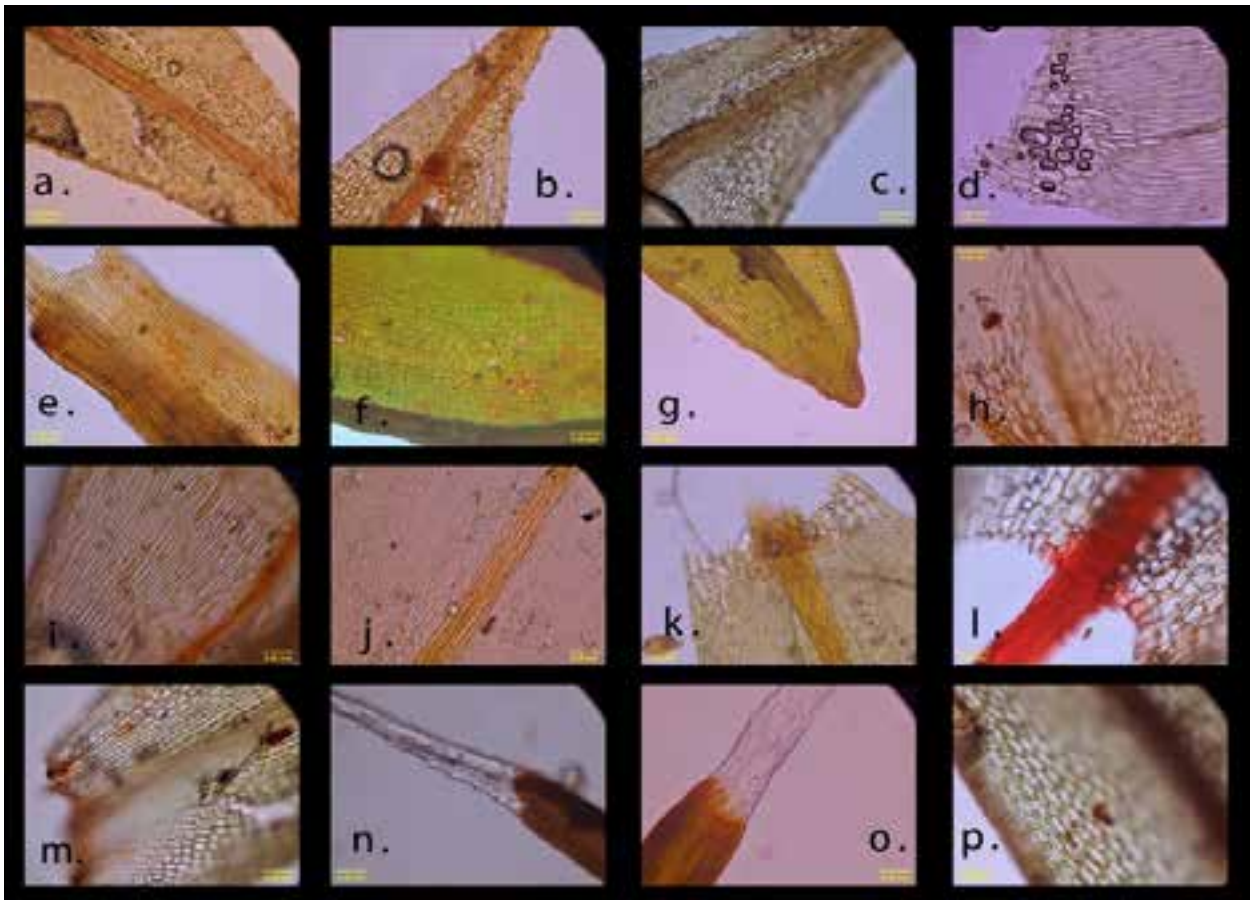

Image 3. Variations in leaf cell types in upper, middle, and basal leaf regions in different moss taxa: a—*Anacolia menziesii* | b—*Philonotis bartramioides* | c—*P. roylei* | d—Differentiated alar cells of *Brachythecium kamounense* | e—Basal leaf cells of *Grimmia fuscolutea* | f—Multipapillose quadrate cells in *Encalypta vulgaris* | g—Apical leaf cells of *Cynodontium polycarpon* | h—Apical rhombic cells of *Bryum argenteum* | i—Basal cells of *B. kashmirense* | j—Middle leaf cells of *Palustriella decipiens* | k—Basal cells and differentiated alar cells of *Cratoneuron filicianum* | l—Basal cells of *Bryum capillare* | m—Basal cells of *Hymenostylium recurvirostrum* | n—Hyaline tip of *G. donniana* | o—Hyaline tip of *G. funalis* | p—Middle leaf cells along with marginal cells of *Ptychostomum pseudotriquetrum*. © Anshul Dhyani.

of a long, hyaline tip which covers ca. 20–40% of leaf length; abaxial papillae which varies from branched to stellate and leaf margin either recurved on lower half or plane. *H. ciliata* has been previously reported from Himachal Pradesh and Uttarakhand (Asthana & Sahu 2014). *H. stellata* has been reported from Kashmir and the distribution of *H. emodica* was previously found in Jammu & Kashmir (Dalton et al. 2013). The presence of *H. emodica* in Himachal Pradesh, therefore, implies the range extension of this taxon. Present populations were found growing on sand rocks, boulders, and creeks as well as the lower trunks of *Cedrus* trees. It appears that *Hedwigia* prefers to grow on acidic substratum.

Bryophyte distribution is affected by the macroclimatic conditions, including precipitation and temperature. However, moisture is considered as an important growth stimulator more than any other factor for bryophyte productivity (Skre & Oechel 1981; Porley & Hodgetts 2005). The dominance of families such as Pottiaceae and Grimmiaceae, generally growing in exposed sites on granite-mica rocks, indicate that the area has harsh and extreme climatic conditions. Wide distribution of members of Bartramiaceae shows presence of calcareous substrata (Tewari & Pant 1994). The average bryophyte cover was higher in exposed sites and under coniferous forest patch, and thus considered as important ground cover in the area. The area is dominated by the acrocarpous turfs and cushion forming mosses in comparison to the pleurocarpous mosses. A deep bryophyte layer thickness is commonly associated with species groups that often have large cover, which therefore, produce a high biomass (Sun et al. 2013). This area harbours rich plant diversity. Less population, low developmental activities, and remote location of the area gives the opportunity to have the high regeneration rate of the species. Moreover, the harsh

environmental conditions stimulate the adaptations in the species, hence the species occurring in the area remain unique. It is important to understand the plant communities, especially of lower plant groups, of such sites for comparative study and distribution modelling in future. There is an abundance of rocky bulges and depressions, which provide refuge to species with morphological adaptations to stressful climates and to rare communities of plants, including bryophytes.

The existence of 21 distinct families in this region serves as a clear indication of the considerable diversity in terms of bryophyte richness and composition. This underscores the importance of conducting expeditions in the surrounding areas to compile a cumulative checklist. Such an endeavour will contribute to the formulation of effective policy management and conservation approaches. Although the area is remote, but the small hydroelectric units and camps on ground may make the habitat vulnerable. These anthropogenic disturbances may pose a threat to the survival of many different moss taxa. Poor dispersal range of bryophytes not only limits the population recruitment but also leads to conservation implications. The niche specificity and the role of associated species together with genetic diversity need to be studied further.

CONCLUSIONS

Bryophytes constitute an important component of the ecosystem and contribute a significant portion of species richness and biomass as well as ground cover. Although, they play a significant role in ecosystem functioning yet they receive less attention in biodiversity mapping. These interesting groups of plants are very sensitive to environmental perturbation and fairly used as indicator species. The present study revealed the species diversity of mosses in Pangi Valley (Himachal Pradesh, India) which will help in forest policies and management to conserve the biodiversity of the area. The developmental projects in the area may cause destruction of habitats of these mosses and thus can be a potential threat to their survival. Therefore, efficient and sustainable forest practices should be adopted to safeguard this economically important plant group.

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COMMUNICATION

Morphological characterization and distribution of four corticioid fungi species (Basidiomycota) in India

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Abstract: During the fungal forays conducted in Kullu district of Himachal Pradesh (India) several specimens of corticioid fungi were collected. Based on morphological characterization, these fungi have been identified as *Aphanobasidium pseudotsugae*, *Cytidiella albida*, *C. nitidula*, and *Phlebia viridesalebrosum*. These four species are new additions to the Indian mycobiota.

Keywords: Agaricomycetes, Agaricales, Basidiomycota, coniferous trees, Himachal Pradesh, mycelium, northwestern Himalaya, Polyporales, white rot, wood rotting fungi.

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Author details: Ms. Tanya Joshi is currently working as CSIR-UGC JRF in the Department of Botany, Punjabi University, Patiala. She has worked on the topic "Taxonomic studies on some corticioid fungi from Kullu district (Himachal Pradesh)" during her M.Sc. (Hons. in Botany) dissertation work. She has described 15 species of the corticioid fungi including four new records for India. Dr. Ellu Ram is presently working as assistant professor in Department of Botany, Government College, Seraj, Lambatyach, Mandi (Himachal Pradesh). He has worked on the topic "Mycofloristic studies on corticioid and poroid fungi of district Kullu (Himachal Pradesh) for his Ph.D. research work. He has thoroughly surveyed district Kullu for the collections of these fungi described 136 taxa of corticioid and poroid fungi from the study area including 36 new records for India. Ms. Avneet Kaur has recently completed her Ph.D. research work on the systematic studies on polyporoid fungi from Punjab and evaluation of selected species for anticancer activity. She has worked on the diversity of polyporoid fungi and has special interest in antioxidant and anticancer activity of medicinally important polyporoid fungi. She has described more than 50 taxa of polyporoid fungi from different parts of India. Dr. Avneet Pal Singh is working as assistant professor in the Department of Botany, Punjabi University, Patiala. His area of specialization is taxonomy, histo-pathology and evaluation of wood rotting corticioid and poroid fungi (Agaricomycetes, Basidiomycota). He actively engaged in the research work for more than two decades and has described more than 300 taxa of these fungi based on morphological and DNA sequence based molecular phylogenetic studies. He has described two new genera and 22 new species of corticioid and poroid fungi.

Author contributions: TJ—has worked out macro and micro-morphological details of the corticioid specimens collected from different parts of Kullu district of Himachal Pradesh. She has compiled the technical description and line diagrams of the new records described presently. ER—has thoroughly surveyed the area of investigation and collected the basidiocarp specimens of the species being described in the present manuscript. He has significantly contributed in working out the macro and micro-morphological details and preparation of taxonomic description and plates for identification. AK—has cririically analyzed the morphological details of the specimens and contributed to the comparison and identification of these four new records of corticioid fungi. She has also contributed in drafting the manuscript. APS—has explored the taxonomic literature for identity of the worked out specimens. He has also contributed to the draft of manuscript and photography of the specimens described presently.

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INTRODUCTION

Corticioid fungi are a heterogenous conglomeration featuring customarily resupinate basidiocarps that are generally adnate or have reflexed-effused margins. These basidiocarps range from soft to hard, crystalline to amorphous and may occur either on gymnospermous or angiospermous wood. The configuration of the hymenophore is diversified in exhibiting smooth, tuberculate, ceraceous, grandinioid, odontoid, corneous, strigose, and sometimes velutinous surface. Microscopically, the basidiocarps are mainly composed of generative or sclerified hyphae.

As per the traditional morphotaxonomic studies, majority of the corticioid fungi were placed in the family Thelephoraceae of the order Aphyllophorales (Rea 1922). However, the modern molecular phylogenetic studies proved this group as a polyphyletic artificial assemblage. Based on these molecular studies, the corticioids are presently assigned to the class Agaricomycetes, belonging to sub-phylum Agaricomycotina of phylum Basidiomycota. Further, these are classified under the orders Agaricales, Atheliales, and Boletales of sub-class Agaricomycetidae; and the orders Auriculariales, Cantharellales, Corticiales, Gloeophyllales, Hymenochaetales, Polyporales, Russulales, Sebacinales, Thelophorales, and Treschisporales clustered under Agaricomycetes incertae sedis (Wijayawardene et al. 2020; Mycobank 2023).

Contributing vitally towards the ecological services, these fungi are known for their wood degrading nature and bioremediation of soil, thus nurturing forest ecosystem through mineral recycling (Pointing 2001). Among the wood rotting fungi, the white rot fungi decay lignin and are considered as good soil litter fungi (Yurchenko 2006).

Kullu district of Himachal Pradesh is bestowed with the forests of deodar, towering above the trees of pine and sprawling orchards. The valley of Kullu is sandwiched between the Pir Panjal, lower Himalaya, and the Great Himalayan ranges. The different localities situated in Banjar subdivision of the study area were surveyed during the rainy season of years 2015–2017 for the collection of corticioid fungi specimens. These specimens were studied for their macro- and micro-morphological features and were identified as *Aphanobasidium pseudotsugae* (Burt) Boidin & Gilles (Agaricales, Radulomycetaceae), *Cytidiella albida* (Berk. & M.A.Curtis) Zmitr. (Polyporales, Meruliaceae), *C. nitidula* (P.Karst.) Ryvarden (Polyporales, Meruliaceae), and *Phlebia viridesalebrosum* J.Erikss. & Hjortstam (Polyporales, Meruliaceae). These four species of the corticioid fungi are new additions to the Indian mycobiota.

MATERIAL AND METHODS

The fungal material was carefully removed from the substrate (surface of logs, stumps, branches, and twigs) with the help of a chisel and hammer or a sharp knife. The features like the nature of the basidiocarp, colour, and type of hymenial surface, and colour and type of margins were noted down carefully in the field. The data with reference to the name of the substrate, locality, type of forest, and date of the collection were also recorded. The fresh specimens were then photographed to compare the change upon drying, if any. Details of various microscopic features such as hyphal system, cystidia, basidia, and basidiospores and their reactions in reagents such as Melzer's reagent, cotton blue, and sulphovanillin were also checked and noted by making crush mounts from the fresh specimens.

The microscopic studies were made by preparing crush mounts and free hand section cut sections in 3%/5%/10% KOH solution, 1% Congo red in distilled water and 1% Phloxine in distilled water. These preparations were used to study the details of hyphae, cycstidia, basidia, and basidiospores at different magnifications of a light microscope. The cyanophilous and amyloid reactions were checked in 1% cotton blue in lactophenol, and Melzer's reagent (0.5 g iodine, 1.5 g potassium iodide, 20 g chloral hydrate, and 20 ml distilled water). The outline of microscopic structures was drawn using the camera lucida at the magnifications mentioned above. The standard features were subjected to the taxonomic keys published in the monographs and other publications (Eriksson et al. 1981; Dhingra 2005; Bernicchia & Gorjón 2010; Chen et al. 2021) for identifying the collected specimens.

All the identified specimens were deposited at the herbarium of the Department of Botany, Punjabi University, Patiala which is internationally recognized with the standard abbreviation PUN. The colour standards used were as per Methuen's Handbook of Colours by Kornerup & Wanscher (1978).

RESULTS

Aphanobasidium pseudotsugae (Burt) Boidin & Gilles Cryptogamic Botany 1(1): 75 (1989).

- *Corticium pseudotsugae* Burt, Annals of the Missouri Botanical Garden 13(3): 246 (1926). (Image 1).

Description: Basidiocarp resupinate, adnate, effused, somewhat ceraceous, up to 120 µm thick in section; hymenial surface smooth to slightly tuberculate; orange white (6A2) when fresh, darkened on drying; margins concolourous to indeterminate.

Hyphal system monomitic; generative hyphae up to 4 µm wide, septate, clamped, ampullate, branched, thin- to thick-walled; horizontal, loosely arranged, less branched, thick-walled in subicular zone; vertical, compact, richly branched, thin-walled in the subhymenial zone. Cystidia absent**.** Basidia cylindrical, plural, 19.5–33.5 × 5.5–8 µm, tetrasterigmate, basally clamped; sterigmata up to 5.2 µm long. Basidiospores subfusiform to subamygdaliform, 8–9.5 × 3.5–4.5 µm, smooth, thin-walled, inamyloid, acyanophilous.

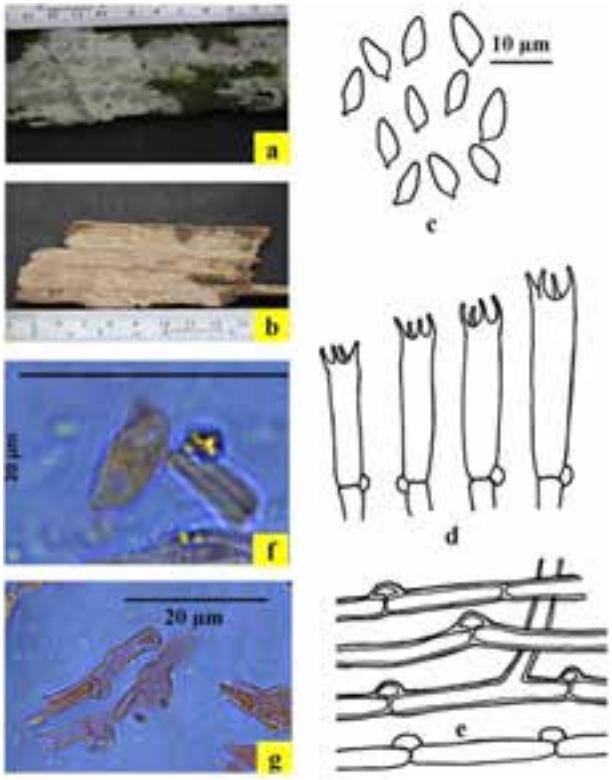

Image 1. *Aphanobasidium pseudotsugae*: a—Basidiocarp showing hyemenial surface (fresh) | b— Basidiocarp showing hymenial surface (dry) | c–e— Line diagrams showing the outline of basidiospores (c.), basidia (d) and generative hyphae (e) | f–g— Photomicrographs showing basidiospore (f) and generative hyphae (g). © a—Ellu Ram, b-g—Tanya Joshi.

Collection examined: India, Himachal Pradesh, Kullu, Banjar, 1 Km from Jalori Pass towards Shoja, on the log of *Abies spectabilis*, Ellu 11372 (PUN), 3 September 2016.

Remarks: *Aphanobasidium pseudotsugae* is marked by ceraceous basidiocarps, clamped, ampullate generative hyphae and distinctive subfusiform to subamygdaliform basidiospores. The only other species of genus *Aphanobasidium*, i.e., *A. subnitens*, differs in having basidia with bifurcated base and obovate to broadly oblong-ellipsoidal basidiospores (Mycobank 2023). It is a new report to India and has been earlier recorded from Germany, Estonia, Czech Republic, Belarus, Belgium, United Kingdom, Sweden, Denmark, Norway, Switzerland, Finland, Italy, Spain and Netherlands by Bernicchia and Gorjón (2010) and Mycobank (2023).

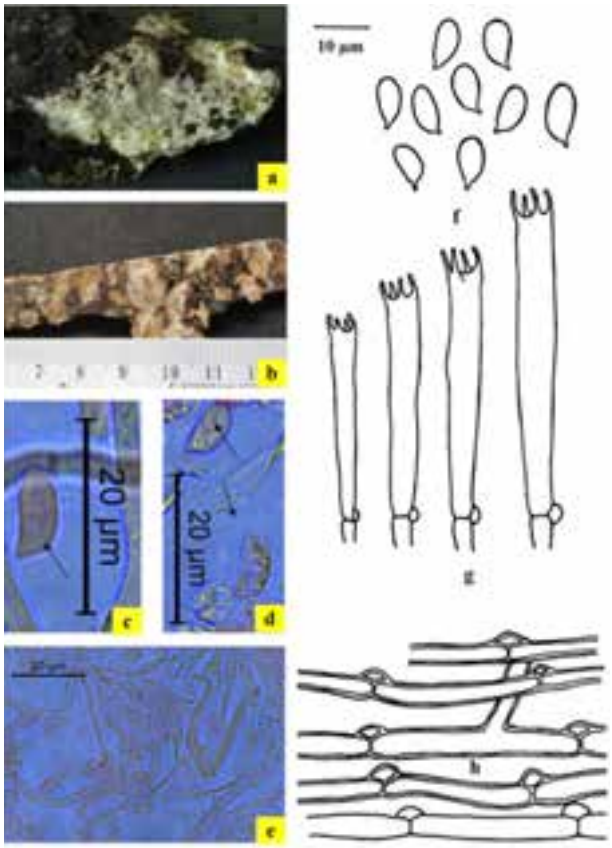

Image 2. *Cytidiella albida*: a—Basidiocarp showing hyemenial surface (fresh) | b— Basidiocarp showing hymenial surface (dry) | c–e— Photomicrographs showing basidiospores (c–d) and generative hyphae (e) | f–h— Line diagrams showing the outline of basidiospores (f), basidia (g), and generative hyphae (h). Image 2. Cytidiella albida a. Basidiocarp showing hyemenial surface (fresh) | b— Basidiocarp showing hymenial surface (dry) | c–e— Photomicrographs showing basidiospores (c–d) and generative hyphae (e) | f–h— Line diagrams showing the outline of basidiospores (f), basidia (g), and generative hyphae (h). © a—Avneet Pal Singh | b-h—Tanya Joshi.

Table 1. Diversity of the genus *Phlebia* in India.

	Current name of the taxon	Earlier described as	Localities	Records
1.	*Phlebia brevibasidia*	*P. brevibasidia*	Punjab	Kaur 2017
2.	*P. centrifuga*	*P. centrifuga*	Uttarakhand	Sharma 2012; Sanyal 2014; Manoharachary et al. 2022
			Himachal Pradesh	Ritu 2019
3.	*P. coccineofulva*	*P. coccineofulva*	Himachal Pradesh	Kaur 2018
4.	*P. crassisubiculata*	*P. crassisubiculata*	Himachal Pradesh	Dhingra et al. 2014
5.	*P. cremeoalutacea*	*P. cremeoalutacea*	Himachal Pradesh	Singh 2007; Priyanka 2012; Kaur 2018
			Jammu & Kashmir	Sharma 2017
6.	*P. cretacea*	*P. cretacea*	Uttarakhand	Sharma 2012
7.	*P. deflectens*	*Phanerochaete deflectens*	Himachal Pradesh	Dhingra et al. 2014; Kaur 2018; Kaur 2020
8.	*P. griseolivens*	*P. griseolivens*	Tamil Nadu	Natarajan & Kolandavelu 1998
9.	*P. himalaica*	*P. himalaica*	Himachal Pradesh	Thind & Rattan 1973
			Uttarakhand	Sharma 2012
10.	*P. kamengii*	*P. kamengii*	Eastern Himalaya	Dhingra 2005; Dhingra et al. 2011
			Himachal Pradesh	Poonam 2020
11.	*P. lilascens*	*P. lilascens*	Uttarakhand	Sanyal 2014
			Himachal Pradesh	Kaur 2018; Poonam 2020
12.	*P. livida*	*P. livida*	Himachal Pradesh	Thind & Rattan 1973; Rattan 1977; Dhingra et al. 2014; Ritu 2019; Poonam 2020; Manoharachary et al. 2022
			Eastern Himalaya	Dhingra 2005; Dhingra et al. 2011
			Uttarakhand	Sharma 2012; Sanyal 2014; Manoharachary et al. 2022
			Jammu & Kashmir	Sharma 2017
13.	*P. microspora*	*P. microspora*	Eastern Himalaya	Dhingra 2005; Dhingra et al. 2011
			West Bengal	Manoharachary et al. 2022
14.	*P. ochraceofulva*	*Mycoacia subochrceae*	Himachal Pradesh	Rattan 1977
		P. subochracea	Uttarakhand	Sharma 2012
			Himachal Pradesh	Sharma 2012
		P. ochraceofulva	Himachal Pradesh	Dhingra et al. 2014; Ritu 2019; Poonam 2020; Manoharachary et al. 2022
15.	*P. queletii*	*Metulodontia queletii*	Himachal Pradesh	Rattan 1977; Dhingra et al. 2006; Ritu 2019
		P. queletii	Himachal Pradesh	Dhingra et al. 2006; Dhingra et al. 2014; Lal Ji 2003; Kaur 2018; Poonam 2020; Kaur 2020; Manoharachary et al. 2022
			Uttarakhand	Sharma 2012; Sanyal 2014; Manoharachary et al. 2022
16.	*P. radiata*	*P. radiata*	Himachal Pradesh	Rattan 1977; Dhingra et al. 2014; Kaur 2018; Ritu 2019; Manoharachary et al. 2022
			Eastern Himalaya	Dhingra 2005; Dhingra et al. 2011
			Uttarakhand	Sharma 2012; Sanyal 2014; Manoharachary et al. 2022
17.	*P. rufa*	*P. rufa*	Eastern Himalaya	Dhingra 1983; Manoharachary et al. 2022
			Tamil Nadu	Natarajan & Kolandavelu 1998
			Himachal Pradesh	Manoharachary et al. 2022
18.	*P. segregata*	*P. segregata*	Himachal Pradesh	Dhingra et al. 2014; Kaur 2018; Poonam 2020; Manoharachary et al. 2022
			Utarakhand	Sanyal 2014
19.	*P. serialis*	*P. serialis*	Himachal Pradesh	Sharma 2012; Manoharachary et al. 2022
			Uttarakhand	Manoharachary et al. 2022

	Current name of the taxon	Earlier described as	Localities	Records
20.	*P. singularisa*	*P. singularisa*	Himachal Pradesh	Dhingra et al. 2014; Poonam 2020; Manoharachary et al. 2022
21.	*P. subalata*	*P. subulata*	Himachal Pradesh	Sharma 2012
			Uttarakhand	Sharma 2012
22.	*P. subceracea*	*P. subceracea*	Maharashtra	Ranadive et al. 2011; Manoharachary et al. 2022
23.	*P. subcretacea*	*P. subcretacea*	Himachal Pradesh	Rattan 1977; Sharma 2012; Dhingra et al. 2014; Manoharachary et al. 2022
			Tamil Nadu	Natarajan & Kolandavelu 1998
			Jammu & Kashmir	Sharma 2017
24.	*P. subserialis*	*P. subserialis*	Himachal Pradesh	Rattan 1977; Dhingra et al. 2014; Kaur 2018; Manoharachary et al. 2022
			Uttarakhand	Sharma 2012; Sanyal 2014; Manoharachary et al. 2022
			Jammu & Kashmir	Sharma 2017
25.	*P. thindii*	*P. thindii*	Eastern Himalaya	Dhingra 2005; Dhingra et al. 2011
			West Bengal	Manoharachary et al. 2022
26.	*P. unica*	*P. unica*	Himachal Pradesh	Dhingra et al. 2014; Ritu 2019; Manoharachary et al. 2022
			Uttarakhand	Sanyal 2014; Manoharachary et al. 2022

Cytidiella albida (H.Post) C.C.Chen & Sheng H.Wu Fungal Diversity 111: 400 (2021).

- *Phlebia albida* H. Post, Monographia Hymenomycetum Sueciae 2: 280 (1863). (Image 2)

Description: Basidiocarp resupinate, adnate, effused, up to 500 µm thick in section; hymenial surface smooth to tuberculate to somewhat strigose; yellowish white (4A2) when fresh, pale orange (5A3) to orange white (6A2) on drying; margins concolourlous, finally fimbriate.

Hyphal system monomitic, generative hyphae up to 5.3 µm wide, septate, clamped, richly branched, thin- to thick-walled; loosely arranged, thick-walled, parallel to the substrate in the basal zone; compactly arranged, thin-walled, vertically arranged in the subhymenial zone. Cystidia absent. Basidia clavate, 36.5–58 × 5.2–8 µm, tetrasterigmate, with basal clamp; sterigmata up to 4.8 µm long. Basidiospores ellipsoid, 8–11.5 × 4–5 µm thin-walled, smooth, inamyloid, acyanophilous.

Collection examined: India, Himachal Pradesh, Kullu, Banjar, Paldi, on stump of *Cedrus deodara,* Ellu 11380 (PUN), 16 August 2017.

Remarks: *Cytidiella albida* is distinctive in having smooth to tuberculate to somewhat strigose hymenial surface, clamped generative hyphae, comparatively larger basidia and ellipsoid basidiospores. It was earlier described under the genus *Phlebia* from various parts of Europe and America (Eriksson et al. 1981; Nakasone 1996). However, Chen et al. (2021) shifted it to the genus *Cytidiella* based on morphological and DNA sequence based molecular studies and recorded its distribution from Europe, North Africa, and temperate regions of Asia. It is a new addition to the corticoid fungi from India.

Cytidiella nitidula (P.Karst.) Zmitr. Folia Cryptogamica Petropolitana 6: 97 (2018).

- *Corticium nitidulum* P. Karst., Meddelanden af Societas pro Fauna et Flora Fennica 6: 11 (1881) (Image 3).

Description: Basidiocarp resupinate, adnate, effused, ceraceous to membraneous, up to 280 µm thick in section; hymenial surface smooth to slightly tuberculate; orange white (6A2) when fresh, white (6A1) to light orange (6A5) upon drying; margins thinning, concolourous, fibrillose.

Hyphal system monomitic, generative hyphae up to 4.5 µm wide, septate, clamped, thin-walled; horizontal, loosely interwoven in the subiculum; dense and vertically arranged in the subhymenium. Cystidia absent. Basidia clavate, 24.5–32 × 5.5–7 µm, tetrasterigmate, basally clamped; sterigmata up to 4.6 µm long. Basidiospores subcylindrical, 7.4–9.5 × 3–4 µm, smooth, thin-walled, inamyloid, acyanophilous.

Collection examined: India, Himachal Pradesh, Kullu, Banjar, Manglore village, on angiospermous twig, Ellu 11381 (PUN), 28 August 2017.

Remarks: *Cytidiella nitidula* is distinguished from *C. albida* and *P. viridesalebrosum* in having subcylindrical

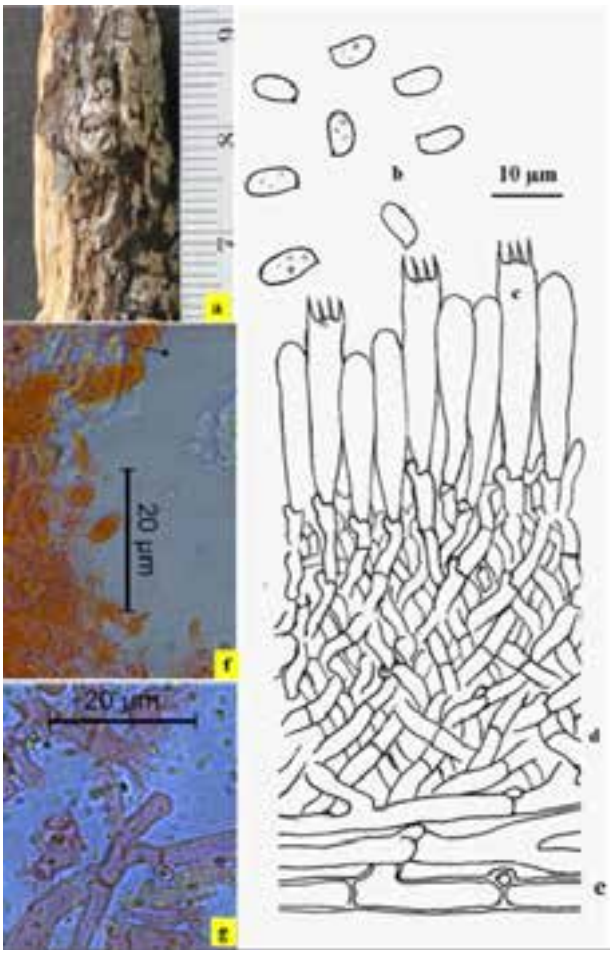

Image 3. *Cytidiella nitidula*: a—Basidiocarp showing hyemenial surface | b–d—Section showing outline of basidiospores (b), basidia (c) Subhymenial generative hyphae (d), basal generative hyphae (e) | f–g— Photomicrographs showing basidiospores (f) and generative hyphae (g). © a—Ellu Ram, b-g—Tanya Joshi.

basidiospores. Previously, it was described as *Phlebia nitidula* but Zmitrovich (2018) proposed it as *Cytidiella nitidula* comb. nov. It is a new report to India. Earlier, the species has been listed from Germany, Croatia, Belgium, Russia, Finland, Iceland, Norway, Italy, Spain, Estonia and North America by Eriksson et al. (1981), Bernicchia & Gorjón (2010), and Mycobank (2023).

Phlebia viridesalebrosum J.Erikss. & Hjortstam

The *Corticiaceae* of North Europe 6: 1127 (1981). (Image 4).

Description: Basidiocarp resupinate, adnate, effused-reflexed, ceraceous when fresh, turns corneous upon drying, up to 265 µm thick in section; hymenial surface smooth to tuberculate; reddish grey (8B2) to greyish-red (8B5) when fresh, darkened on drying; margins somewhat thick, paler concolourous.

Hyphal system monomitic, generative hyphae up to 4.5 µm wide, simple-septate, thick-walled; somewhat parallel to the substrate, loosely packed in the subicular zone; vertical and compactly arranged in the subhymenium. Cystidia absent. Basidia clavate, 30–37.5 × 4.5–7 µm, tetrasterigmate, without basal clamp; sterigmata up to 4.6 µm long. Basidiospores ellipsoid, 5.5–7.5 × 3–3.7 µm, thin-walled, smooth, inamyloid, acyanophilous.

Collection examined: India, Himachal Pradesh, Kullu, Sainj, Dhaugi, on the angiospermous log, Ellu 11378 (PUN), 4 August 2015.

Remarks: This species is different from *C. albida* in having corneus basidiocarp and simple-septate generative hyphae. The species contributes a new record from India. The earlier available account is from France, Austria, and Italy (Bernicchia & Gorjón 2010; Mycobank 2023).

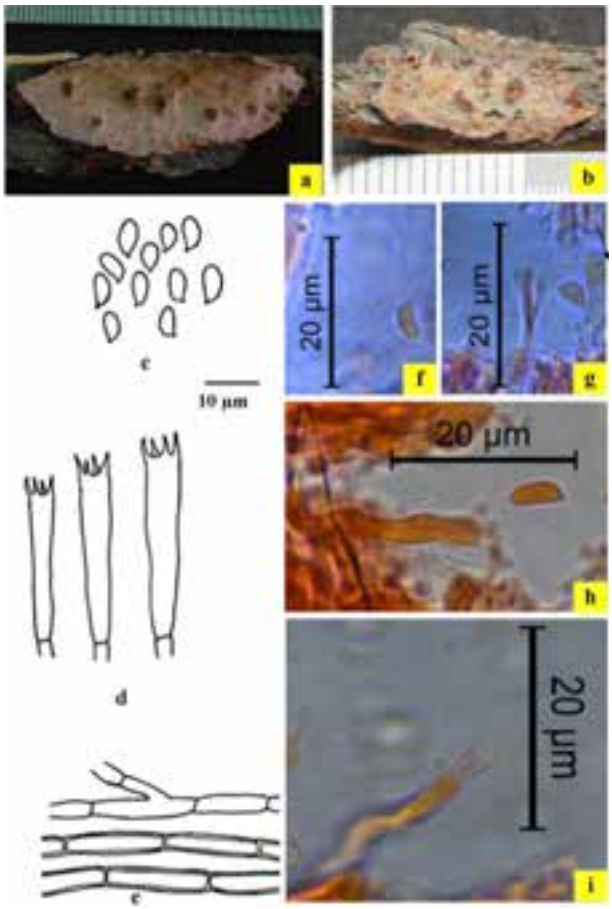

Image 4. *Phlebia viridesalebrosum*: a—Basidiocarp showing hyemenial surface (fresh) | b. Basidiocarp showing hyemenial surface (dry) | c–e. Line diagrams showing the outline of basidiospores (c), basidia (d) and generative hyphae (e) | f–i. Photomicrographs showing basidiospores (f–h) and basidium (i). © a—Ellu Ram; b—Avneet Pal Singh, c-i—Tanya Joshi.

DISCUSSION

The present compilation presents an account of four corticioid species belonging to three genera. Among these, the genus *Aphanobasidium* has been earlier described on the basis of a single species, i.e., *A. subnitens* from Shimla district of Himachal Pradesh (Prasher & Ashok 2013). Presently, *A. pseudotsugae* is being described as new to India as it is earlier known only from different parts of Europe (Bernicchia & Gorjón 2010; Mycobank 2023).

The genus *Cytidiella* is being recorded for the first time from India based on *C. albida* and *C. nitidula* that have been described presently. Earlier, *C. albida* has been reported from Europe, northern Africa, and temperate regions of Asia (Chen et al. 2021) to India whereas that of *C. nitidula* has been extended from northern Scandinavia and other parts of Europe to India. The genus *Phlebia* has been worked out from different parts of India on the basis of 26 species (Table 1). Of these, 21 species have been described from northwestern India (Himachal Pradesh, Jammu & Kashmir, Punjab, and Uttarakhand), seven species from southern India (Maharashtra and Tamil Nadu), and six species from eastern Himalaya. The present studies have also added *Phlebia viridesalebrosum*, earlier known from France, Austria, and Italy (Mycobank 2023), as new to India.

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COMMUNICATION

Taxonomy and molecular systematics of marasmioid fungi (Basidiomycetes: Agaricales: Marasmiaceae) occurring in Puducherry, India

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Abstract: In this study, five species of *Marasmius* namely, *M. bambusiniformis*, *M. haematocephalus*, *M. leveilleanus*, *M. midnapurensis*, and *M rotalis*, plus *Paramarasmius palmivorus* are described, based on morphotaxonomic and molecular characters. Sequence data from internal transcribed spacers were used for phylogenetic analyses of the six species, supporting their identification based on macro and micromorphological characters. All of these species are reported for the first time from Puducherry region.

Keywords: *Agaricales*, *Basidiomycota*, litter fungi, *Marasmiaceae*, molecular characterization, morphotaxonomy, mushrooms, *Paramarasmius*, phylogeny, southern India.

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Author contributions: YK—undertook field trips to sample gilled fungi, recorded macro- and microscopic characters. TSM—analysed the ITS sequence and carried out phylogenetic analysis. SG—assisted in identifying and describing some of the species of agarics mentioned in the present study. VK—carried out field trips to various places in Puducherry to record gilled fungi. He reviewed the morphological and microscopic characterization of marasmioid fungi done by the scholar and wrote the manuscript.

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INTRODUCTION

The genus *Marasmius* Fr. (*Marasmiaceae* Roze ex Kühner) was first accepted by Elias Magnus Fries in 1835 (Tan et al. 2009). Singer (1986) recognized 12 different sections, viz., *Androsacei*, *Hygrometrici*, *Leveilleani*, *Scotophysini*, *Epiphylli*, *Marasmius*, *Sicci*, *Inaequales*, *Fusicystides*, *Neosessiles*, *Alliacei*, and *Globulares* that were represented by 356 species. However, the genus *Marasmius* sensu lato, according to Singer (1986), is polyphyletic. Based on the phylogenetic analysis of nuclear ribosomal Large Subunit rRNA gene (nLSU), the members of the section *Androsacei* were merged into the genus *Gymnopus*, whereas the section *Alliacei*, along with some other members, was elevated to the generic level as *Mycetinis*. The sections *Hygrometrici, Leveilleani*, *Scotophysini*, *Marasmius*, *Sicci*, *Neosessiles*, and *Globulares* were recognized by Wilson & Desjardin (2005).

The genus *Marasmius* is one of the largest genera of the order *Agaricales,* comprising about 600 species that are distributed worldwide, particularly in tropical regions (Wannathes et al. 2009). A review of literature revealed that more than 80 species have been listed in India (Manjula 1983; Natarajan et al. 2005; Kaur & Gupta 2019). Of these, 13 species have been newly described from different regions (Dutta et al. 2015; Farook & Manimohan 2015; Das et al. 2019; Manoharachary et al. 2022). The present study records the occurrence of five species of *Marasmius* in Puducherry, namely, *M. bambusiniformis* Singer, *M. haematocephalus* (Mont.) Fr., *M. leveilleanus* (Berk.) Sacc. & Trotter, *M. midnapurensis* A.K.Dutta, P.Pradhan & K.Acharya, and *M. rotalis* Berk. & Broome and a species of *Paramarasmius*, viz., *P. palmivorus* (Sharples) Antonín & Kolařík. All these species are being reported for the first time in the Puducherry region. *Marasmius midnapurensis,* a recently described new species from West Bengal, India (Dutta et al. 2014), was also collected and studied, and is being reported for the first time in southern India. It is pertinent to mention that Kumaresan et al. (2021) reported three species belonging to *Marasmiaceae* among 33 species of gilled fungi reported from Puducherry, but none belonging to the genus *Marasmius*.

MATERIALS AND METHODS

Study area

The basidiomes of *Marasmius* spp. were collected from various places of Puducherry, India during the north-east monsoon season of November and December 2021.

Sampling and morphological characterization

During sampling, photographs of basidiomes were taken, and morphological characters such as colour (Kornerup & Wanscher 1978), size, and gill attachment were recorded in the field (Senthilarasu & Kumaresan 2018). The basidiomes were dried using an electric drier at 50°C for an hour or more depending on their delicate nature or thick fleshy texture. The dried basidiomes were sealed carefully in polythene covers after labeling, for further microscopic studies. The samples are being maintained in the mushroom herbarium collection in the Department of Botany, Kanchi Mamunivar Government Institute for Postgraduate Studies and Research, Puducherry, India by designating unique alphanumeric numbers.

The thin hand-made sections taken from basidiomes were revived in 5% KOH, stained in 1% phloxine B and observed under the microscope (Labomed iVu 3100); camera lucida diagrams were drawn. Microscopic characters such as shape and size of basidia, basidioles, basidiospores were observed, presence or absence of pluerocystidia, cheilocystidia, pileocystidia, and caulocystidia with their shape and size were recorded following Largent et al. (1977). Around 20 measurements for basidia and cystidia were derived from each specimen. X_m is the arithmetic mean of the spore length and spore width with standard deviation for n spores. The spore quotient (Q) was obtained by dividing the spore length by its width and Q_m was calculated by the mean of Q-values (Zhang et al. 2017).

DNA extraction and PCR amplification

Basidiomes of *Marasmius* spp. were processed for genomic DNA isolation following the method of Gardes & Bruns (1993). Primers ITS1 (TCCGTAGGTGAACCTGCGG) and ITS4 (TCCTCCGCTTATTGATATGC) were used for PCR amplification of the internal transcribed spacer (ITS) region (White et al. 1990). The PCR reaction mixture consisted of 2X Phire Master Mix 5 µL, distilled water 4 µL, ITS1 0.25 µL, ITS2 0.25 µL, and genomic DNA 50 ng. The PCR amplification was formed as follows: 98 °C for 30 s, 40 cycles of 98 °C for 5 s, 58 °C for 10 s, 72 °C for 15 s; 72 °C for 60 s, 4 °C for ∞. The PCR products were purified and sequenced using ABI 3500 DNA Analyzer (Applied Biosystems), prior to which sequencing reaction was done in a PCR thermal cycler (GeneAmp PCR System 9700, Applied Biosystems) using the BigDye Terminator v3.1 Cycle sequencing Kit (Applied Biosystems, USA).

Phylogenetic analyses

Sequences with significant matches obtained using NCBI Blast were selected and aligned using ClustalW (Thompson et al. 1994), and evolutionary history was inferred using the Neighbour-Joining Approach and Maximum Likelihood approach using MEGA11 (Tamura et al. 2021). A bootstrap test (1,000 replicates) was performed and the percentage of replicate trees in which the same taxa clustered together is given next to the branches (Felsenstein 1985). For neighbour joining tree, evolutionary distances were calculated using maximum composite likelihood model (Tamura et al. 2004), while Tamura-Nei model was used for maximum likelihood tree (Tamura & Nei 1993). The species *Crinipellis zonata* was used as an out-group for the analysis. Accession numbers of sequences belonging to the genera *Marasmius* and *Paramarasmius* included in the phylogenetic analysis are given in Table 1.

RESULTS

Marasmius bambusiniformis, *M. haematocephalus*, *M. leveilleanus*, *M. midnapurensis, M. rotalis*, and *P. palmivorus* collected and described in this study are newly reported to Puducherry.

Taxonomy

***Marasmius bambusiniformis* Singer**, *Fl. Neotrop.*, Monogr. 17: 1C7 (1976) (Image 1a–e)

Pileus 4–11 mm diam., conical with small umbo, dull, disc brownish orange (5C5), pale red (7B3) towards margin. Lamellae adnexed, subdistant, cream white. Stipe 12–26 × 2–3 mm, brown (7D7), light yellow towards the apex, central, wiry, non-insititious.

Image 1. *Marasmius bambusiniformis:* a—Fruit body | b, e—Cheilocystidia | c—Pileipellis | d—Basidiospores. © Yuvarani Krishnan.

Basidiospores 14–16 × 3–4 µm (X_m = 15.4 ± 0.7 × 3.8 ± 0.1 µm, Q = 3.5–4.0, Q_m = 3.9 ± 0.1), narrowly fusoid, thin-walled, hyaline, inamyloid. Basidia not observed. Basidioles 20–24 × 4–6 µm, fusoid to clavate. Cheilocystidia of *Siccus*-type broom cells, main body 8–17 × 7–10 µm, cylindrical to clavate, inamyloid, thin-walled, apical setulae 2–6 × 1–1.5 µm. Pleurocystidia absent. Pileal elements composed of *Siccus*-type broom cells, main body 9–15 × 8–11 µm, cylindrical to clavate, crowded, thick-walled, apical setulae 2–6 × 1–1.5 µm. Clamp connections present.

Specimen examined: Lawspet, Puducherry, gregarious on twig litter. K. Yuvarani (PYKM136, GenBank: OP415534).

Notes: The basidiomes of *M. bambusiniformis* reported from Thailand is similar in pileal size (3–10 mm diam.) with slight variation in having reddish brown to brownish orange pileus (Wannathes et al. 2009). The Malaysian species of *M. bambusiniformis* slightly differs from present collection morphologically in smaller pileus (1.5–5 mm diam.) and microscopically having slightly longer basidiospores of up to 19 µm (Tan et al. 2009). This is the first record from southern India.

***Marasmius haematocephalus* (Mont.) Fr.**, *Epicr. syst. mycol* (Upsaliae): 382 (1838) [1836–1838] (Image 2a–g)

Pileus 4–11 mm diam., convex, sulcate striate, dull, orangish red (8B6) to pastel red (8B5). Lamellae free to adnexed, subdistant, white. Stipe 10–28 × 3–4 mm, central, cylindrical, wiry, smooth, white above, reddish brown (8D5) towards base.

Basidiospores 17–19 × 4–5 µm (X_m = 18.4 ± 0.7 × 4.9 ± 0.1, Q = 3.4–3.8, Q_m = 3.7 ± 0.1), clavate to fusoid, often curved, inamyloid. Basidia not observed. Basidioles 23–26 × 5–6 µm, fusoid to clavate. Cheilocystidia composed of *Siccus*-type of broom cells 9–16 × 5–8 µm, cylindrical to clavate, crowded, inamyloid, thin-walled, apical setulae 2–5 × 1 µm. Pleurocystidia 35–39 × 7–9 µm, gloeocystidioid, fusoid to clavate, at times mucronate, inamyloid, thin-walled. Pileal elements hymeniform, composed of *Siccus*- type broom cells, 10–19 × 6–8 µm, clavate, inamyloid, apical setulae 2–6 × 1–2 µm. Clamp connections present.

Specimen examined: Veerampattinam, Puducherry, gregarious on soil along with grass, 28 October 2021, K. Yuvarani (PYKM110, GenBank: OP415535).

Notes: *Marasmius haematocephalus* is known to occur widely and has been reported from Tamil Nadu

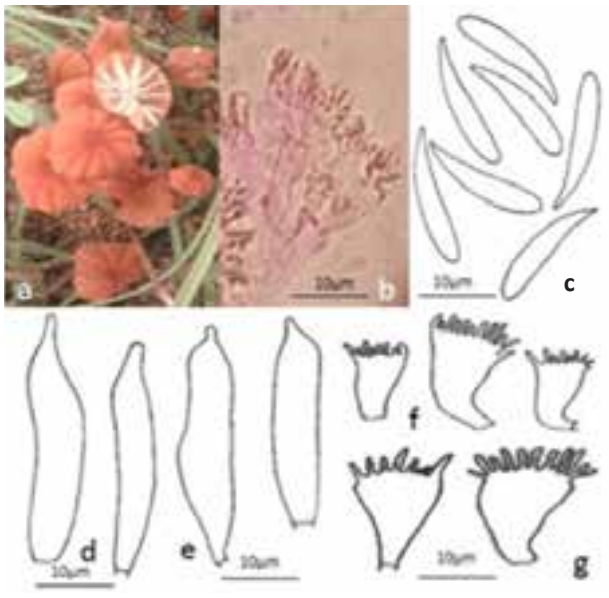

Image 2. *Marasmius haematocephalus*: a—Fruit body | b, g—Pileipellis | c—Basidiospores | d, f—Cheilocystidia (d—Non-setulose Cheilocystidia & f—Siccus- type Cheilocystidia) | e—Pleurocystidia. © Yuvarani Krishnan.

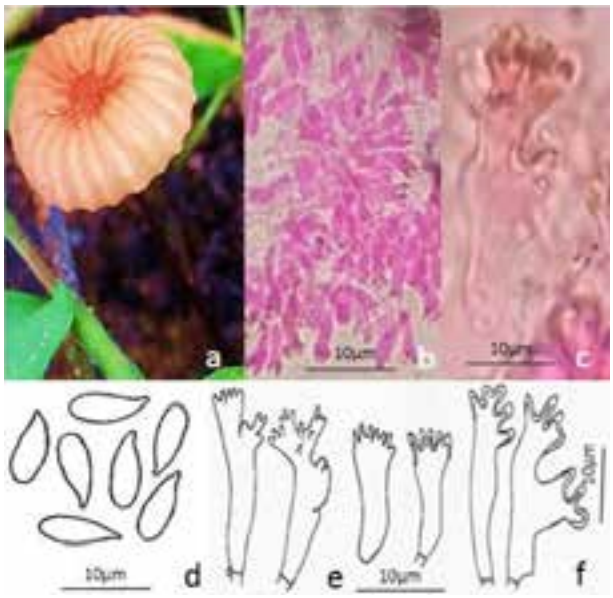

Image 3. *Marasmius leveilleanus*: a—Fruit body | b, e—Cheilocystidia | c, f—Pileipellis | d—Basidiospores. © Yuvarani Krishnan.

(Natarajan and Manjula 1983), Kerala & Maharashtra (Manoharachary et al. 2022), and Assam (Roy et al. 2022).

***Marasmius leveilleanus* (Berk.) Sacc. & Trotter**, *Syll. fung*. (Abellini) 23: 149 (1925) (Image 3a–f)

Pileus 5–18 mm diam., convex to hemispherical when young, becoming convex to depressed in the central part, umbilicate, dull to shiny, reddish-orange (7B6) to pastel red (8B3); margin brownish-orange (5C5). Lamellae free, subdistant, broad, white or cream. Stipe 9–25 × 5–8 mm, central, cylindrical, brownish-red (8E7), insititious.

Basidiospores 10–12 × 4–5 µm (X_m = 10.8 ± 0.6 × 4.7 ± 0.4, Q = 2.2–2.5, Q_m = 2.3 ± 0.1), ellipsoid, inamyloid, thin-walled. Basidia 20–23 × 6–9 µm, cylindrical to clavate, 4-spored, inamyloid. Cheilocystidia of *Siccus*-type broom cells, main body 16–28 × 6–9 µm, cylindrical to clavate, thin-walled, inamyloid with apical setulae 1–4 × 1–1.5 µm. Pileipellis hymeniform, composed of *Siccus*-type broom cells, main body clavate to oblong, 15–22 × 7–10 µm, thin to thick-walled, inamyloid, with apical setulae 3–5 × 1.5–3 µm. Clamp connections present.

Specimen examined: Puthupattu, Puducherry, scattered on twigs and decaying wood, 7 December 2021, K. Yuvarani (PYKMS14, GenBank: OP415538).

Notes: *Marasmius leveilleanus* has been recorded from Tamil Nadu (Natarajan & Manjula 1982) and Kerala (Manoharachary et al. 2022).

***Marasmius midnapurensis* A.K.Dutta, P.Pradhan & K.Acharya**, in Dutta, Chandra, Pradhan & Acharya, *Mycotaxon* 128: 119 (2014) (Image 4a–f)

Pileus 8–24 mm diam., convex to broadly convex, umbonate, smooth, moist, light brown (5D5) to light greyish-brown (6D3) with irregular light yellowish brown (5D6) patches in the pileus surface, hygrophanous, striate. Lamellae adnexed, subdistant, white (1B1), margin creamy, slightly undulating or even. Stipe 51–81 × 1.5–2 mm, central, creamy near the apex, reddish-brown (7D7) below, terete, hollow, dry, smooth, non-insititious, white to light yellow at the base.

Basidiospores 10–12 × 3–4 µm (X_m = 10.9 ± 0.9 × 3.9 ± 0.1, Q = 2.5–3.4, Q_m = 2.7 ± 0.3) narrowly ellipsoid to fusoid, slightly curved, smooth, inamyloid, thin walled. Basidia 21–25 × 5–7 µm, clavate, 4-spored. Basidioles 19–23 × 5–7 µm, clavate. Cheilocystidia of *Siccus*-type broom cells, 11–17 × 6–10 µm, cylindrical to clavate, with thin to thick-walled apical setulae, 4–10 × 1–1.5 µm. Pleurocystidia absent. Pileipellis composed of *Siccus*-type broom cells, 12–16 × 7–11 µm, clavate, inamyloid, apical setulae crowded, 4–10 × 1–1.5 µm. Caulocystidia present. Clamp connections present.

Specimen examined: Lawspet, Puducherry, gregarious and scattered on twig and leaf litter, 27th August 2021, K. Yuvarani (PYKM76 & PYKM78, GenBank: OP415532, OP415533); Lawspet, gregarious and scattered, 30 August 2021, K. Yuvarani (PYKM87).

Notes: *Marasmius midnapurensis* was first described

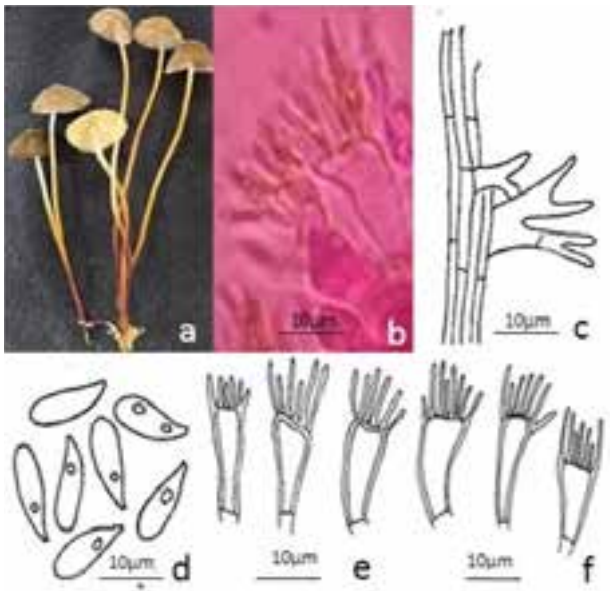

Image 4. *Marasmius midnapurensis*: a—Fruit body | b, e—Cheilocystidia | c—Caulocystidia | d—Basidiospores | f—Pileipellis. © Yuvarani Krishnan.

from Midnapur district of West Bengal, India (Dutta et al. 2014). Morphotaxonomically, the present collection resembles *M. midnapurensis* in all the characters, but slightly differs in having longer stipe (51–81 mm vs 53–65 mm).

***Marasmius rotalis* Berk. & Broome**, *J. Linn. Soc.*, Bot. 14 (no.73): 40 (1873) [1875] (Image 5a–f)

Pileus 3–6 mm diam., convex, umbilicate, striate, to sulcate; surface dull, dry, uniformly pale orange (5A3) to pale white (5A1), umbilicus with a darker central spot; margin undulating. Lamellae horizontal, distant, white. Stipe 14–10 × 2 mm, central, surface shiny, dry, reddish-brown (8E8) to brownish-red. Mycelium running over on attached leaf.

Basidiospores 6–8 × 4–5 µm (X_m = 7.6 ± 0.4 × 4.3 ± 0.4, Q = 1.6–2, Q_m = 1.7 ± 0.1), ellipsoid, inamyloid, thin-walled. Basidia 20–23 × 4.5–5.5 µm, clavate, 4 spored, inamyloid. Cheilocystidia 10–12 × 8–10 µm, scattered of *Rotalis*-type broom cells, broadly clavate, thin walled. Pleurocystidia absent. Pileal surface with *Rotalis*-type broom cells, 10–15 × 10–12 µm, broadly clavate or pyriform or sub-vesiculose, thin-walled, inamyloid, Clamp connections present. Stipe hyphae up to 5 µm broad, thick-walled.

Specimen examined: Lawspet, Puducherry, scattered on leaf litter and fallen *Caesalpinia* fruit, 30 October 2021, K. Yuvarani (PYKM101, GenBank: OP415536).

Notes: *Marasmius rotalis* was previously described from Madras (now Chennai), Tamil Nadu by Natarajan & Manjula (1982). The specimen examined in the present work is similar to *M. rotalis* described from Chennai in all the morphotaxonomic characters.

***Paramarasmius palmivorus* (Sharples) Antonín & Kolařík**, in Antonín, Hosaka & Kolařík, *Pl. Biosystems*: 10.1080/11263504.2022.2100503, 2 (2022) (Image 6a–f)

Pileus 6–34 mm diam., hemispherical to convex, surface dull, moist to dry, young white, becoming yellowish white (1A2) when mature. Lamellae adnate, subdistant to distant, with 4 series of lamellulae. Stipe

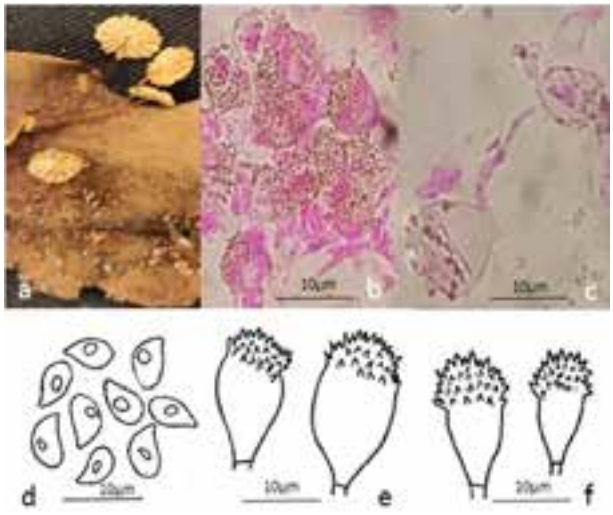

Image 5. *Marasmius rotalis*: a—Fruit body | b, e—Cheilocystidia | c, f—Pileocystidia | d—Basidiospores. © Yuvarani Krishnan.

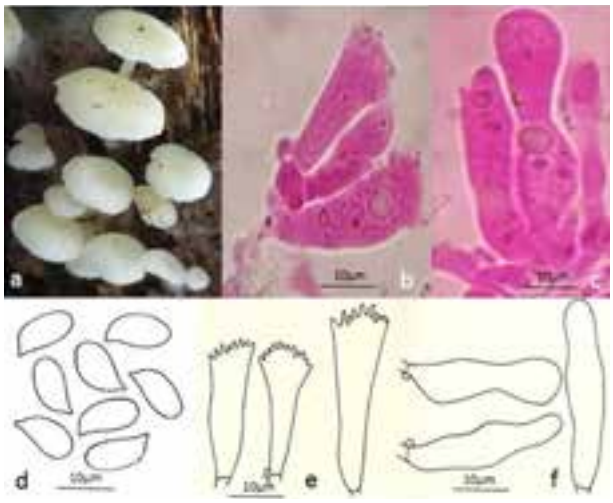

Image 6. *Paramarasmius palmivorus*: a—Fruit body | b, e—Cheilocystidia | c, f—Pileipellis hyphae | d—Basidiospores. © Yuvarani Krishnan.

Table 1. List of Marasmius species used for phylogenetic analysis.

Species	Country	Section	GenBank accession no.
Marasmius cystidiatus	India	Globulares	MH216191
Marasmius cystidiatus	India	Globulares	MH216042
Marasmius leveilleanus	India	Leveilleani	KX154213
Marasmius leveilleanus	India	Leveilleani	OP415538*
Marasmius leveilleanus	Thailand	Leveilleani	MW426440
Marasmius leveilleanus	Sri Lanka	Leveilleani	KR733544
Marasmius brunneoaurantiacus	China	Marasmius	MZ133622
Marasmius rotalis	India	Marasmius	MF189068
Marasmius rotalis	India	Marasmius	MF189069
Marasmius rotalis	India	Marasmius	OP415536*
Marasmius somalomoensis	USA	Marasmius	KX149002
Marasmius tenuissimus	China	Neosessiles	MF061773
Marasmius midnapurensis	India	Sicci	KY785179
Marasmius midnapurensis	India	Sicci	MF189041
Marasmius midnapurensis	India	Sicci	OP415532*
Marasmius midnapurensis	India	Sicci	OP415533*
Marasmius haematocephalus	Thailand	Sicci	EU935525
Marasmius haematocephalus	Thailand	Sicci	EU935527
Marasmius haematocephalus	Thailand	Sicci	MW426462
Marasmius haematocephalus	India	Sicci	OP415535*
Marasmius auranticapitatus	Brazil	Sicci	ON502671
Marasmius bambusiniformis	Thailand	Sicci	MW504974
Marasmius bambusiniformis	Thailand	Sicci	EU935521
Marasmius bambusiniformis	Thailand	Sicci	EU935522
Marasmius bambusiniformis	India	Sicci	MW453134
Marasmius bambusiniformis	India	Sicci	OP415534*
Marasmius coasiaticus	Brazil	Sicci	ON502681
Marasmius graminicola	Korea	Sicci	FJ917618
Marasmius graminicola	Korea	Sicci	FJ917617
Marasmius nodulocystis	USA	Sicci	KX953740
Marasmius nodulocystis	USA	Sicci	KX953742
Marasmius ochroleucus	Russia	Sicci	KF912952
Marasmius rubicundus	Brazil	Sicci	ON502659
Marasmius rubicundus	Brazil	Sicci	ON502663
Marasmius strobiluriformis	Korea	Sicci	GU266263
Paramarasmius palmivorus	India	-	MK788181
Paramarasmius palmivorus	USA	-	MF100969
Paramarasmius palmivorus	India	-	MG251431
Paramarasmius palmivorus	India	-	OP415537*#
Paramarasmius palmivorus	Thailand	-	MW647877
Crinipellis zonata	USA	-	MK217458

**Marasmius* spp. and *Paramarasmius palmivorus* recorded in the present study
#Submitted as *Marasmius palmivorous*, presently basionym of *Paramarasmius palmivorus* (Sharples) Antonín & Kolařík (2022).

4–12 × 1–1.5 mm, central to slightly eccentric, slightly enlarged at the base, white near the apex, light yellowish brown towards the base, insititious.

Basidiospores 10–12 × 5–6 µm (X_m = 11.4 ± 0.7 × 5.1 ± 0.6, Q = 2–2.6, Q_m = 2.2 ± 0.2) ellipsoid, smooth, inamyloid, thin-walled. Basidia 35–37 × 7–9 µm, clavate, to cylindrical, 4-spored. Pleurocystidia absent. Cheilocystidia 24–26 × 8–11 µm, cylindrical to clavate, inamyloid, thin-walled, irregular in outline, with apical lobules. Pileipellis loosely interwoven, not a hymeniform layer, hyphae up to 8 µm wide, thin-walled.

Specimen examined: Puthupattu, Puducherry, sacred grove (Near Puducherry), gregarious on decaying coconut fibre, 28 October 2021, K. Yuvarani (PYKMS40, GenBank: OP415537).

Notes: The present collection resembles *M. palmivorus* (presently *Paramarasmius palmivorus*) reported by Dutta & Acharya (2018) from West Bengal in all the morphotaxonomic characters, but slightly differs in having longer cheilocystidia (24–26 µm vs up to 19 µm).

A phylogenetic analysis was performed on 41 ITS sequences of different species of *Marasmius* (seven from the current study and 33 from public databases) with *Crinipellis zonata* as outgroup. All ambiguous positions were removed for each sequence pair and the final dataset included 286 positions. Both Neighbour joining analysis and Maximum likelihood approach provided similar results with all our isolates clustered together in separate clades (Figures 1, 2). The boostrap support for different clades was found to be generally low across all nodes. When the isolates were separated based on the section to which they belonged, the members of section *Marasmius* formed a monophyletic clade with strong support (100%) while the species belonging to *Paramarasmius* (earlier reported as *Marasmius palmivorus*) were grouped together (100% bootstrap support).

DISCUSSION

Of the five species of *Marasmius* examined, *M. midnapurensis*, *M. bambusiniformis* and *M. haematocephalus* belong to sect. *Sicci*, *M. leveilleanus* to sect. *Leveilleani* and *M. rotalis* to sect. *Marasmius*. *Marasmius palmivorus* displays unique pileipellis morphology (Dutta & Acharya 2018) and hence, Antonin et al. (2022) proposed a new combination *P. palmivorous* for *M. palmivorous* due to the absence of hymeniderm pileipellis in the latter. *Marasmius*

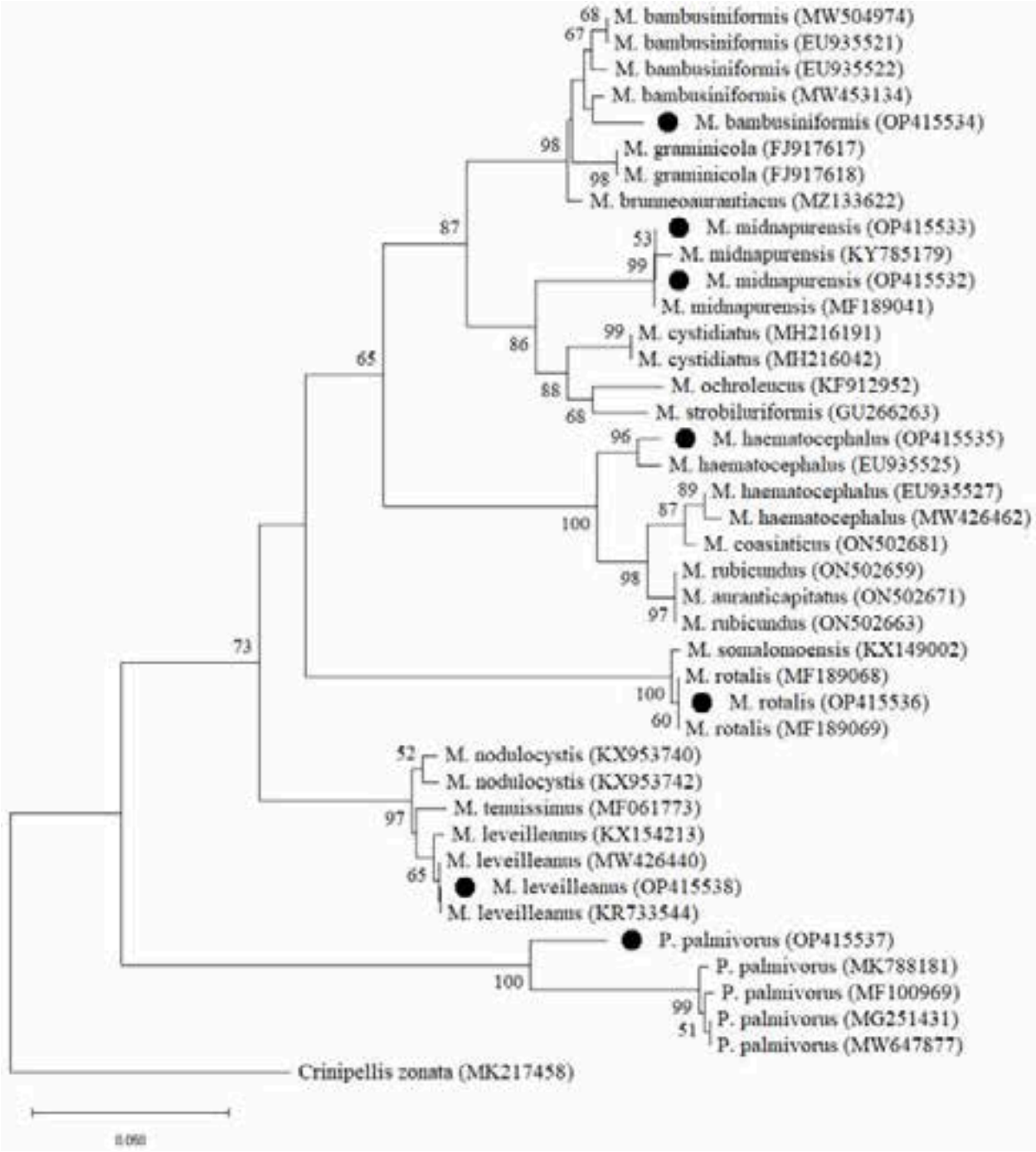

Figure 1. Phylogenetic relationship of *Marasmius* and *Paramarasmius* spp. inferred from ITS sequences analysis by neighbour joining method. The solid black circle indicates the taxa reported in the present study. Numbers next to branches indicate bootstrap support from 1,000 replicates.

midnapurensis is being described for the first time from southern India. Natarajan & Manjula (1982) reported *M. haematocephalus*, *M. leveilleanus* and *M. rotalis* from southern India. Wannathes et al. (2009) recognized six different forms of *M. haematocephalus* although not formally established and, to confirm this more specimens have to be analyzed. Further, *Marasmius* species are known to have their morphologically vicariant taxon in other geographical areas (Antonin et al. 2014) making molecular analysis an important tool in differentiating such species. Phylogenetic analysis using both neighbour joining method and maximum likelihood method gave similar results (Figures 1, 2). Our phylogenetic analysis further showed that Internal Transcribed Spacer

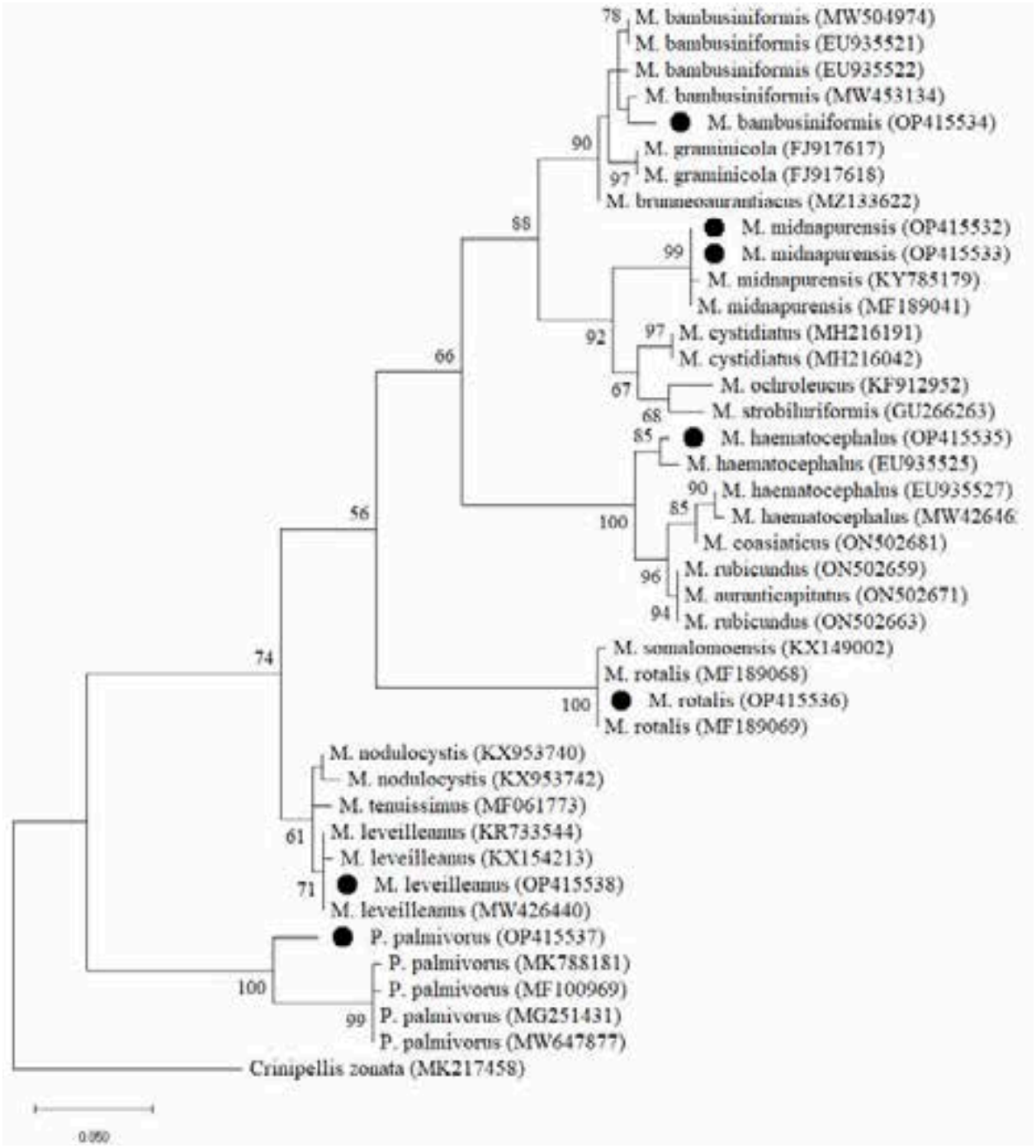

Figure 2. Phylogenetic relationship of *Marasmius* and *Paramarasmius* spp. inferred from ITS sequences analysis by maximum likelihood method. Tree with highest log likelihood is shown. The solid black circle indicates the taxa reported in the present study. Numbers next to branches indicate bootstrap support from 1,000 replicates.

might not be a reliable marker to distinguish different sections in genus *Marasmius* but had strong support for members of section *Marasmius*. A similar result was obtained by nuclear large subunit sequence analysis by Douanla-Meli and Langer (2008). Our results also agreed with that of Oliveira et al. (2020) in that the members of *Globulares* to be non-monophyletic and the clade included members from different sections and lacked stronger support.

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SHORT COMMUNICATION

OPEN ACCESS

First photo evidence of Siberian Weasel *Mustela sibirica* Pallas, 1773 (Mammalia: Carnivora: Mustelidae) in Gaurishankar Conservation Area, Nepal

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Abstract: Five photographs of Siberian Weasel were captured by camera traps in two locations at an elevation of 2,840-3,200 m. in Gaurishankar Conservation Area. The species was identified based on its uniform yellowish-brown coat, the presence of a black mask that surrounded its eyes and the white chin, which are key characteristics that distinguishes it from other weasel species. This is the first confirmation of the presence of Siberian Weasel in Gaurishankar Conservation Area, Nepal. Based on present and previous confirmed records, a distribution map of the species has been updated for Nepal.

Keywords: Carnivore, distribution, mustelid, Nepal Himalaya, opportunistic record.

Mustelidae is a diverse family of carnivorous mammals. It includes weasels, badgers, otters, martens, and wolverines. The genus *Mustela* consists of 14–17 species (Corbet 1978; Abramov 2000; Macdonald 2001; Wozencraft 2005). In Nepal, 11 species are recognized belonging to family Mustelidae (Chetri et al. 2014; Thapa 2014). Among them, five species of the genus *Mustela*: Mountain Weasel *M. altaica*, Yellow-bellied Weasel *M. kathiah*, Stripe-backed Weasel *M. strigidorsa*, Steppe Polecat *M. eversmanii*, and Siberian Weasel *M. sibirica* are known to occur in Nepal (Chetri et al. 2014; Thapa 2014). The existence of Stoat in Nepal *M. ermenia* remains doubtful (Thapa 2014). According to Abramov et al. (2016), the taxonomic status of the Himalayan and central Asian population of *M. sibirica* is uncertain. The species from Kashmir and Sikkim in India, and Nepal, are morphologically distinct and can be treated as a separate species *M. subhemachalana* Hodgson, 1837 (Abramov et al. 2018). The average body weight range of Siberian Weasel *M. sibirica* is 650-820 g for males and 360-430 g for females (Hunter 2011). Globally, the species is listed as 'Least Concern' on the IUCN Red List of Threatened Species (Abramov et al. 2016). However, very little information is available on the species distribution and ecology from Nepal Himalaya (Jnawali et al. 2011; Ghimirey & Acharya 2014). This paper presents the first camera trap photo evidence of the presence of Siberian Weasel in the Gaurishankar Conservation Area (GCA).

Survey area and methods

The survey was conducted in the GCA (27.87^{0}N, 86.18^{0}E) within an elevation range of 1,650–5,000 m (Figure 1). GCA is located between Langtang National

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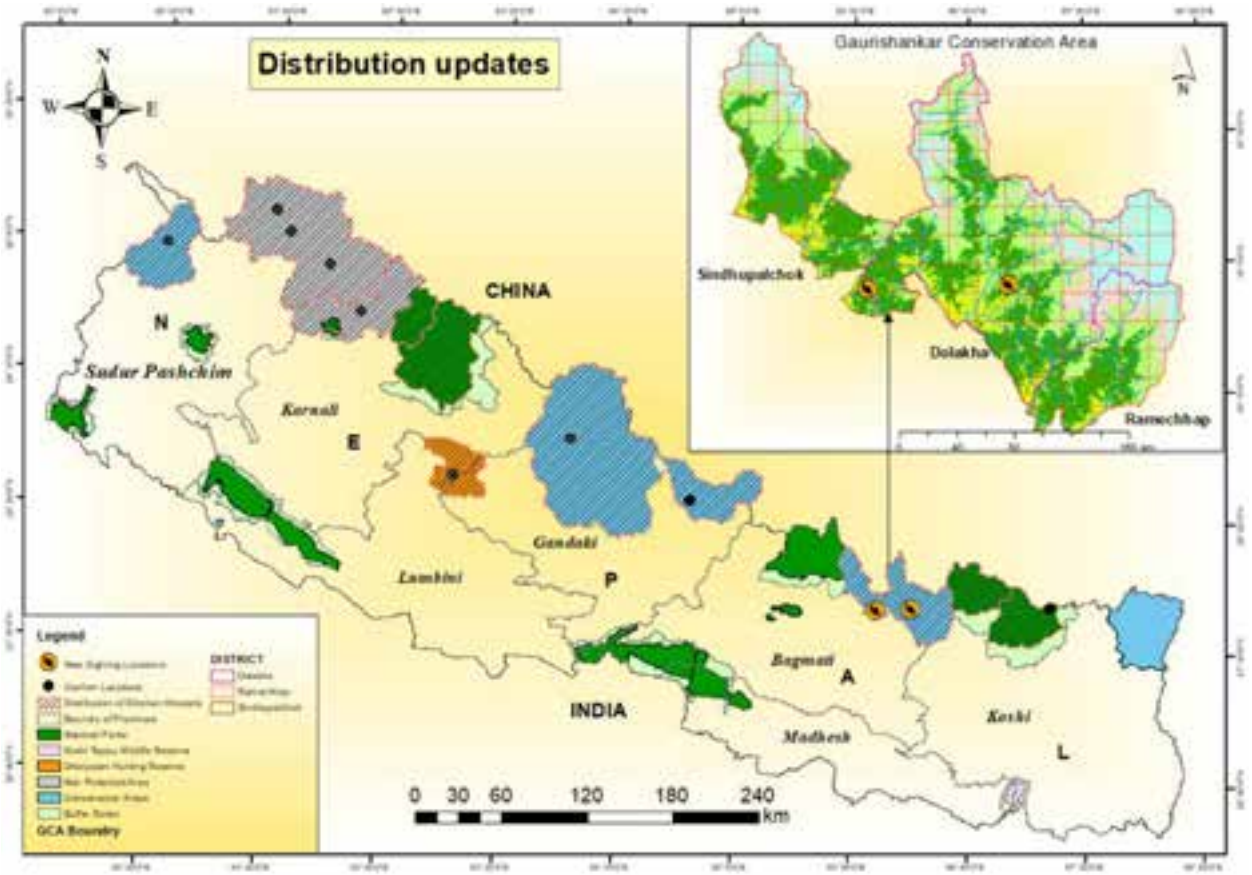

Figure 1. Distribution updates of Siberian weasel in Nepal. Dot signs represent new sighting locations of species in Gaurishankar Conservation Area, Nepal.

Park in the west and Sagarmatha National Park in the east. The northern border is adjacent to the Qomolangma National Nature Reserve, the largest nature reserve in the Tibetan autonomous region of the People's Republic of China. GCA covers an area of 2,179 km^2 along three districts - Dolakha, Rammechhap, and Sindupalchok. Within 120 km of south-north, the elevation rises from less than 1,000 m to over 7,000 m in Dolakha District. The physiographic and climatic zones vary from mid-hills to high mountains and from sub-tropical to alpine. The diverse physiographic and climatic zones vary from mid-hills to high mountains and from subtropical to alpine mosaics habitats with many threatened species of flora and fauna (GCA 2013). The area harbors more than 700 plant species. The most common ungulates seen at lower altitudes is the Himalayan Goral *Naemorhedus goral*. Three primate species are found in the region, including the globally near-threatened Assamese Macaque *Macaca assamensis* (Boonratna et al. 2020). The area also harbours Chinese Pangolin *Manis pentadactyla*, Red Panda *Ailurus fulgens*, Asiatic Black Bear *Ursus thibetanus*, Common Leopard *Panthera pardus*, Snow Leopard *Panthera uncia*, and Himalayan Wolf *Canis lupus chanco*.

Nearly 70,000 people are living within GCA. The pressure on forest habitats is high. National Trust for Nature Conservation-Gaurishankar Conservation Area Project has been managing the area since July 2010 and has initiated important conservation work in partnership with the concerned stakeholders and local communities. At higher altitudes, rangelands are used for grazing livestock such as goats, sheep, cows, horses, yak-hybrid (chauri & dzo), yak and demu (female yak). During summer, livestock such as goats, sheep, yak and yak-hybrids are taken to higher altitudes for grazing by using temporary cattle sheds. To escape severe winter, some northern villages also have a tradition of temporary migrating to lower altitudes for 3–4 months with livestock herds.

The entire GCA was overlaid with 5 x 5 km grid cells using ArcGIS (see Figure 1). Among 97 grid cells, we avoided 34 cells due to difficult terrain, human settlements, and agricultural farmland. Pairs of camera traps were set to obtain pictures of both flanks of the

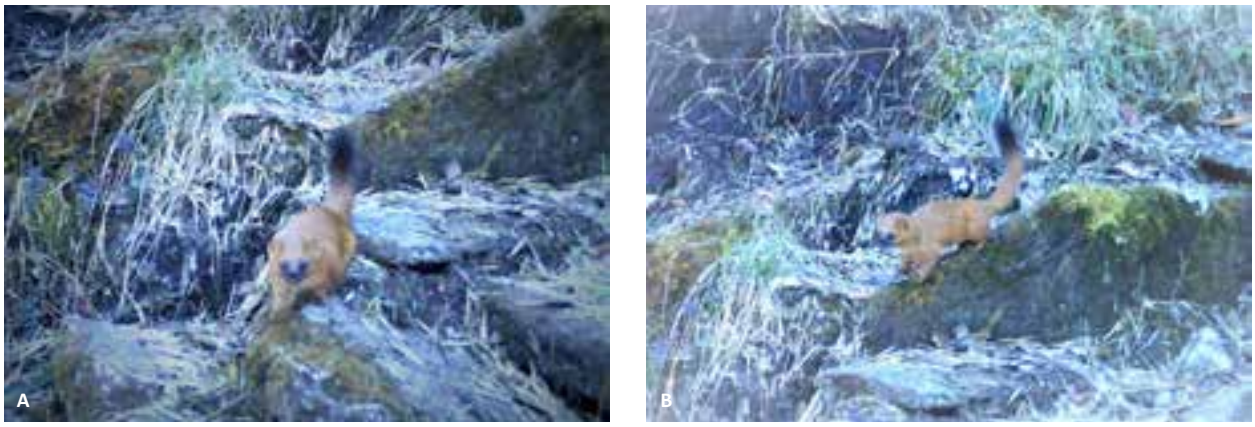

Image 1. Siberian Weasel *Mustela sibirica* in Gaurishankar Conservation Area: A--Front view showing the dark muzzle, white chin and black tip tail | B-Lateral view. © NTNC-GCAP.

Table 1. List of mammalian and bird species recorded along with Siberian Weasel in the study area.

	Species	Family	IUCN Red List Status (2023)	Camera location
1	Siberian Weasel *Mustela sibirica*	Mustelidae	LC	Khare (Dolkha) & Khalsa (Sindhupalchok)
2	Red Panda *Ailurus fulgens*	Ailuridae	EN	Khare (Dolkha)
3	Common Leopard *Panthera pardus*	Felidae	VU	Khalsa (Sindhupalchok)
4	Leopard Cat *Prionailurus bengalensis*	Felidae	VU	Khalsa (Sindhupalchok)
5	Barking Deer *Muntiacus muntjac*	Cervidae	LC	Khalsa (Sindhupalchok)
6	Wild Boar *Sus scrofa*	Suidae	LC	Khalsa (Sindhupalchok)
7	Himalayan Serow *Capricornis sumatraensis*	Bovidae	VU	Khalsa (Sindhupalchok)
8	Himalayan Goral *Naemorhedus goral*	Bovidae	NT	Khalsa (Sindhupalchok)
9	Red Gaint Flying Squirrel *Petaurista petaurista*	Sciuridae	LC	Khalsa (Sindhupalchok)
10	Himalayan Monal *Lophophorus impejanus*	Phasianidae	LC	Khalsa (Sindhupalchok)
11	Blood Phasant *Ithaginis cruentus*	Phasianidae	LC	Khalsa (Sindhupalchok)

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

animal species. Altogether, 183 camera locations were used during the survey period (April 2022–May 2023). Camera traps were placed at key locations for 43 days (except one camera trap), including major livestock trails, junctions of the trails, ridgelines, and in mountain passes, where we expected a high likelihood of wildlife activity. Depending on the topography and gradients, cameras were placed ca. 40–100 cm above the ground, and they were programmed to take three photos per triggered event.

Observations

We obtained five photos of Siberian Weasel in two locations (Image 1A-B) during April 2023 in GCA. At both locations, Siberian Weasels were captured during daytime, one at 0702 h (two photographs, elevation: 3,200 m) and another at 1735 h (three photographs, elevation: 2,840 m). Both cameras were located at an approximate distance of 4–5 km from a human settlement. One of the locations was in a main livestock/human trail dominated by Nigalo Bamboo *Drepanostachyum* spp. with patches of *Rhododendron* species, and the other was in an animal trail at the base of the ridge with forest dominated by *Rhododendron* spp., *Pinus wallichiana*., *Drepanostachyum* spp., and *Litsea* spp. The species was identified based on uniform yellowish-brown coat, black tip tail and dark chocolate coloration on the snout (Law 2015). Several other mammalian species were also recorded from the two camera stations (Table 1). Two pheasants, i.e., Himalayan Monal and Blood Pheasants were also recorded.

The animal is locally known as 'Malsapro' in Nepali language. We talked with the local communities who are using the areas for livestock grazing and other forest

resources. However, local people failed to identify the species, and they were completely unaware of its presence, probably due to their rarity in the area. Based on the present and earlier records, a distribution map has been updated for the species in Nepal (see Figure 1).

Discussion

Among the five species of mustelids in Nepal, two species—Mountain Weasel *M. altaica* and Siberian Weasel *M. sibirica*—were found in the GCA. Although the Siberian Weasel is listed as Least Concern in the National Red List of Nepal (Jnawali et al. 2011), its conservation status needs reevaluation. Ghimirey & Acharya (2012) suggested the species need to be placed in Data Deficient category as very limited information available for assessing status of the species. The GCA was established in 2010, and thereafter, several research- and biodiversity surveys have been conducted (GCA 2013). The recently published mammalian checklist of GCA highlighted the possibility of the presence of Siberian Weasel through a literature survey (Chetri et al. 2022). However, there was no confirmed evidence of their presence until the present finding.

Few authenticated localities of Siberian Weasel presence are known in Nepal. There have been recent confirmation records of its presence in Dhorpatan Hunting Reserve (Basnet et al. 2022). Earlier, the presence of the species was also reported from Makalu-Barun National Park and Manaslu Conservation Area (Ghimirey & Acharya 2012; Katuwal et al. 2013) and from Mugu and Humla districts which lie outside the protected area (Ghimirey & Acharya 2014; Yadav et al. 2019).

Weasels played an important role in controlling rodents from agricultural fields, but in some countries, they cause significant damage to poultry (Jo et al. 2018), and therefore they may be persecuted (Abramov et al. 2016). In GCA, human activities and livestock grazing pressure was high in the forests, as local communities are residing within the conservation area. Also, the awareness level of several forest dependent ethnic communities is limited. Therefore, awareness campaigns regarding the importance of the species are needed. As the taxonomic status of the Himalayan and Central Asian population of *M. sibirica* is still uncertain (see Abarmov et al. 2016), and several subspecies are currently recognized (Suzuki et al. 2013; Wozencraft 2005), we believe it is important to undertake a genomic study in the future.

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SHORT COMMUNICATION

Post-tsunami status, distribution, and way forward for the conservation of Andaman Teal *Anas albogularis* Hume, 1873 (Aves: Anatidae) in the Andaman Islands

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Abstract: Historically, Andaman Teal *Anas albogularis* have been primarily found in South Andaman. However, the land uplifts and subsidence resulting from the 2004 tsunami and the earthquake have created new wetlands across the island. These wetlands became suitable habitats for the Andaman Teal, leading to population expansion within South Andaman and a range shift to North Andaman.

Keywords: Avian ecology, distribution extension, land reclamation, mangrove colonization, new intertidal, new wetland.

The avifauna family Anatidae constitutes 53 genera and 174 species. They are widely distributed across the globe, from the colder regions in the Northern Hemisphere to the tropical regions in the Southern Hemisphere (Gilbert et al. 2006). Among 53 genera, the genus *Anas* is the most species-rich with 31 species, of which 11 are categorized as threatened (1 Extinct, 1 Critically Endangered, 3 Endangered, 4 Vulnerable, 2 Near Threatened), and remaining 20 categorized as 'Least Concern' as per the IUCN Red List (IUCN 2017; Winkler et al. 2020). Of the six *Anas* species reported from India (19%), two are distributed in the Andaman Islands, namely *A. albogularis* (Andaman Teal) and *A. acuta* (Northern Pintail) (eBird Basic Dataset 2023). The Andaman Teal is endemic to the Andaman Islands of India and the Great Coco Island of Myanmar in the Bay of Bengal. It currently falls under the 'Vulnerable' category (BirdLife International 2024).

Earlier, the taxonomic position of Andaman Teal was problematic, as ornithologists misplaced them in the *Nettion* genus. Later, it was misidentified as conspecific with another 'Near Threatened' species, *A. gibberifrons* (Sunda Teal). However, in 2014, the taxonomic confusion was resolved to accept the Andaman Teal as a monotypic species based on their differences in the color pattern around the eyes and the speculum (BirdLife International 2024). Further, the Andaman Teal's prime habitats to roost, feed, and breed are inland water bodies ranging from freshwater streams, ponds, agriculture fields,

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mangroves, lagoons, brackish swamps, tidal creeks, estuaries, and open sea (Grimmett et al. 1998). Natural catastrophic events like cyclones and tsunamis could directly impact these habitats, devastatingly affecting the island's vulnerable Andaman Teal population (Sutherland et al. 2012).

The 2004 Sumatra-Andaman earthquake, epicentred 200 km from Andaman & Nicobar Islands (hereafter ANI), produced large tsunami waves that severely destructed the coastal forest ecosystem, including wetlands and creeks (Sankaran 2005). Additionally, the earthquake of 9.1 intensity on the Richter scale permanently altered the island's geomorphology, leading to vertical movement of the island (Meltzner et al. 2006). The northern part of the Island (North Andaman) experienced a coastal uplift of up to 1.35 m, while the southern part (South Andaman) subsided by ~1 m (Meltzner et al. 2006). The altered geomorphology resulted in the degradation of around 150 km^2 of coastal forest habitat (largely mangroves) across Andaman Islands (135 km^2 in uplift sites of North Andaman and 15 km^2 in subsided sites of South Andaman) (Ramakrishnan et al. 2020; ShivaShankar et al. 2020). The impacts of Tsunami, coastal uplift, and subsidence on the water birds remain under-studied in the Andaman Islands. A study by Mamannan & Vijayan (2009) reported a 60% decline in the Andaman Teal population from ~136 individuals in 2004 to ~58 individuals in 2007 from South Andaman (Mohanty & Padmavati 2022).

The coastal uplift and subsidence have also created new intertidal habitats across the Andaman Islands suitable for the colonization of wetland flora and fauna (Ramakrishnan et al. 2020; ShivaShankar et al. 2020). The land uplift created new intertidal zones towards the seaward zone along North Andaman, previously colonized by corals and reef beds (Images 1A & B) (Ramakrishnan et al. 2020). Meanwhile, the subsidence created around 25 new wetlands (30 km^2) towards the landward zone in South Andaman, previously agriculture fields, terrestrial forests, or coconut plantations (Images 1E & F) (ShivaShankar et al. 2020; Purti et al. 2022). In addition to mangrove colonization, these new wetlands offer suitable habitats for waterbirds, including the vulnerable Andaman Teal, to relocate and colonize. These new habitats often exposed rocks and mudflats with molluscs, arthropods, and insects during the low tide, providing perfect roosting and feeding ground for the Andaman Teal. The formation of new habitats (Images 1B, D, E, & F) with ample food resources might be the paramount factor for the increase in Andaman Teal population in the islands by 48%, from 674 individuals in 2005 to ~1000 individuals in 2014 (Vijayan et al. 2006; Rahmani 2012; Rajan & Pramod 2017; Purti et al. 2022).

Andaman Teal, despite being endemic to the entire Andaman Island, their distribution within the island group was historically reported sporadic (Image 2A). For instance, their distribution before the 2004 tsunami was mostly in and around the wetlands of South Andaman (Kulkarni & Chandi 2003; Vijayan et al. 2006; Rahmani 2012; Rajan & Pramod 2017; Purti et al. 2022). Some literature also suggests that Andaman Teals were residents of the wetlands of South Andaman, rarely migrating to North Andaman (North Reef and Interview Island) in groups of 20–30 individuals as visitor birds (Andrews & Whitaker 1994; Vijayan 1996; Vijayan et al. 2000). Further, on accessing the location of point count of Andaman Teal before and after 2004 tsunami from the e-bird database, we found their distribution and abundance were mostly restricted to South Andaman before the tsunami (Image 2A). Their sighting reports and abundance extended to the North and Middle Andaman post-2004 tsunami (Images 2A & B). The reporting of bird sightings on the e-bird database before the 2004 tsunami from the islands would be scarce mostly due to the remoteness and inaccessibility of the Islands. Meantime, while conducting the mangrove survey in the new intertidal habitat of North Andaman, we observed 30–40 individuals (including young ones) of Andaman Teal for three consecutive years (2021–2023) at two locations, namely Chippo (Caren Basti—13.5478^{0}N & 93.0104^{0}E), and Beach Dera (13.4645^{0}N & 93.0167^{0}E) (Image 2A & B). These observations were further inquired with the village head of Beach Dera (Gabriel Toppo) and Chippo (Saw Solomon & Saw Lakapow), who confirmed that these ducks (vernacular name: Paani Batak) were not present before the 2004 tsunami but seen permanently residing here for around the last 5–6 years.

Even though Andaman Teal's population status and distribution show an increasing trend in Andaman Island (Vijayan et al. 2006; Rahmani 2012; Rajan & Pramod 2017; Purti et al. 2022) (Image 2B), they are under threat from various natural and anthropogenic disturbances. The new intertidal habitat is currently under succession from unvegetated (post-tsunami event) to gradual colonization by mangroves and associates. Mangroves would eventually occupy the new wetlands and intertidal habitats, leading to Andaman Teal and other waterbird populations shrinking in the future. Further, the new wetlands formed in subsided sites of South Andaman, where a large proportion of the Andaman Teal population resides, are largely privately owned farmlands (Images

Image 1. Formation of new wetlands and intertidal habitats with water bird and mangrove colonization in Andaman Island: A & B—Andaman Teal using the wetlands in the uplifted site in Chippo of North Andaman Island | C & D—Andaman Teal using the wetlands in the uplifted site at Beach Dera of North Andaman Island | E & F—Andaman Teal in the new wetland at the subsided site of South Andaman with land reclamation from behind. © A & C—Google Earth | B & D—Anoop Raj Singh | E & F—Vishnu Thavara.

1E & F) (Purti et al. 2022). Now, these lands (currently new wetlands) are undergoing reclamation by the landowners (Images 1E & F), which will again endanger the population status of Andaman Teal in the near future. Hence, identifying and mapping potential habitats and management of land under private ownership will be a crucial step towards sustaining the Andaman Teal population in the Andaman Islands. Moreover, long-

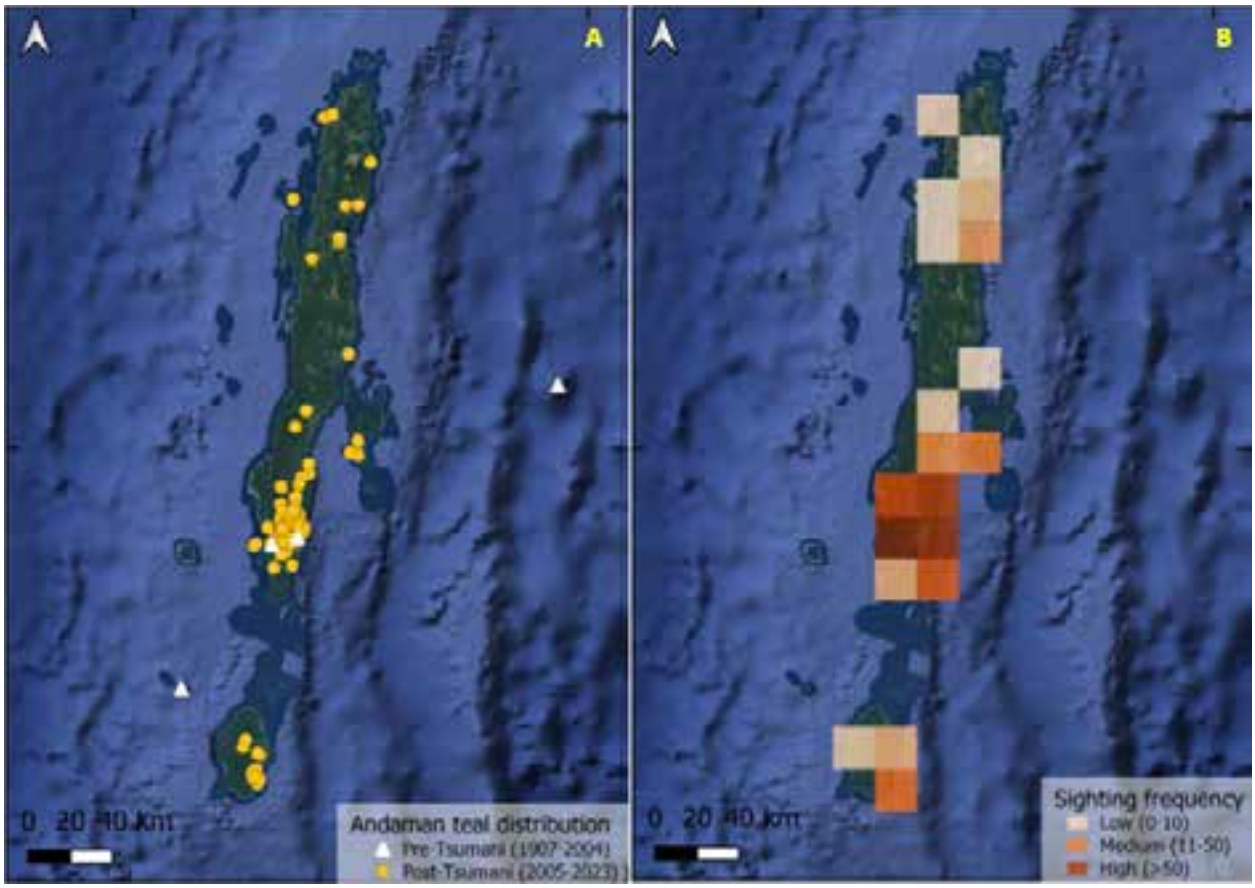

Image 2. Spatial distribution of *A. albogularis* (Andaman Teal) in the Andaman Group of Islands based on ebird data (eBird Basic Dataset 2023): A—distribution of Andaman Teal in the islands before and after the 2004 tsunami | B—sighting frequency of Andaman Teal in the islands after the 2004 Tsunami. (Map prepared in ArcMap Version 10.5).

term monitoring of these new wetlands with continuous population estimation should be a priority to conserve Andaman Teal and other water birds on the island. To strengthen our baseline information, focused research on Andaman Teal movement ecology, habitat use, diet, and breeding ecology is of utmost importance, which will help the managers and policymakers to conserve the species upon any futuristic catastrophic events.

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SHORT COMMUNICATION

A preliminary checklist of Copepoda in the mangrove areas of Munroe Island, adjacent to Ashtamudi estuary, Kerala, India

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Abstract: The present investigation was conducted to assess the species composition of Copepoda in Munroe Island from October 2020 to September 2022. As the information about the species composition of Copepoda is scarce in the mangrove habitats of the southern part of Kerala, their appraisal assumes greater significance. Copepod samples collected from the mangrove habitats of Munroe Island of Kerala (southern India) revealed 31 species belonging to 18 genera and 15 families. The order Calanoida was recognized as the most dominant taxa with 23 species, followed by Harpacticoida (five species) and Cyclopoida (three species). Among the 15 families encountered, Acartiidae, Centropagidae, Harpacticidae, Paracalanidae and Pseudodiaptomidae were the most diverse. Species such as *Acartia bilobata*, *Paracalanus parvus*, *Pseudodiaptomus aurivillii*, *Pseudocalanus elongatus*, *Microsetella norvegica*, and *Oithona similis* were found to be perennial. The investigation calls for intensive copepod surveys to reveal their ecology and diversity in the hitherto less-studied region in southern India.

Keywords: Copepod, diversity, ecology, mangrove habitats, species, survey.

Copepods are considered one of the major planktonic taxa due to their unique tactical position in the aquatic food webs. Their sheer abundance and diversity make them dominant in a wide variety of aquatic habitats. Furthermore, they play a pivotal role in the energy transfer of freshwater as well as marine ecosystems (Hani & Jayalakshmi 2023). Taxonomic investigations on Copepoda from Indian brackish waters began more than a century ago (Sewell 1914; Gurney 1916; Sewell 1924).

The Indian literature shows a scarcity of research on the faunal diversity of Copepoda from the mangrove areas. The relevant works from southern India are limited to reports from the Pichavaram mangroves, Muthupet mangroves, Ayiramthengu mangroves and the Ashtamudi estuary of Kerala (Kathiresan 2000; Santhanam et al. 2013; Ranjana & Amina 2019; Rajan 2020). On the other hand, Copepoda inhabiting mangrove areas in various parts of southern India are yet to be exposed. Hence, the present investigation on the diversity of copepods of the mangrove areas of Munroe Island, Kerala assumes a great significance from both taxonomical and conservation perspectives. Identified species from Munroe Island are listed in this paper. The preliminary data obtained on the 31 species of copepods in the study area will be an asset for future environmental monitoring investigations.

Materials and Methods

Study area: The Munroe Island (8.9911^{0}N & 76.6097^{0}E) (Image 1) is situated at the confluence of the Ashtamudi estuary and the Kallada River in the Kollam district of Kerala. Munroe Island comprises a significant geological portion of the South Indian peninsula, crystalline rocks

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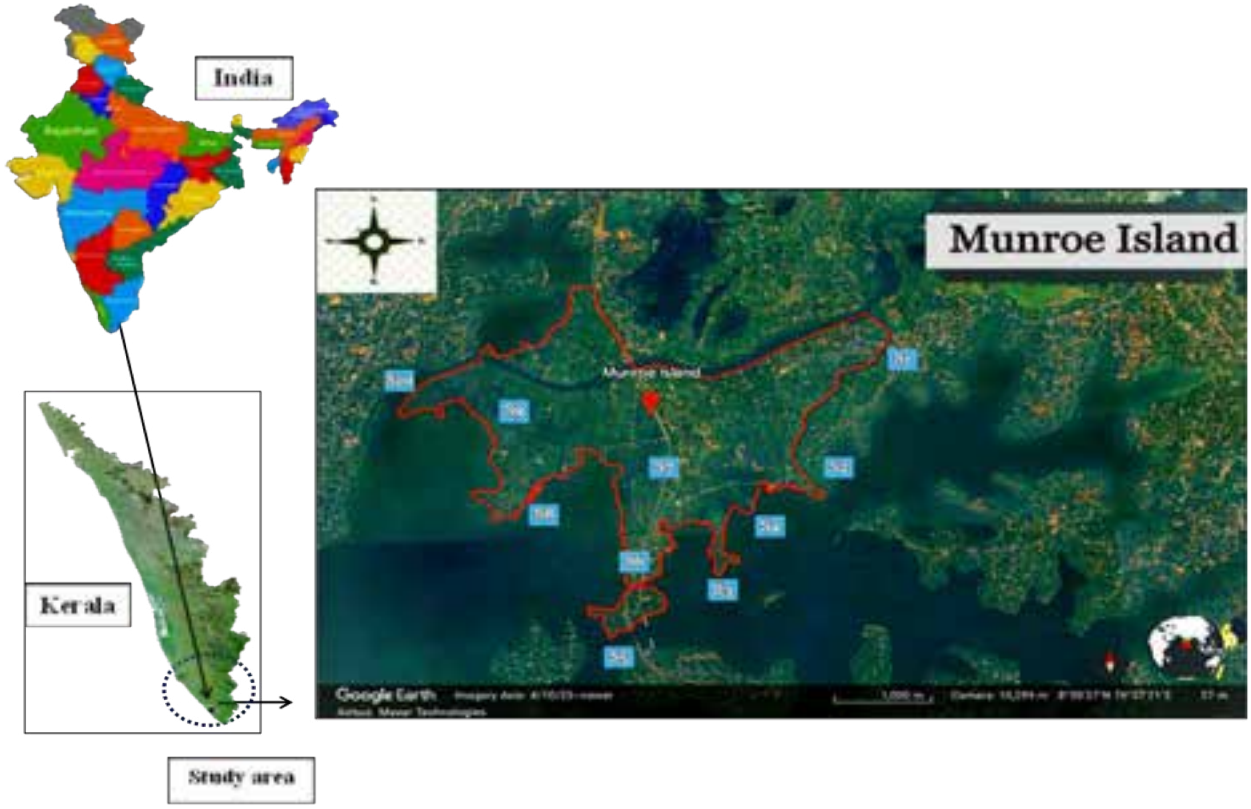

Image 1. Study area with sampling sites.

and tertiary sediments being the major components of the estuary. The annual rainfall and mean temperature of Munroe Island are 270 cm and 25–32 ^{0}C, respectively. Additionally, 75% of the annual rainfall occurs during the southwest monsoon (June–September) and northeast monsoon (October–November). The land use pattern mainly consists of coconut gardens and mixed crops. The study area is also characterized by 11 mangrove species and numerous tidal creeks.

Methods of study: Copepod samples were collected using working party plankton net with a mouth area of 200 µm, 60 cm diameter, and a length of 2 m, equipped with a flow meter (Norinco). The net was hauled for 10 minutes at the surface using a boat traveling at a speed of approximately 2 knots. The samples were transferred to a pre-cleaned bottle and 10% buffered formaldehyde solution was used for fixation (Goswami 2004). Subsequently, the samples were transported to the Zoology Research Centre, St. Stephen's College, Pathanapuram for further analysis.

All the samples were screened using a trinocular compound microscope (Weswox MHL-46TR). Taxonomic keys were referred for copepod species identification (Davis 1955; Kasturirangan 1963; Sebastian 1966; Wimpenny 1966; Newell & Newell 1986; Santhanam & Perumal 2008).

Results and Discussion

This pioneering study on the copepod diversity of Munroe Island records 31 species (Table 1). Species such as *Acartia bilobata, Paracalanus parvus, Pseudodiaptomus aurivillii, Pseudocalanus elongatus, Microsetella norvegica*, and *Oithona similis* occurred in all sampled sites. Conversely, species such as *Heliodiaptomus cinctus, Mesocyclops aspericornis*, and *Mesocyclops leuckarti* occurred exclusively in stations with strong freshwater influence. On the other hand, the remaining copepod communities were exclusively found in the stations adjacent to the Ashtamudi estuary.

This report raises the number of copepod species known from southern Kerala to 61 species. The number of copepod genera in Munroe Island was marginally higher than the 14 genera noticed at the Ashtamudi estuary by Rajan (2020), but lesser than the 104 species from Coleroon estuary by Rajkumar et al. (2014) and 112 species from Rushikulya estuary by Srichandan et al. (2015).

Few reports are available on zooplankton species-

Table 1. Systematic list of the examined species.

	Phylum: Arthropoda von Siebold, 1848
	Class: Copepoda Milne Edwards, 1840
	Order: Calanoida Sars G.O., 1903
	Family Acartiidae Sars G.O., 1903
1	*Acartia bilobata* Abraham, 1970
2	*Acartia centrua* Giesbrecht, 1889
3	*Acartia southwelli* Sewell, 1914
4	*Acartia spinicauda* Giesbrecht, 1889
5	*Acartiella major* Sewell, 1919
	Paracalanidae Giesbrecht, 1893
6	*Acrocalanus gibber* Giesbrecht, 1888
7	*Acrocalanus gracilis* Giesbrecht, 1888
8	*Acrocalanus longicornis* Giesbrecht, 1888
9	*Paracalanus parvus* (Claus, 1863)
	Pontellidae Dana, 1852–1853
10	*Calanopia aurivilli* Cleve, 1901
	Centropagidae Giesbrecht, 1892
11	*Centropages alcocki* Sewell, 1912
12	*Centropages furcatus* (Dana, 1849)
13	*Centropages trispinosus* Sewell, 1914
	Diaptomidae Baird, 1850
14	*Diaptomus glacialis* Lilljeborg, 1889
15	*Heliodiaptomus cinctus* (Gurney, 1907)
	Euchaetidae Giesbrecht, 1893
16	*Euchaeta marina* (Prestandrea, 1833)
17	**Pseudodiaptomidae** Sars G.O., 1902
	Pseudodiaptomus annandalei Sewell, 1919
18	*Pseudodiaptomus aurivillii* Cleve, 1901
19	*Pseudodiaptomus binghami* Sewell, 1912
20	*Pseudodiaptomus serricaudatus* Scott T., 1894
	Clausocalanidae Giesbrecht, 1893
21	*Pseudocalanus elongatus* (Brady, 1865)
	Temoridae (Giesbrecht, 1893)
22	*Temora stylifera* (Dana, 1849)
	Calanidae Dana, 1849
23	*Undinula vulgaris* (Dana, 1849)
	Order Harpacticoida Sars G.O., 1903
	Tachidiidae Sars G.O., 1909
24	*Euterpina acutifrons* (Dana, 1847)
	Harpacticidae Dana, 1846
25	*Harpacticus clausi* Scott A., 1909
26	*Harpacticus gracilis* Claus, 1863
27	*Harpacticus littoralis* Sars G.O., 1910
	Ectinosomatidae Sars G.O., 1903
28	*Microsetella norvegica* (Boeck, 1865)
	Order Cyclopoida Burmeister, 1834
	Cyclopidae Rafinesque, 1815
29	*Mesocyclops aspericornis* (Daday, 1906)
30	*Mesocyclops leuckarti* (Claus, 1857)
	Oithonidae Dana, 1853
31	*Oithona similis* Claus, 1866

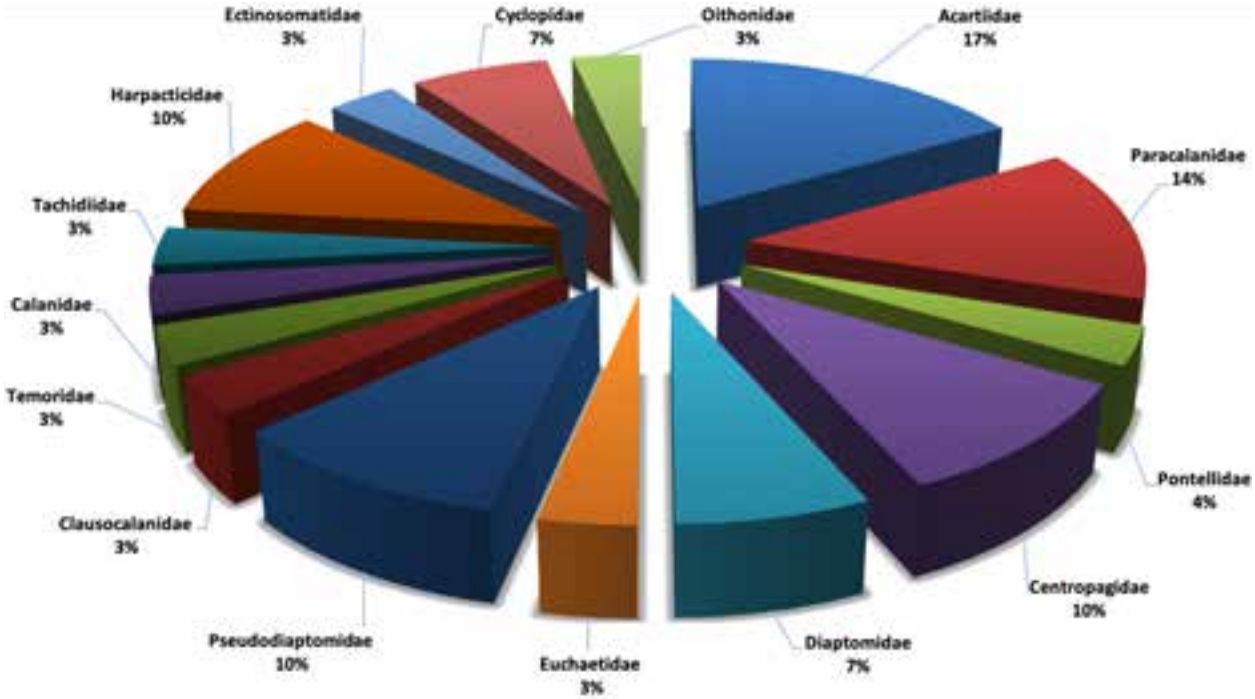

Figure 1. Percentage composition (%) of recorded copepod communities on Munroe Island.

level distribution in the adjacent estuaries in Kerala. In the case of Ashtamudi estuary, Arunachalam & Nair (1988) collected a total of 19 species representing eight families of harpacticoid copepods; Rajan (2020) collected 14 genera of copepods; Hani & Jayalakshmi (2023) collected a total of 53 copepod species under 31 genera belonging to 20 families.

In the present investigation, Calanoida was the most dominant taxa in terms of species richness (23 species) (Figure 1). Also, these findings support the reports of Gaonkar et al. (2010) from Mumbai ports; Pillai et al. (2014) from the Andaman Islands; Srichandan et al. (2015) from Rushikulya estuary. According to the existing literature on copepod diversity in most cases, calanoids stood foremost while the richness of other copepod taxa varied due to environmental changes.

Conclusion

This study recorded a total of 31 copepod species, belonging to 15 families and three orders. They were in the following order of dominance: Calanoida > Harpacticoida > Cyclopoida. These findings reveal the copepod diversity in Munroe Island which could be potentially used as a repository for further environmental monitoring of Munroe Island.

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First photographic record of Asiatic Brush-tailed Porcupine *Atherurus macrourus* Linnaeus, 1758 from Sonai Rupai Wildlife Sanctuary, Assam, India

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The Asiatic Brush-tailed Porcupine *Atherurus macrourus* is a nocturnal rodent species endemic to southern Asia and is distributed throughout central China, north-eastern India, Bhutan, Bangladesh, Myanmar, Laos, Vietnam, and Thailand (Dhendup & Dorji 2017; Molur 2020). In northeastern India, the species has been reported from Arunachal Pradesh (Agarwal 2000; Datta et al. 2008), Assam (Choudhury 2013), Meghalaya (Agarwal 2000), Mizoram (Forest Clearance 2013), Nagaland (Kumar & Kaul 2013) and northern West Bengal (Dash et al. 2021). In Assam specifically, it has been camera-trapped in Barak Valley (Gassah & Ismavel 2020) and Manas National Park (Bhatt et al. 2023). Despite being recorded in various protected areas (PAs), the species is considered uncommon in the northeastern states of India, with its geographic distribution limited to specific pocket areas (Talukdar et al. 2019). The species is classified as 'Least Concern' by the IUCN Red List of Threatened Species (Molur 2020) and in India, it is listed in Schedule I of the Wild Life Protection Act, 1972 (amended). There is a pressing need to ascertain the distribution of the species, given reports indicating a 20 percent (approx.) global decline in the populations of all three porcupine species found in the region, including the Indian Crested Porcupine *Hystrix indica*, Himalayan Crestless Porcupine *Hystrix brachyura*, and Asiatic Brush-tailed Porcupine *Atherurus macrourus* (Molur et al. 2005). Despite these concerning trends, very limited literature is available on their population, behavioural ecology, feeding, and nesting habits, posing challenges for the formulation of effective conservation action plans.

Sonai Rupai Wildlife Sanctuary is situated in the foothills of the eastern Himalaya and is contiguous with Doimara Reserve Forest and Eaglenest Wildlife Sanctuary in Arunachal Pradesh. Out of the 220 km^2 of eastern wet alluvial grasslands, moist deciduous, and semi-evergreen forests (Champion & Seth 1968), most parts have been encroached upon. In 2015, the remaining 120 km^2 of the forested area was notified as a 'satellite core' of Nameri Tiger Reserve. Once abundant with Greater One-Horned Rhinoceros *Rhinoceros unicornis*, Wild Buffalo *Bubalus arnee*, White-winged Wood Duck *Asarcornis scutulata*, and Bengal Florican *Houbaropsis bengalensis*, which are now locally extinct (BirdLife International 2023). Furthermore, it has been recognized as an Important

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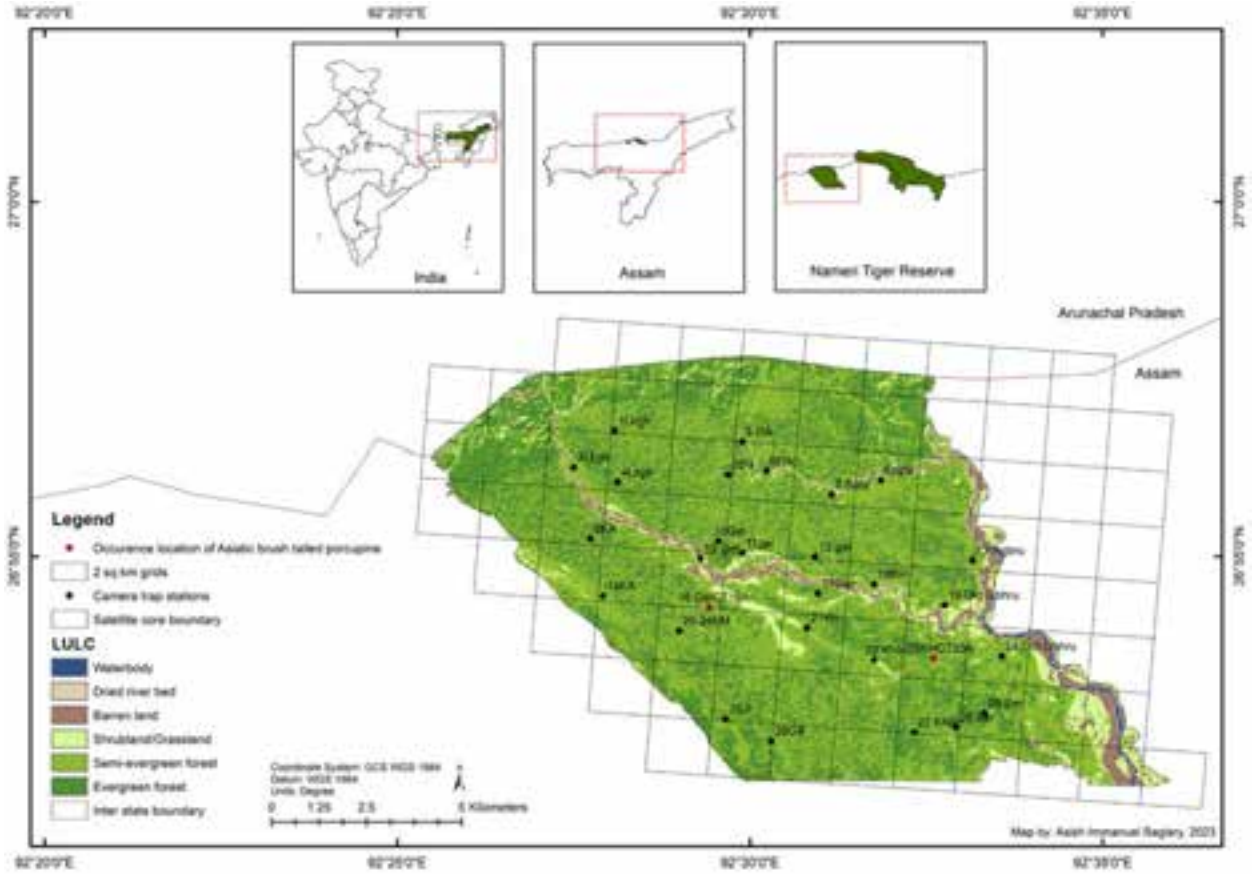

Figure 1. Map showing camera trap locations in Satellite Core of Nameri Tiger Reserve.

Bird Area (IBA) and is home to rich avifauna including migratory birds (Nameri Tiger Reserve 2023).

As part of the Phase IV Protocol of the National Tiger Conservation Authority 2022–23, 58 camera traps were deployed in the satellite core area with a sampling effort (n = 30) from 25 November to 25 December, 2022. Each trail camera (CUDDEBACK X-Change Color Model 1279) was positioned in a fabricated camera trap holder at a height of approximately 30–45 cm above the ground. The cameras were placed to face each other in 2 km^2 grids (Figure 1). The species was recorded from two camera trap stations (92.543°N, 26.892°E & 92.490°N, 26.904°E) with three independent captures (Image 1). The captures occurred post-midnight at 0055 h, 0209 h, and 0106 h, indicating its nocturnal nature. The species was observed in a semi-evergreen forest with tree species such as *Bombax ceiba*, *Stereospermum tetragonum*, and *Amoora wallichii*. Moreover, the species is not site-specific and inhabits tropical wet evergreen, tropical semi-evergreen, and sub-tropical broadleaf hill environments (Talukdar et al. 2019; Bhatt et al. 2023). The species can be distinguished from the Indian Crested Porcupine and Himalayan Crestless Porcupine due to the absence of a crest, with its dorsal covered with rigid spines and its tail-bearing scales with short spiny bristles in-between, ending in a cluster of alternately expanded and contracted papery hair 8–10 cm long, giving it a brush-like appearance (Agarwal 2000). Given that this is the first photographic record of the Asiatic Brush-tailed Porcupine in Sonai Rupai Wildlife Sanctuary, it will assist in the upgradation of the IUCN Red List distribution map for the concerned species. Furthermore, this is a least studied species and no robust information is available, making it extremely important to systematically study the species, its distribution, and ecology before any potential threats arise.

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Image 1. Captured images of *Atherurus macrourus*.

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New country record of *Trimeresurus uetzi* Vogel, Nguyen & David, 2023 (Reptilia: Squamata: Viperidae) from India

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The systematics of the White-lipped Pit Viper *Trimeresurus albolabris* Gray, 1842 group has been reviewed by several workers, and a subspecies level taxonomy was historically proposed (Kramer 1977; Regenass & Kramer 1981). However, the original members of this group—*T. insularis* Kramer, 1977 and *T. septentrionalis* Kramer, 1977—were eventually elevated to species status by Giannasi et al. (2001). Later, genetic studies also showed the paraphyly of *T. albolabris* group (Malhotra & Thorpe 1997, 2000; Zhu et al. 2016), and the distribution range of *T. albolabris* sensu stricto was subsequently restricted to southeastern China and northeastern Vietnam (Chen et al. 2021). Several new species were described from the *T. albolabris* group during recent years, such as, *T. caudornatus* Chen, Yu, Vogel, Shi, Song, Tang, Yang, Ding & Chen, 2020; *T. davidi* Chandramouli, Campbell & Vogel, 2020; *T. guoi* Chen, Shi, Gao, Vogel, Song, Ding & Dai, 2021; *T. salazar* Mirza, Bhosale, Phansalkar, Sawant, Gowande & Patel, 2020; and most recently, *T. uetzi* Vogel, Nguyen & David, 2023 (see also Vogel et al. 2023).

In this study, we examined specimens of *Trimeresurus* species housed in the collection of Departmental Museum of Zoology, Mizoram University (MZMU). Head measurements were taken using Mitutoyo dial vernier caliper (Model 505–730) to the nearest 0.01 mm, while the snout-vent length (SVL) and tail length (TaL) were taken using measuring tape. Ventrals (Ve) and mid dorsal scales row (MSR) were counted following Dowling (1951), and the terminal scute is excluded while counting subcaudals (Sc). Dorsal scales were counted at one head length just behind the head, at mid body, and one head

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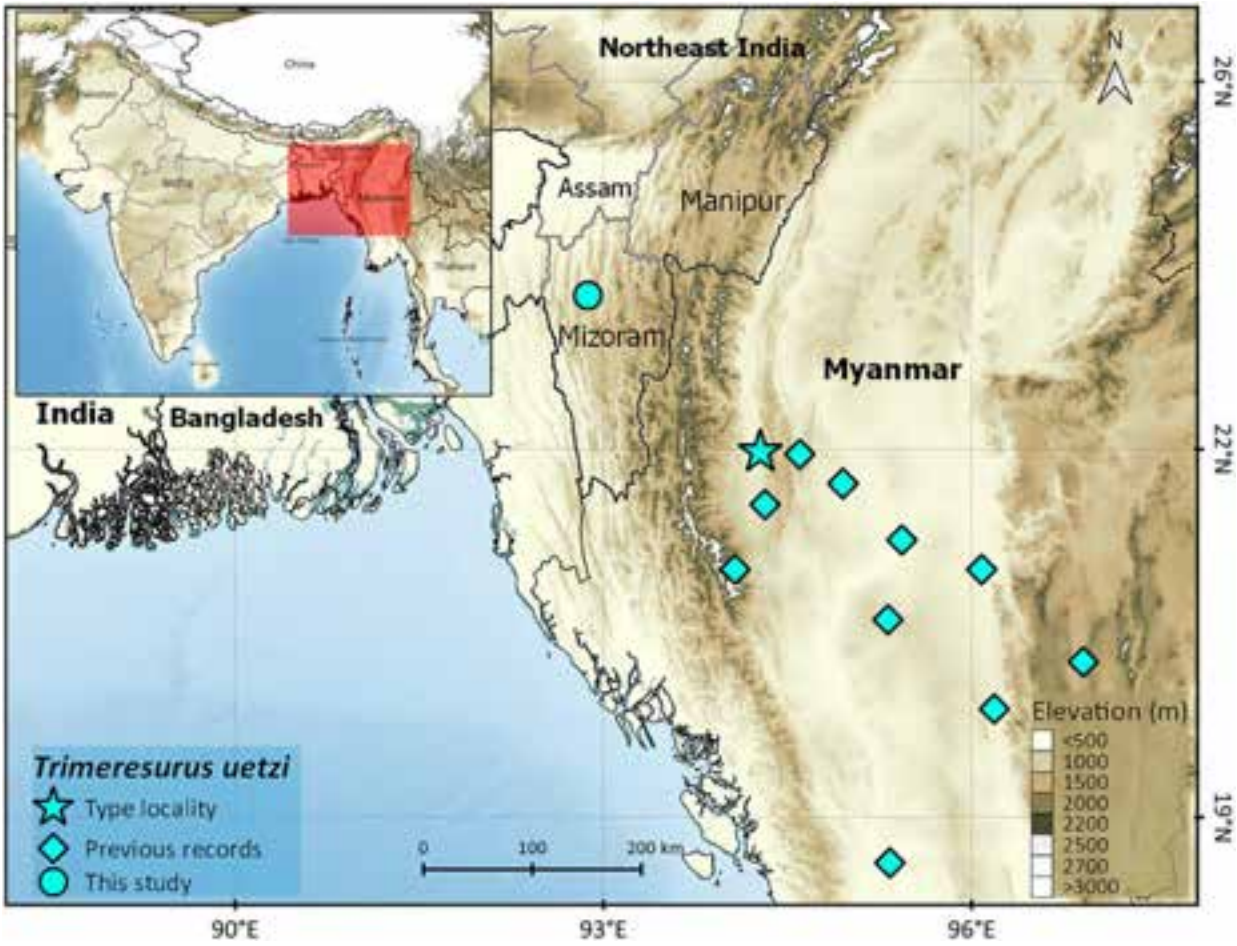

Figure 1. Map showing distribution records of *Trimeresurus uetzi*: type locality in Mauk Village, Gangaw Township, Pakhokku District, Magway Region, Myanmar (red star); other previous records in Myanmar (blue diamonds), and new collection site (red circle) from Aizawl, Mizoram, India. The published records are adopted from Vogel et al. (2023).

length just before the vent.

Morphologically, one adult male of the examined museum specimens collected from Mizoram University campus (23.7384°N; 92.6642°E; 822 m; Figure 1) did not match with the taxonomic features of other *Trimeresurus* species, which were already confirmed from Mizoram State and adjacent regions. MZMU 3333 differs from regional congeners in having Ven 165 versus 159–164 in male *T. caudornatus* Chen, Ding, Vogel and Shi, 2020, MSR 21 vs 23 (24, 25) in male *T. erythrurus* (Cantor 1839); ventrolateral stripes and a postocular stripe present vs absent, iris copper vs firebrick-red or deep red in males *T. guoi* Chen, Shi, Vogel & Shi, 2021; ventrolateral stripe white vs stripe bicolor (red and white), Ven 165 vs 157–162, and Sc 69 vs 54–67 in males *T. mayaae* Rathee, Purkayastha, Lalremsanga, Dalal, Biakzuala, Muansanga & Mirza, 2022, and 10 cephalic scales feebly keeled between the supraoculars vs 11–13, iris copper coloured vs red to deep red, and ventrolateral stripes and a postocular stripe present vs absent in males of *T. popeiorum* Smith, 1937 (see also Mathew 2007; Lalremsanga et al. 2011; Mirza et al. 2023; Vogel et al. 2023; Idiiatullina et al. 2024). Instead, it is in agreement with the diagnostic features of the recently described *T. uetzi* as provided in the original description (Vogel et al. 2023): presence of white postocular stripe in males; first supralabial not fused with nasal scale; 10 cephalic scales feebly keeled (range 9–10); Ven 165 (range 154–171) in males; Sc 69 (range 50–71 in males); dorsal scale rows 21:21:15 (Images 1 & 2). Other morphological data of MZMU 3333 are provided in Table 1. The live snake depicted in Image 2, is not the Aizawl voucher specimen, but an uncollected male, sighted in Reiek Community Reserve Forest, some 5 km aerial distance west of Mizoram University campus – the collection site of MZMU 3333. We also attribute this individual to *T. uetzi*, as it possesses 21 dorsal mid body scale rows, green gold colored iris; a grass green

Image 1. Male specimen of *Trimeresurus uetzi* (MZMU 3333) from Mizoram University Campus, Aizawl, Mizoram, India. Scale bar = 10 mm. © Lal Muansanga.

Image 2. Uncollected live male individual of *Trimeresurus uetzi* from Reiek Community Reserve Forest, Mizoram, India. © Lal Muansanga.

Table 1. Morphometric (in mm) and meristic data of *Trimeresurus uetzi* from Mizoram, northeastern India. The general data for the species were adopted from Vogel et al. (2023).

Sources	This study	General data from Vogel et al. (2023)	
Museum voucher	**MZMU 3333**		
Sex	male	males	females
Snout-vent length (mm)	485	251–472	242–689
Tail length (mm)	127	48–119	53–122
Tail length/Total length	20.8%	16%–22%	14%–16%
Head length (mm)	25.84	-	-
Head width (mm)	14.71	-	-
Horizontal eye diameter (mm)	3.79	-	-
Eye to nostril distance (mm)	5.79	-	-
Snout tip to anterior eye distance (mm)	7.98	-	-
Snout width (mm)	5.70	-	-
Interorbital distance (mm)	11.34	-	-
Internarial distance (mm)	5.04	-	-
Ventrals (mm)	165	154–172	157–171
Preventral	2	-	-
Subcaudals	69	60–71	50–55
Dorsal scale rows	21:21:15	21:21:15	21:21:15
Supralabials	10/11	10–12/10–12	9–12/9–11
Infralabials	12/13	10–14/11–13	11–14/11–14
Anal scale	undivided	-	-
Cephalic scales	10	9–10	9–10

dorsum and yellowish-green venter; a white postocular streak from the anterior margin of the nasal scale that connects posteriorly to the white dorsolateral stripe at the corner of the mouth, plus lack of red stripes on facial and ventrolateral regions. *Trimeresurus uetzi* is a species so far known from central and southern Myanmar but unrecorded from India (Vogel et al. 2023). The present specimen MZMU 3333 from Aizawl, thus represents the longest male recorded so far, 612 mm in total length against the existing maximum total length 591 mm (Holotype; CAS 243024) (see Vogel et al. 2023) and forms the first record of this species from within Indian boundary.

Unfortunately, we were unable to generate DNA data from the MZMU 3333 due to preservation of the specimen in formalin. We recommend obtaining more specimens and genetic data from a fresh sample to corroborate the present report and to further investigate putative cryptic diversity especially among green pit-vipers in northeastern India. However, this work represents a new country record of the species from India and a range extension of the species by ca. 215 km aerial distance northwestward from the type locality at Mauk Village, Gangaw Township, Pakhokku District, Magway Region, Myanmar which is also the nearest known locality from our record (see Vogel et al. 2023). Considering the refinement of the range of the previously confused species, *T. septentrionalis* sensu stricto (now restricted to the western and central Himalayan regions of Nepal and northern India), there is high probability that the population of *T. septentrionalis* in Bangladesh as also doubted by Vogel et al. (2022) might actually be *T. uetzi* or *T. salazar*, considering that records of the later species are closer to Bangladesh which will require further reassessment. Apart from the criteria of geographical range, we discriminated our male specimen of *T. uetzi* by its lower total number of ventral and subcaudal scales, i.e., 234 vs. 241.67±7.76 in male *T. septentrionalis*; white postocular stripe wide and conspicuous covering 1–2 scales vs. usually absent or thin and pale, covering 1 scale in *T. septentrionalis* (fide Vogel et al. 2023).

We also opine that the Indian population may not be unheard of, but just that the recent description of *T. uetzi* by Vogel et al. (2023) enabled us to recognize it as a species. Although several workers have recently described new *Trimeresurus* species particularly from the Indo-Burma region (e.g., Mirza et al. 2020; Rathee et al. 2022; Chan et al. 2023; Vogel et al. 2023), the systematics of many *Trimeresurus* species from this region need further reassessment through integrated taxonomic approaches (Vogel et al. 2023). Limited sampling bolstered by intricated phenotypic variations and phylogenetic uncertainty are seemingly attributable to the systematics challenges for this group in the Indo-Burma region (see Malhotra & Thorpe 2000; Chandramouli et al. 2020; Chen et al. 2020; Mallik et al. 2021; Vogel et al. 2022, 2023).

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New record of Giant Redeye *Gangara thyrsis thyrsis* (Fabricius, 1775) (Lepidoptera: Hesperiidae) from Garhwal region of western Himalaya, India

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The Giant Redeye, *Gangara thyrsis thyrsis* is the largest skipper with a wingspan of 70–76 mm, known for its quick darting flight, and occurring in the Indian peninsular region (Evans 1932). *G. thyrsis* prefers lowland forests and plantations having a flight period from January to December (Kehimkar 2016). It is an elusive butterfly owing to its crepuscular habit. *G. thyrsis* occurs as four subspecies – *clothilda* (Herrich-Schaffer, 1869) is endemic to Ceylon (Sri Lanka); *thyrsis* (Fabricius, 1775) has distribution extending in peninsular India from Maharashtra to Kerala, Andhra Pradesh, and in northeastern India from West Bengal to Sikkim & Arunachal. In northwestern India it has been reported only from Delhi & Kangra in Himachal Pradesh and also from Andaman & Nicobar Islands (Evans 1949); *pandina* (Evans, 1949) inhabits Java in Indonesia; and *philippensis* (Fruhstorfer, 1911) is found in Philippines (Evans 1932; Kehimkar 2014, 2016; Vashney & Smetacek 2015). *G. thyrsis* has also recently been reported from Chitwan National Park in central Nepal where it is 'very rare' and during April & August preferring 'riverine' and 'sal forests' habitats (Smith 1997). A single visual record of *G. thyrsis* during August 2015 is known from Pawalgarh Conservation Reserve, Nanital District and another one from Champawat District in Kumaon region of Uttarakhand (Sondhi & Kunte 2018). However, there is no other record of its occurrence within the Garhwal region of Uttarakhand and recent surveys have failed to record this species in the state (Singh & Sondhi 2016; Singh 2021).

Present observations

On 24 October 2023, *G.t. thyrsis* (Fabricius, 1775) was recorded in the New Forest Campus of Forest Research Institute (30.3368° N & 77.9994° E; 663 m; 1035 h; Temp. 23.5° C; RH 43%), Dehradun, India. Only one individual was recorded, feeding on refuse along the roadside in a forested area. As it could not be properly identified on the wing, the specimen was collected, pinned, and preserved in the laboratory for further identification (Image 1a,b). This specimen was later identified as *G.t. thyrsis* on comparison with a museum specimen of *G.t. thyrsis* from Khasi Hills, Assam, India kept in the National Forest Insect Collection (NFIC) at the Forest Research Institute, Dehradun (Image 2a,b).

G. thyrsis is identified by some of its distinctive features like relatively large body size, large wine-red eyes, large quadrate semi-transparent yellow spots and three smaller apical spots on forewings and the underside of both wings dusted with grey scales forming distinct bands (Evans 1932; Kehimkar 2016). It is different from Palm Redeye, *Erionota thrax* (Linnaeus, 1767) which also occurs in its distribution range and is more common but lacks three apical spots on the forewings besides the absence of dusting of grey scales undersides of both wings (Kehimkar 2016) (Images 1 & 2).

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Figure 1. Map depicting the location of the present record of Giant Redeye *Gangara thyrsis* in Dehradun Valley, Uttarakhand in relation to its records in other sites in northern India, as mentioned in text.

Furthermore, another individual of *G.t. thyrsis* had been previously observed feeding on refuse in the Vasant Vihar residential area (30.3285° N & 78.0006° E; 660 m; 07.vii.2023) in Dehradun, Uttarakhand at dusk.

The larval host plants of *G.t. thyrsis* belong to the family Arecaceae (Robinson et al. 2010), i.e., *Calamus* sp., *Calamus pseudofeanus*, *C. thwaitesii*, *C. rotang*, *Caryota urens*, *Chamaerops humilis*, *Cocos nucifera* (Wynter-Blyth 1957; Kunte 2000, 2006; Robinson et al. 2010), *Coryphaum braculifera*, *Licuala grandis*, *Licuala chinensis*, *Phoenix acaulis*, *P. loureiroi* (Wynter-Blyth 1957; Kunte 2000, 2006; Nitin et al. 2018) (Arecaceae); *Zingiber officinale* (Zingiberaceae) (Kalesh & Prakash 2007); and *Cyperus alternifolius* (Cyperaceae) in Bengaluru (Saji et al. 2018). Robinson et al. (2010) have also reported *Saccharum officinarum* (Poaceae) as its unconfirmed larval host. In the New Forest Campus (botanical garden & plantations), a variety of larval host plants can be found. Notably, species such as *Calamus* spp., *Phoenix acaulis*, *Caryota urens*, *Phoenix rupicola*, *Sabal domingensis* are present, providing a favourable environment for the potential breeding of *G. thyrsis*.

This is the first known authentic record of *G.t. thyrsis* from the Garhwal region of Uttarakhand, India.

Image 1. Giant Redeye *Gangara thyrsis thyrsis* (Fabricius, 1775): a—Dorsal aview | b—Ventral view. Specimen collected in New Forest Campus, Dehradun, Uttarakhand, India (24.x.2023, wingspan: 70 mm. Collection: Arun P. Singh, FRI; collector: Ankita Singh Sajwan.

Image 2. Giant Redeye *Gangara thyrsis thyrsis* (Fabricius, 1775) from NFIC-FRI, Dehradun (Accession No.13407; Khasi Hills, Assam, India, coll. O.C. Ollenbach, 1916).

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Strobilanthes khasyana (Acanthaceae): an addition to the flora of Nagaland, India

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The genus *Strobilanthes* Blume belonging to Acanthaceae is represented by 454 species (POWO 2024) in the world mostly distributed in Asia tropical and sub-tropical hilly regions (Wood et al. 2021). In India, the taxon is represented by 150 species (Wood et al. 2021), 167 species (BSI 2024), and about 85 species reported from northeastern India mostly reported from the states of Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, and Tripura (Wood et al. 2021). In Nagaland state, about 20 species of *Strobilanthes* have been reported (Mao et al. 2017) and about 33 species were updated in the website (BSI 2024). Moaakum & Chaturvedi (2015) reported eight species of *Strobilanthes* from Zunheboto district, Kapfo (2018) had reported nine species of *Strobilanthes* from Pulie Badze Wildlife Sanctuary and Jotsoma Community Forest, Kohima. Mozhui (2014) and Sachu (2018) had reported one species each of *Strobilanthes* from Dimapur district and Japfu Mountain. Lea (2023) reported seven species of *Strobilanthes* from Phek district.

During the field exploration to Phek District of Nagaland, an interesting species of *Strobilanthes* was collected at Khulazu Basa Forest of Zanübu mountain range. On further critical examination of the species and consultation with the available literature (Kanjilal et al. 1939; Clarke 1884, 1885; Wood 2001; Venu 2006; Mao et al. 2017), the species was identified as *Strobilanthes khasyana*, which is hitherto unknown to angiospermic flora of Nagaland, Northeast India. The taxon has been reported to be an endemic to the states of Meghalaya, Sikkim, and West Bengal (BSI 2024). The occurrence of *S. khasyana* is an extension of its new distributional range to Nagaland state.

Plants were collected, dried, and pressed and herbarium sheet were prepared following the standard given by Jain & Rao (1976). Field photographs were taken using Canon EOS200D. Measurements of plant parts were based on the living plant specimens. Herbarium have been deposited in the Angiospermic Herbarium, Department of Botany, Nagaland University for future reference [NU-PM-260].

Taxonomic treatment

Strobilanthes khasyana (Nees) T. Anderson, J. Linn. Soc., Bot. 9: 471. 1867. *Endopogon khasyanus* Nees in A.P.de Candolle, Prodr. 11: 104. 1847; *Listrobanthes khasyana* (Nees) Bremek. in Verh. Kon. Ned. Akad. Wetensch., Afd. Natuurk., Sect. 2, 41(1): 254.

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Image 1. *Strobilanthes khasyana* (Nees) T. Anderson. a—Plant habit | b—An inflorescence showing a flower and bracts | c—Flower showing corolla tube and exerted stamens | d—Flowers in front view. © Pfüchüpe-ü Mero

1944. (Image 1 & 2)

Plant shrubs, 1–2 foot tall, stem quadrangular, green, with distinct nodes, glabrous to pubescent, hairy; petiolate, petiole 0.7–1 cm long; stipules on leaf axil. Leaves opposite, unequal in size, leaf lamina/blade, broadly elliptic to ovate long, 7–9 x 2.5–4 cm, apex acuminate, base cuneate, and tapering into petiole, margin serrate, pubescent, lateral veins 3–7 pairs.

Image 2. *Strobilanthes khasyana* (Nees) T. Anderson herbarium specimen submitted to the Angiospermic Herbarium, Department of Botany, Nagaland University. Photo credit: Pfüchüpe-ü Mero

Inflorescence lateral spike, arising from the branch node of unequal clusters of spikes, spike 2–9.5 cm long, rachis pubescent; bracts are 5–8 mm long, bracteole 6 mm. corolla purple to white, 5–7 mm long, basal corolla tube white, 1–1.3 cm long; funnel shaped, sepals 5–6 mm long, stamens 2, strongly exerted.

Ecology: The plants were found growing in moist shaded area along with other herbs like *Pilea* sp., *Stobilanthes* sp., *Elatostema* sp., and *Macropanax* sp.

Distribution: India (Meghalaya, Sikkim, West Bengal, Nagaland – present report)

Specimen examined: India: Nagaland: Phek District, Zanübu mountain range, Khulazu Basa Forest, 25.392°N & 94.170°E; 1,600–1,800 m, NU-PM-260 (Image 2).

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NOTE

Sonerila konkanensis Resmi & Nampy (Melastomataceae) – an addition to the flora of Karnataka, India

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Melastomataceae are the eighth-largest family of angiosperms, with 177 genera and 5,858 known species in the world (Christenhusz & Byng 2016). The members of the Melastomataceae family species are important to today's tropical flora (Renner 1993). The name *Sonerila* was first used by Roxburgh in his 'Hortus Bengalensis' (1814) and was validated later in his 'Flora Indica' (1820). Globally, the genus *Sonerila* comprises about 180 taxa of caulescent and acaulescent herbs. This genus is chiefly concentrated in Sri Lanka, India, Nepal, Bhutan, southern China, Taiwan, southeastern Asia, and the Malaya Archipelago (Cellinese 1997; Resmi et al. 2021). In India, *Sonerila* is represented by 49 species and one variety of which six species and one variety (about 86%) are endemic to the Western Ghats (Resmi et al. 2022). In Karnataka, 13 *Sonerila* species have been recorded till now, the *Sonerila talbotii* and *Sonerila raghaviana* both are endemic to the state (Saldanha 1984; Sanjappa & Sringeswara 2019; Ravikumar & Tangavelau 2021). *Sonerila* species collected in the field survey from the place Thirthahalli taluk, Shivamogga district, Karnataka, India were identified with the help of type specimens and taxonomic key evidence to conclude it is *Sonerila konkanensis* (Resmi et al. 2021; Resmi & Nampy 2022). The characters were tallied with reference articles and given comprehensive descriptions with photographs. The article deliberates the species *Sonerila konkanensis* Resmi & Nampy is an addition to the Karnataka state flora, which describes the place Goa as a type locality.

Materials and Methods

Study Area: The specimen was collected from Kavaledurga fort, located in the taluk Thirthahalli, Shivamogga district, Karnataka, India (Figure 1). The coordinate 13.7189N, 75.1177E, 08.09.2023 dated. The mentioned place or the region belongs to Western Ghats and comprises the seven lakes, Sahyadri hill range with dense canopy and shady hill rocks (Lateritic Rocky plateau). The specimen collected area covers the Southern tropical evergreen forest slightly.

Taxonomic Treatment: *Sonerila konkanensis* Resmi, S., Nampy, S., & F, Akshatra. 2021. *Sonerila konkanensis* (Melastomataceae), a new species from South Goa, India. *Candollea*. 76: 139–143.

Tuber-mediated (perennating), caulescent, erect herb, 5–30 cm high; tubers globose with root hairs, 0.5–1.7 cm in diam., white to pale green. Stems quadrangular, subangular at the base, 0.2–0.5 cm thick, dark pink, fleshy with branched, gland-tipped trichomes in dense; internodes 2–5 cm long, nodes with prominent

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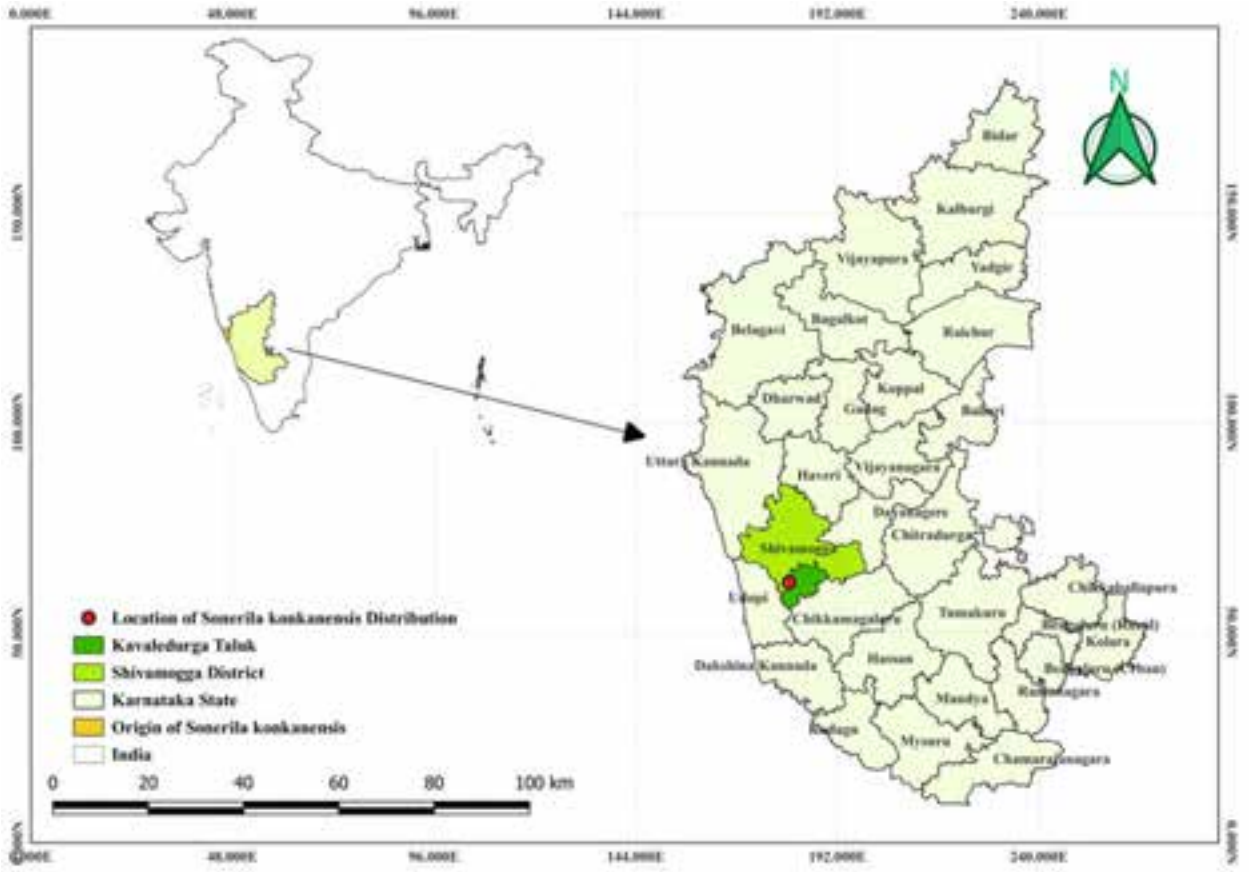

Figure 1. Distribution of *Sonerila konkanensis* in Karnataka.

leaf scars and densely covered gland-tipped trichomes. Leaves decussate at the distal node region; petiole canaliculated 2–3 × c. 0.2 cm, green, slightly claret, with gland-tipped trichomes on the lamina, ovate to elliptic, 3–8 × 1.5–5 cm, lime green on adaxial side, pale green on abaxial side, slightly cordate or sub-rounded at base with slightly dentate margins with small trichomes at each tooth end, acute to acuminate at apex, with dense glandular trichomes adaxially, only on veins abaxially, pinnately veined, 2 or 3 pairs above midrib and base only 2 pairs, less branched (approximately 2–5); Inflorescence terminal with 5–16 flowered terminal; peduncles quadrangular, 5–7 × 0.15–0.2 cm, longer than the petioles, dark pink or claret-tinged, densely covered with gland-tipped trichomes; leaf-like bracts foliaceous, elliptic, 0.4–2.3 × 0.5–1.5 cm, densely glandular-pubescent adaxially, only on veins abaxially, persistent. Flowers trimerous, 1–1.6 × 1–1.4 cm; pedicels sub-angular, 4–10 × 1–2 mm, claret tinged, densely covered with gland-tipped trichomes. Hypanthia campanulate, 4–5 ×1.5–3 mm, 3-lobed, 3-ribbed, distally claret-tinged, densely covered with gland-tipped trichomes; lobes triangular, 1–2 × 1–2.5 mm, acute at apex. Petals 3, ovate to oblong, 10–12 × 4–5 mm, dark pink or fuchsia, pink, with dark midrib, obtuse at base, mucronate at apex, gland-tipped trichomes on midrib abaxially. Stamens 3; filaments 5–6 mm long, dark pink at base and pale pink towards the apex and glabrous; anthers lanceolate, 5–7 mm long, yellow, acuminate to rostrate at apex. Ovary 2–3 × 2–3 mm; style 8–12 mm long, dark pink; stigma capitate, dark pink, glabrous. Capsules campanulate, 4–5 × 3–5 mm, distally green claret-tinged, brown when mature, obscurely 3-ribbed, densely covered with gland-tipped trichomes. Seeds many, obovoid 0.5–0.6 × 0.2–0.3 mm, pale brown (Image 1).

Species examined: INDIA, Karnataka, Shivamogga District, Thirthahalli Taluk (Kavaledurga Hill), 08 September 2023, Prashant Karadakatti. Collector Number: M006, Herbarium Accession Number: UASB 5611 (University of Agricultural Sciences, GKVK Campus, Bangalore, Karnataka, India).

Habitat: dripping rocky and marshy areas, in association with *Ariopsis peltata* Nimmo, *Impatiens talbotii* Hook.f. and *Murdannia simplex* (Vahl) Brenan.

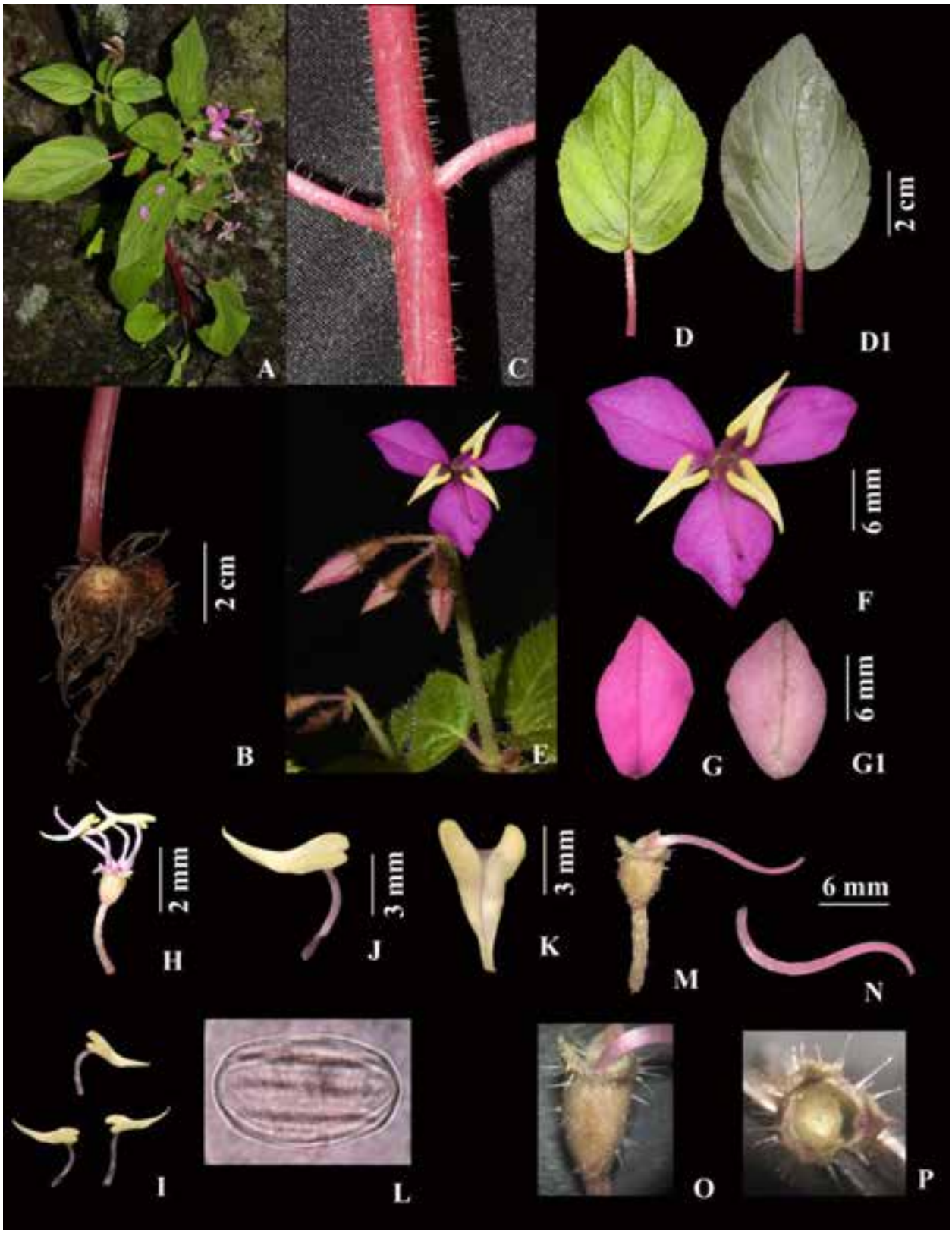

Image 1. ***Sonerila konkanensis*** **Resmi & Nampy.: A—Habitat | B—Tuber | C—Stem with gland-tipped trichomes | D—Leaf dorsal surface, D1—Leaf ventral surface | E—Inflorescence, F—Flower, G—Petal dorsal view | G1—Petal ventral view | H—Hypanthium | I & J—Stamens | K—An anther with two lobes close-up | L—Pollen | M—Gynoecium with pedicel | N—Style and stigma | O & P—Fruit. © Shreyas Betageri.**

Flowering Season: August–September.

Fruiting: September.

Distribution: Goa (Konkan), Karnataka (Thirthahalli) (Present survey).

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