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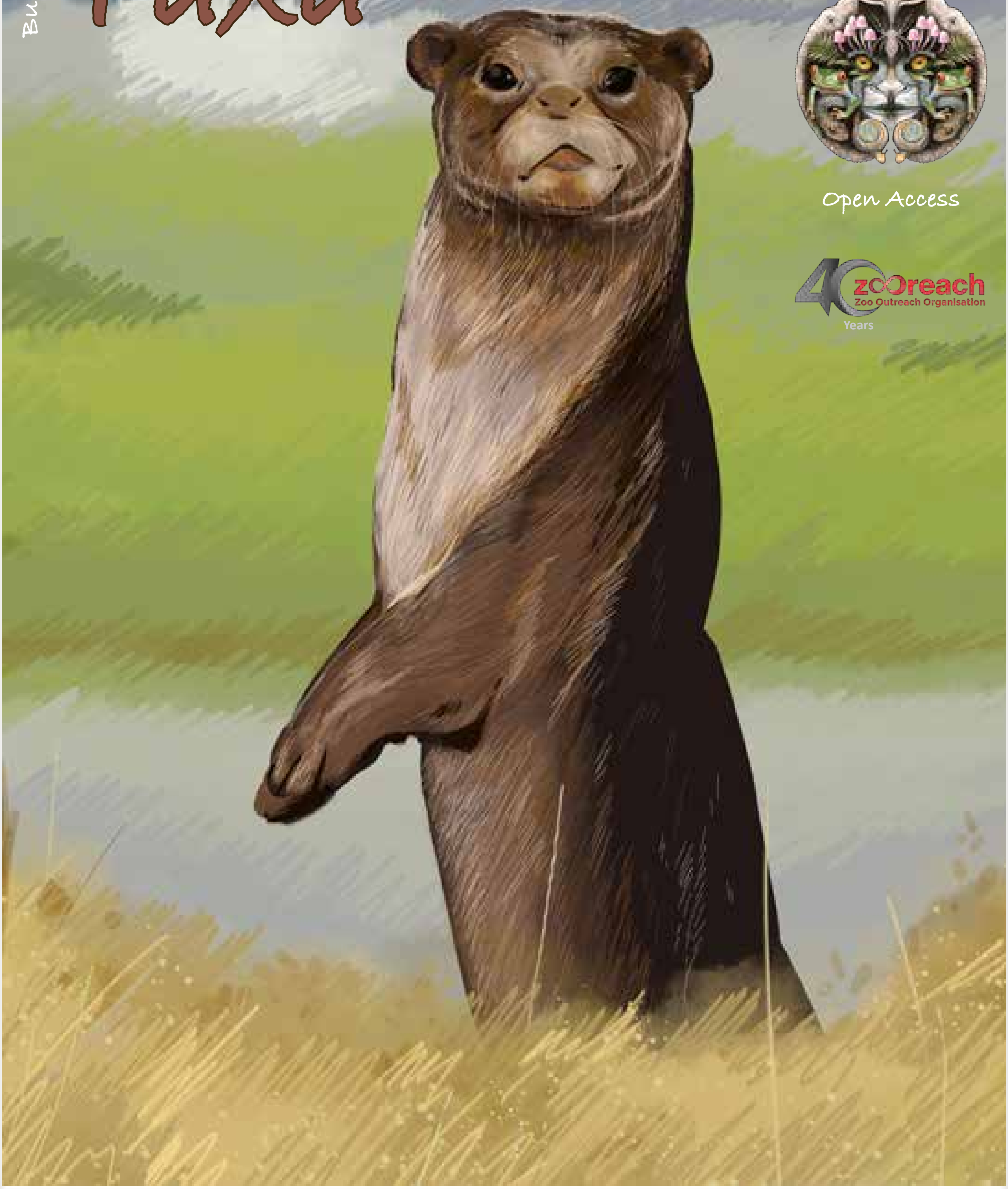

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**Cover: Digital illustration of Smooth-coated Otter *Lutrogale perspicillata* by Dupati Poojitha. Reference from the picture taken by Rana & Sugandhi.**

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ARTICLE

# Predicting the potential habitat of *Tragopan blythii* (Jerdon, 1870) (Aves: Galliformes: Phasianidae) in Mehao Wildlife Sanctuary of Arunachal Pradesh, India

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**Abstract:** The Blyth's Tragopan *Tragopan blythii* is a medium-sized pheasant endemic to the eastern Himalaya and is classified as 'Vulnerable'. This species thrives in dense forest ecosystems at higher altitudes. Species distribution modelling (SDM) helps identify potential suitable habitats by relating species occurrence to key environmental variables, especially in areas with limited field data. The present study aims to predict the potential habitat of *T. blythii* in Mehao Wildlife Sanctuary, Arunachal Pradesh, using the maximum entropy (MaxEnt) method. The study offers valuable insights into the ecological and environmental conditions necessary for the survival of this vulnerable species. The results showed 3.93% (11.09 $km^2$) of the total area as suitable, followed by 4.94% (13.91 $km^2$) as moderately suitable, 18.55% (52.22 $km^2$) as least suitable, and 72.58% (204.30 $km^2$) as unsuitable. Model performance was good with a mean area under the curve (AUC) of 0.915 (SD = 0.040) and a true skill statistic (TSS) value of 0.798. The jackknife test revealed that the distribution of *T. blythii* is primarily determined by the mean diurnal range (BIO2), with additional influence from the temperature annual range (BIO7) and precipitation seasonality (BIO15). An analysis of the model output revealed a restricted distribution of *T. blythii* in the northern parts of the study area. These results support habitat prioritization and conservation planning for the long-term protection of the species. Thus, the model results can be used in further investigation to explore the natural habitat of this vulnerable species.

**Keywords:** Climate change, community awareness, conservation, eastern Himalaya, endemic, environmental variables, habitat, pheasant, species distribution modelling, vulnerable.

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**Author details:** Eba Tapo is currently pursuing a PhD at the Department of Geography, Rajiv Gandhi University, Arunachal Pradesh, on the topic "Status of population, habitat occupancy and conservation of Tragopan blythii in Mehao Wildlife Sanctuary, Lower Dibang Valley District of Arunachal Pradesh". His research interest is in biogeography, specifically ornithogeography. Gibji Nimasow is currently a professor and head of the Department of Geography at Rajiv Gandhi University, Arunachal Pradesh. He has guided around ten Ph.D. theses and published about 60 research articles in reputed journals. His research interests include biogeography, mountain ecology, human geography, forest resources, traditional ecological knowledge, and remote sensing & GIS.

**Author contributions:** ET conceived, designed, and drafted the paper. GN interpreted, edited the language/ grammar, and revised the manuscript. Both authors read the revised manuscript and approved the submitted version.

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## INTRODUCTION

Species distribution modelling (SDM) has become a powerful tool for understanding the spatial patterns of bird species, informing conservation efforts, and predicting responses to environmental changes. This approach combines species occurrence data with environmental variables to predict where species are likely to be found. SDMs rely on high-quality data obtained from various sources like eBird and bird atlases, telemetry data from tracked migratory birds, museum historical records, and satellite imagery (Papeş 2007; Jiguet et al. 2011; Santos et al. 2023; Shirley et al. 2013). The commonly used predictors include bioclimatic variables such as temperature, precipitation, climate extremes, elevation, slope, terrain complexity, forest structure, wetland extent, agricultural areas, and the availability of prey species or competitors (Heikkinen et al. 2007; Shirley et al. 2013; Prosser et al. 2018; Pshegusov & Chadaeva 2023; Tamang et al. 2023). SDMs have been applied to a wide range of bird species, from migratory waterfowl to threatened vultures, and have proven essential in addressing conservation challenges (Papeș 2007; Prosser et al. 2018; Pshegusov & Chadaeva 2023). SDM is a cornerstone of conservation planning, helping to identify priority areas for habitat protection, assess the coverage of protected areas, identify gaps, and predict future habitat shifts due to climate change (Papeş 2007; Wu et al. 2014; Briscoe et al. 2021). By assessing habitat suitability, SDMs help design protected areas and corridors, support restoration efforts for degraded habitats, and aid in managing human-impact landscapes, viz., agricultural regions (Pshegusov & Chadaeva 2023; Tamang et al. 2023). SDMs can estimate population trends by modelling how environmental changes influence species distributions and predict areas susceptible to invasion by non-native bird species, allowing for pre-emptive control measures (Prosser et al. 2018; Briscoe et al. 2021).

Various SDM techniques are applied in birds, with maximum entropy (MaxEnt) being a prominent presence-only method known for its simplicity and effectiveness (Pshegusov & Chadaeva 2023; Tamang et al. 2023). MaxEnt enables researchers to conduct analyses with little programming expertise. It promotes reproducible research and offers features for model comparison and cross-validation (Mayer et al. 2024). It is also used to forecast invasive species and to predict future habitat expansions due to climate change scenarios (Schmid et al. 2024). Recent developments in MaxEnt modelling feature innovative optimisation algorithms that effectively manage large-scale, non-smooth data, especially in wildfire science. These algorithms greatly enhance convergence rates and computational efficiency (Langlois et al. 2024).

*Tragopan blythii* (Image 1) is listed as 'Vulnerable' under criterion 'C2a(i)' by the IUCN Red List of Threatened Species in 2020 (BirdLife International 2020a). *Tragopan blythii* is distributed from Bhutan through Arunachal Pradesh, Nagaland, Mizoram, and Manipur in northeastern India, extending into northern Myanmar and southeastern Tibet, as well as northwestern Yunnan, China (Birdlife International 2001). The adult male *T. blythii* differs from other species within the tragopan group by having a restricted patch of red on its upper breast (Madge & McGowan 2002). It is vulnerable primarily due to its declining population size across small subpopulations (BirdLife International 2020b). In some regions, its population is estimated to comprise around 38 individuals only (Ghose et al. 2003). *Tragopan blythii* inhabits moist, evergreen, broadleaf forests featuring thick understorey, dense scrub, and montane bamboo on steep slopes, typically occurring either singly or in pairs or small groups of four to five individuals (Sathyakumar & Kaul 2007). The documented altitudinal range of the species is from 1,400 m (winter) to 3,300 m (summer), but the majority of records come from a narrower range of 1,800–2,400 m (BirdLife International 2020b). The vocalisations of *T. blythii* are significant for courtship and territorial displays, featuring distinct calls that assist in species identification. Acoustic analyses reveal that these calls are subject to sexual selection pressure, acting as a mechanism for species isolation (Islam & Crawford 2010). Recent research has concentrated on the phylogenetic analysis of *T. blythii* using mitochondrial DNA and multi-locus analyses (Randi et al. 2000; Zou et al. 2021), resulting in the discovery of a new phylogeographic population of *T. blythii* in Mount Kennedy, Myanmar (Zou et al. 2021). These findings underscore the need to comprehend the genetic diversity and population structure of *T. blythii* for effective conservation strategies. It is rare throughout much of India, with an estimated 50% of the population in the Nagaland area (Eastern Mirror Nagaland 2017). Studies on *T. blythii* emphasize the necessity of genetic analyses, population, and conservation measures to safeguard this vulnerable species and its unique populations (Randi et al. 2000; Zou et al. 2021). To ensure long-term survival, further research is essential to understand its phylogeography, behaviour, and ecology.

Arunachal Pradesh is the largest state in North East India and falls within the Himalayan global biodiversity hotspots (Sen & Mukhopadhyay 1999; Meyers et al. 2000; Sinha et al. 2005). The state is also considered India's biodiversity frontier (Borges 2005; Mishra & Datta 2007; Borang et al. 2008). However, due to its remote location and mountainous topography, the rich terrestrial biodiversity, including wildlife, has been inadequately documented or relatively unexplored. The state is home to over 850 bird species, representing nearly two-thirds of India's avifauna. In particular, the Dihang Dibang Biosphere Reserve is noted for 492 species, including 37 that are globally threatened (Rangini et al. 2014). The population of *Tragopan blythii* is small, declining, and fragmented into minor subpopulations within the heavily disrupted habitat. Thus, the species is designated as a Schedule I bird under the Wildlife (Protection) Act 1972 (2022 amendment), India. The vulnerability is likely to intensify due to hunting practices and habitat degradation. As per reports, *Tragopan blythii* have been sighted in the Mishmi Hills of Arunachal Pradesh (King et al. 2008). Hence, this study attempts to understand the habitat and predict the distribution of *Tragopan blythii* in Mehao Wildlife Sanctuary, Arunachal Pradesh, which falls under the Mishmi Hills, using field methods and geospatial technology.

## MATERIALS AND METHODS

### Study area

The study area, Mehao Wildlife Sanctuary (MWS), is located between 28º 05' to 28º 15'N and 93º 30' to 95º 45' E in the Lower Dibang Valley District of Arunachal Pradesh (Figure 1). It spans approximately 282 $km^2$ and features a diverse topography with elevations of 500–3,000 m. The climate is predominantly temperate, with significant rainfall and various vegetation types, including subtropical forests, bamboo groves, and temperate forests. MWS is one of the oldest of the 13 sanctuaries in Arunachal Pradesh. Koronu, Injuno, Balek, Cheta, Ejengo, Rayang, and Tiwarigaon villages are located on the periphery of the sanctuary. The sanctuary hosts vital plant species such as *Terminalia myriocarpa*, *Duabanga grandiflora*, *Phoebe cooperiana*, *Bombax ceiba*, *Canarium strictum*, *Lagerstroemia speciosa*, *Michelia champaca*, *Gmelina arborea*, *Coptis teeta*, *Messua ferrea*, *Dillenia indica*, *Castanopsis indica*, and *Bischofia javanica*, along with various orchids. The wildlife includes Tigers, Black Bear, Leopards, Elephants, Wild Boar, Capped Langur, White-browed Gibbon, Musk Deer, and Mishmi Takin. Furthermore, numerous bird species inhabit the area, such as hornbills, babblers, bulbuls, warblers, flycatchers, pigeons, and a range of reptiles, snakes, insects, and leeches (Murali et al. 2012).

### Occurrence data

The occurrence data were collected from both primary and secondary sources. Field surveys were conducted for two years (2022–2024) following the point count methods by strategically selecting the survey sites and using handheld Garmin global positioning system (GPS) devices (Volpato et al. 2009). The point counts were spaced at least 200 m apart, and each count captured species seen or heard within a radius of approximately 20 m. The survey covered various altitudinal zones and seasons during the morning hours when birds were most active. The surveys were conducted seasonally, in 18 locations during autumn (September), winter (December), spring (March), and summer (June) each year, totalling 144 counts over two years. Additionally, camera trapping techniques were employed to record *T. blythii* and assess its habitat conditions. The bird was identified in consultation with the ornithologists from the Department of Zoology, Rajiv Gandhi University. To limit spatial autocorrelation and sampling bias, occurrence records were filtered using the spThin package in R by applying a 10 km minimum distance between points. This reduced clustering caused by uneven sampling effort and improved the reliability of the species distribution model (Kramer-Schadt et al. 2013; Aiello-Lammens et al. 2015). After removing the coordinates falling outside boundary of MWS, only 36 occurrence records were used to run the final model.

### Environmental parameters

To predict the distribution of *T. blythii*, a set of environmental data, such as topographical (12.5 m) and climatic (30 arc-second) spatial resolution, has been acquired from various sources using ArcGIS 10.3. The elevation data was sourced from the Alaska Satellite Facility (n.d.), which provided key topographic parameters, including altitude, slope, and aspect. This high-resolution DEM provides a detailed dataset that offers insights into earth's surface, capturing the elevation data for producing topographic attributes. Additionally, 19 bioclimatic variables were downloaded from the WorldClim website (Fick & Hijmans 2017). These variables offer extensive global climate layers for various applications, such as mapping and spatial modelling. Multicollinearity among predictor variables was evaluated using the Variance Inflation Factor (VIF) in R, and variables with VIF values greater than seven were excluded to reduce redundancy and improve model

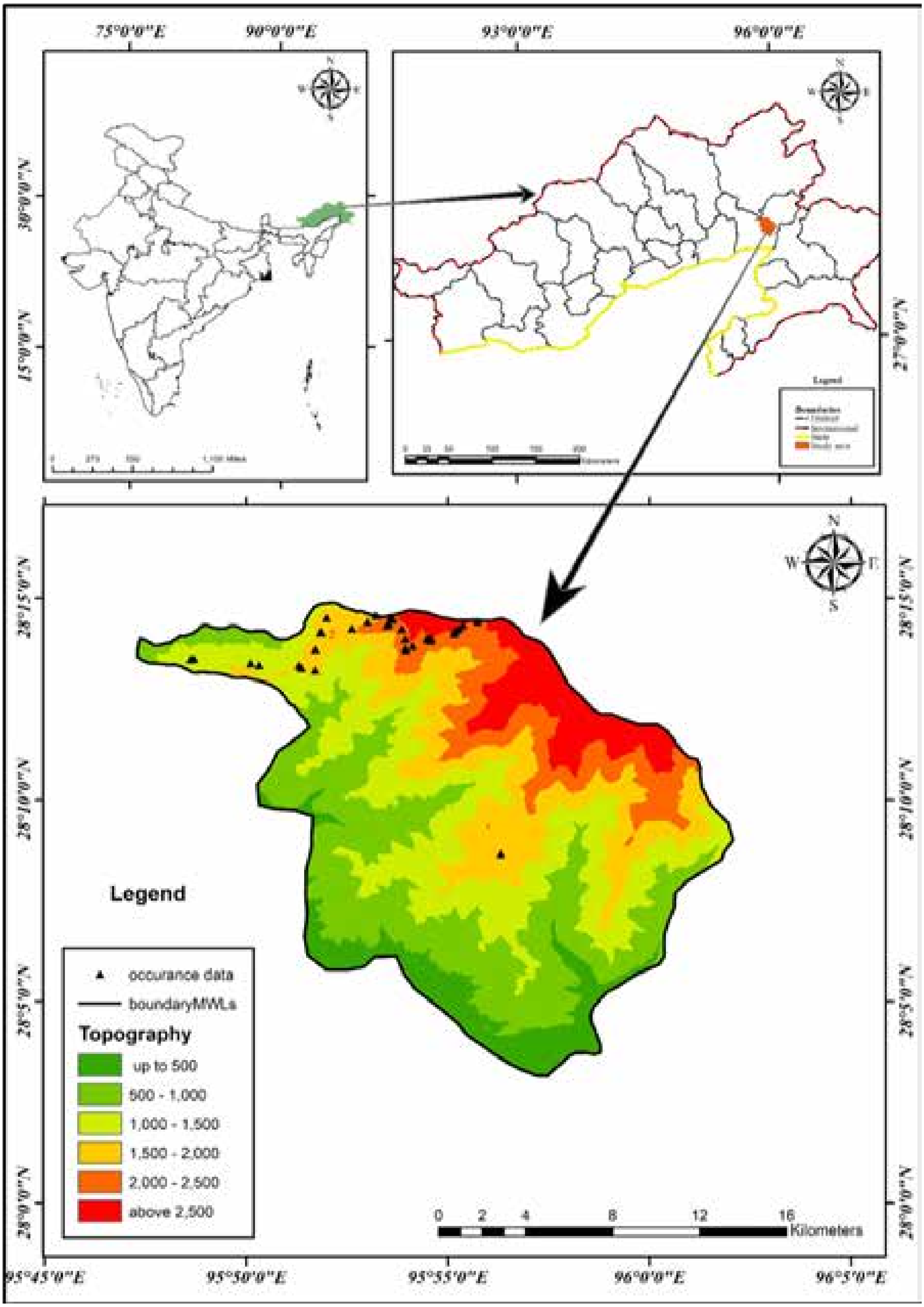


**Figure 1. Location map of the study area showing occurrence records of *Tragopan blythii*. Source: The Gazette of India: Extraordinary Draft Notification declaring Eco Sensitive Zone around Mehao Wildlife Sanctuary [22.02.2018].**


**Image 1. A & B—Male *Tragopan blythii* | C & D—Female *Tragopan blythii*. © Eba Tapo.**

performance (Zuur et al. 2010; Dormann et al. 2013; James et al. 2013; Manzoor et al. 2018). According to Parolo et al. (2008), Dormann et al. (2013), Merow et al. (2013), and Manzoor et al. (2018), highly correlated parameters affect model performance negatively and lead to inaccurate predictions. Hence, such parameters were removed by performing a multicollinearity (Pearson's R) test using the usdm package in *R* (Naimi & Araújo 2016). After the test, 12 predictor variables, namely Mean diurnal range (BIO2), isothermality (BIO3), temperature seasonality (BIO4), minimum temperature of the coldest month (BIO6), temperature annual range (BIO7), mean temperature of the coldest quarter (BIO11), precipitation seasonality (BIO15), precipitation of the driest quarter (BIO17), precipitation of the warmest quarter (BIO18), altitude, slope, and aspect were included in the final model (Figure 2).

**Model settings and evaluation**

The species distribution model of *T. blythii* was generated using MaxEnt (version 3.4.1). MaxEnt (Phillips et al. 2006; Phillips & Dudík 2008) is regarded as one of the leading species distribution modelling techniques and has been widely used (Elith et al. 2011). It is deterministic and approaches the probability distribution linked to maximum entropy (Berger et al. 1996; Phillips et al. 2006; Baldwin 2009). All model parameters were kept at their default settings in MaxEnt. Variable importance was assessed using the jackknife test, which evaluates the relative contribution of each environmental predictor by sequentially excluding individual variables and by running models with each variable in isolation. This approach helps identify variables that contain unique information and those that most strongly influence model performance, based on changes in training gain. The jackknife test is particularly important for understanding predictor relevance and reducing redundancy among correlated variables in species distribution modelling (Phillips et al. 2006; Baldwin 2009; Elith et al. 2011). Five replicate runs were used with cross-validation to ensure and evaluate the model's reliability (Pearson et al. 2004). Model performance was assessed using the threshold-independent area under the curve (AUC) of the receiver operating characteristic (ROC) curve, and true skill statistic (TSS). The values of AUC range from models with no predictive ability (AUC ≤ 0.5) to models having perfect predictions (AUC = 1.0), where 0.9–1 = excellent; 0.8–0.9 = good; 0.7–0.8 = satisfactory; 0.6–0.7 = poor and < 0.6 = very poor or model failed (Araújo et al. 2005; Lissovsky & Dudov 2021). The TSS takes into account both omission and commission errors, and success due to random guessing, and ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random (Allouche et al. 2006). The methodology applied is shown in Figure 3.

## RESULTS

### Model performance

The model results showed that the distribution of *T. blythii* is mostly influenced by the mean diurnal range of temperature (33.7%), temperature annual range (17.8%), precipitation seasonality (15.1%), altitude (11.1%), and temperature seasonality (9.2%). Slope (4.7%), aspect (2.7%), precipitation of the driest quarter (2.5%), and precipitation of the warmest quarter (2.25%) also exerted some influence on the distribution of *T. blythii*. Model evaluation indicated excellent predictive performance, with a mean AUC of 0.915 (SD = 0.040) and a high TSS value of 0.798, reflecting robust model reliability and classification accuracy (Figure 4). The jackknife test revealed that the distribution of *T. blythii* was primarily influenced by the mean diurnal range of temperature (BIO2), which accounted for 33.7% of the explained variable, followed by temperature annual range (BIO7) and precipitation seasonality (BIO15) with 17.8% and 15.1%, respectively. The contribution of other parameters was relatively lesser with altitude (11.1%), temperature seasonality (9.2%), slope (4.7%), aspect (2.7%), precipitation of the driest quarter (2.5%), and precipitation of the warmest quarter (2.2%). Isothermality (BIO3), minimum temperature of the coldest month (BIO6), and mean temperature of the coldest quarter (BIO11) showed meagre influence on the distribution of *T. blythii* (Table 1).

### Species distribution modelling of *T. blythii*

The model predicted the potential distribution of *T. blythii* in the MWS within a range of 0–0.9, which was categorised into five suitability categories, viz. highly suitable (>0.8), suitable (0.6–0.8), moderately suitable (0.4–0.6), least suitable (0.2–0.4), and not suitable (< 0.2). The results showed an area of 2.48 km² (0.88%) as highly suitable and 8.59 km² (3.05%) as suitable. Further, the model predicted an area of 13.91 km² (4.94%) as moderately suitable, 52.22 km² (18.55%) as least suitable, and the largest area of 204.30 km² (72.58%) as not suitable (Table 2). An examination of the final model revealed that the northern parts of the study area are suitable for *T. blythii*, owing to higher altitude, thick understorey, pronounced slopes, and cooler temperatures. On the other hand, the southern parts, mostly characterized by lower elevations, dense

**Table 1. Parameter contributions based on the MaxEnt model, codes, units, and source of the database.**

| Parameters | Contribution (%) | Code | Units | Source |
|---|---|---|---|---|
| Mean diurnal range | 33.7 | BIO2 | °C | WorldClim |
| Temperature annual range | 17.8 | BIO7 | °C | WorldClim |
| Precipitation seasonality | 15.1 | BIO15 | Unitless | WorldClim |
| Altitude | 11.1 | Elevation | Meter | ALOS PALSAR |
| Temperature seasonality | 9.2 | BIO4 | Unitless | WorldClim |
| Slope | 4.7 | Slope | Degree | ALOS PALSAR |
| Aspect | 2.7 | Aspect | Degree | ALOS PALSAR |
| Precipitation of the driest quarter | 2.5 | BIO17 | Mm | WorldClim |
| Precipitation of the warmest quarter | 2.2 | BIO18 | Mm | WorldClim |
| Isothermality | 0.5 | BIO3 | Unitless | WorldClim |
| Min. temperature of the coldest month | 0.4 | BIO6 | °C | WorldClim |
| Mean temperature of the coldest quarter | 0.2 | BIO11 | °C | WorldClim |

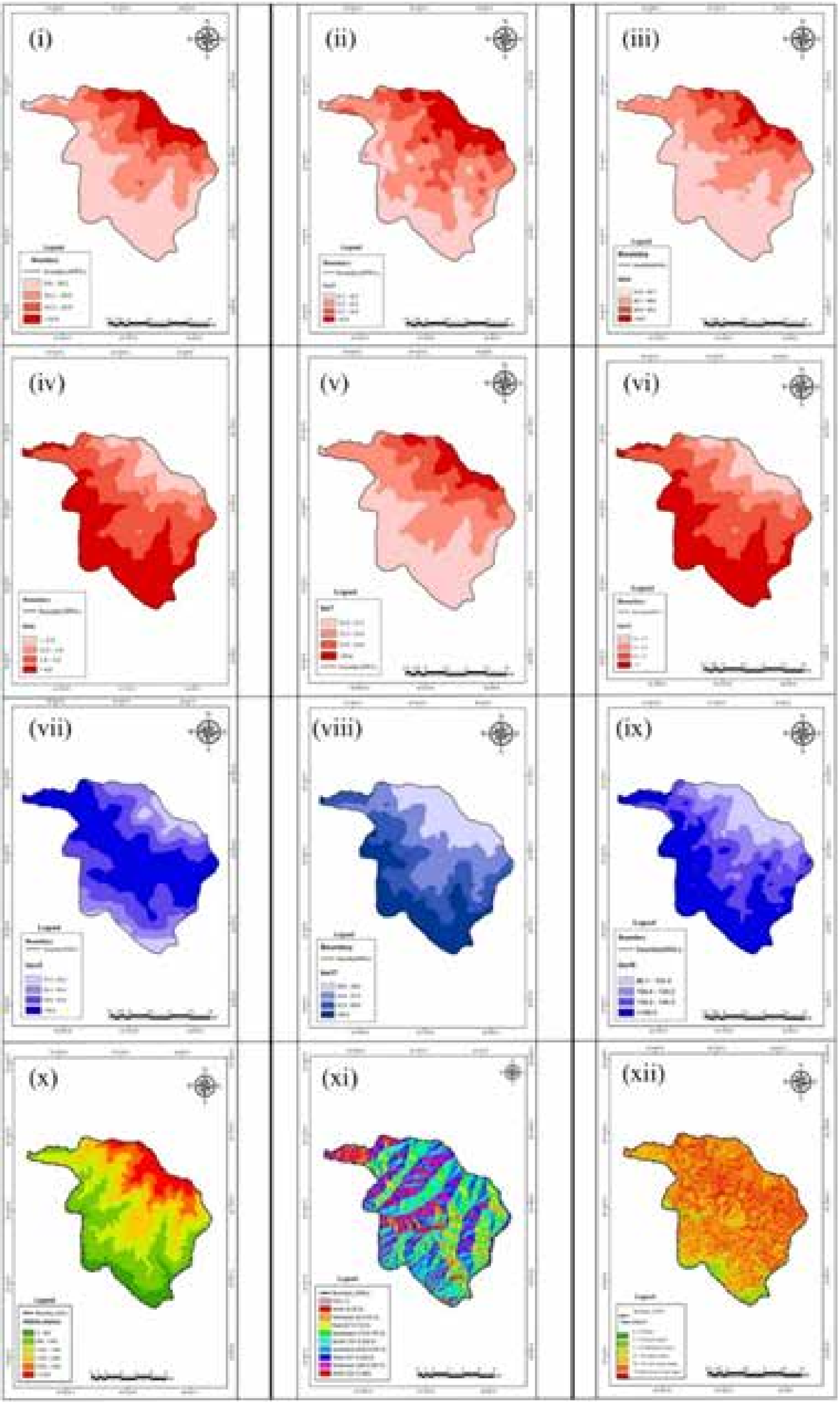


**Figure 2. Environmental parameters used in the final model. [(i) = BIO2, (ii) = BIO3, (iii) = BIO4, (iv) = BIO6, (v) = BIO7, (vi) = BIO11, (vii) = BIO15, (viii) = BIO17, (ix) = BIO18, (x) = Altitude, (xi) = Aspect, (xii) = Slope]**

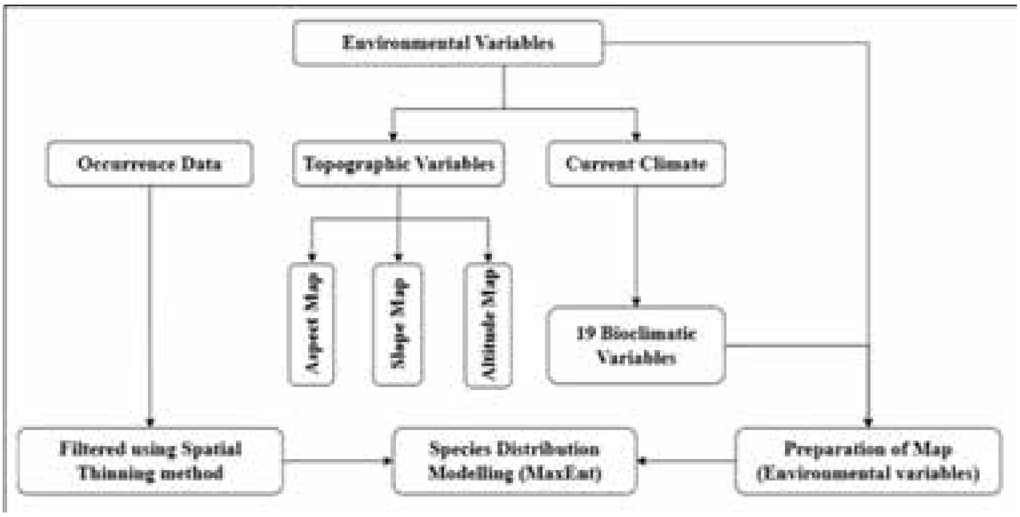


**Figure 3. Flowchart of the methodology.**

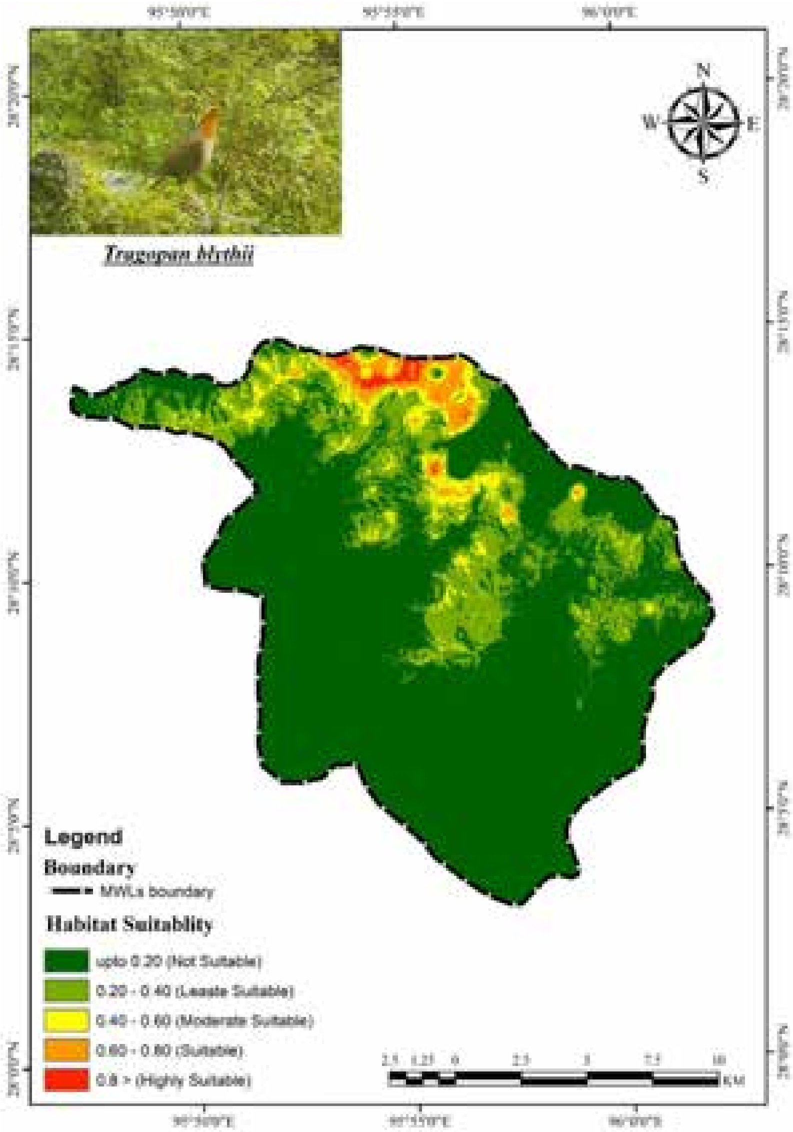


**Image 2. Habitat suitability of *T. blythii* in the study area.**

**Table 2: Suitable categories of *T. blythii* in the study area.**

| Suitable categories | Value | Area (km²) | Area (%) |
|---|---|---|---|
| Not Suitable | 0 - 0.20 | 204.30 | 72.58 |
| Least Suitable | 0.20 - 0.40 | 52.22 | 18.55 |
| Moderate Suitable | 0.40 - 0.60 | 13.91 | 4.94 |
| Suitable | 0.60 - 0.80 | 8.59 | 3.05 |
| Highly Suitable | 0.60 - 0.80 | 2.48 | 0.88 |
| **Total** | | **281.50** | **100.00** |

canopy, and hot temperatures, have been predicted as unsuitable habitat for *T. blythii*. The suitable habitats are mostly found throughout the Mayodia Pass, which is characterized by higher elevation, cooler temperatures, and winter snowfall (Image 2).

## DISCUSSION

Model performance was high, with a mean AUC of 0.924 and a TSS value of 0.798, indicating excellent discriminatory power and reliable prediction of suitable habitats for *T. blythii* (Swets 1988; Elith et al. 2006; Phillips et al. 2006). Among the predictor variables, mean diurnal temperature range, annual temperature range, and precipitation seasonality emerged as the most influential climatic factors shaping the species' distribution. The results support earlier findings of climate as a primary determinant of species' geographic limits, especially for montane and habitat-specialist birds (Parmesan & Yohe 2003; Root et al. 2003; Reside et al. 2010; Hill & Preston 2015).

The diurnal temperature range, representing the difference between daytime and nighttime temperatures, is biologically important because it influences metabolic expenditure, thermoregulation, and activity patterns in birds (McKechnie & Wolf 2010; Wang et al. 2023). Large fluctuations in daily temperature can impose physiological stress and reduce habitat suitability for forest-dwelling pheasants adapted to stable microclimatic conditions. Similar patterns have been reported for the Western Tragopan *Tragopan melanocephalus* in the western Himalayas, where diurnal temperature range strongly influenced habitat suitability (Singh et al. 2020). Experimental and field studies further indicate that increased thermal variability can negatively affect growth, survival, and reproductive success across taxa (Vasseur et al. 2014; Stoks et al. 2017), suggesting that *T. blythii* may be particularly vulnerable to ongoing climatic instability.

Precipitation seasonality also played a major role in determining habitat suitability. Rainfall regimes regulate forest structure, understorey density, and availability of food resources such as seeds, shoots, and invertebrates (Choudhury 2001; Guisan & Thuiller 2005; Sathyakumar & Kaul 2007). High seasonal variability in precipitation may disrupt breeding cycles and reduce nesting success through habitat degradation and changes in vegetation phenology (Both et al. 2006; Soria-Auza et al. 2010). Comparable relationships between precipitation patterns and habitat suitability have been documented for pheasants and other montane birds across the Himalayas and southeastern Asia (Chhetri et al. 2018; Cohen et al. 2020; Li et al. 2022).

Topographic variables, particularly altitude and slope, were also significant predictors of *T. blythii* distribution. The species was predicted to occur primarily at 1,000–2,500 m, which closely matches earlier observations ranging 1,400–3,300 m (BirdLife International 2008; Ghosh 2003). Altitude integrates multiple environmental gradients such as temperature, humidity, vegetation type, and human disturbance, all of which influence species occupancy (Körner 2007; Elsen & Tingley 2015). Steeper slopes may provide refugia from anthropogenic pressures such as agriculture and logging, thereby enhancing habitat persistence for forest-dependent species (Jetz et al. 2007; Laurance et al. 2011). The strong association of *T. blythii* with primary evergreen broadleaf forests observed in this study corroborates previous findings emphasizing its dependence on intact forest ecosystems (Choudhury 1997; Ghose et al. 2003; Sathyakumar & Kaul 2007).

Model projections revealed that only a small fraction of the study area was classified as highly suitable (0.88%) or suitable (3.05%), whereas most regions were categorized as least suitable (18.55%) or unsuitable (72.58%). This limited availability of suitable habitat corresponds with the species' current vulnerability status and narrow ecological niche requirements (BirdLife International 2020b; IUCN 2023). Narrow climatic tolerances have been associated with heightened extinction risk under climate change, particularly for montane endemics (Thomas et al. 2004; Freeman et al. 2018). The results, therefore, suggest that even modest climatic shifts could lead to further habitat contraction and population decline in *T. blythii*.

Although this study employed MaxEnt due to its robustness with presence-only data and small sample sizes (Phillips et al. 2006; Elith et al. 2011), recent studies emphasize the advantages of ensemble ecological niche models that combine multiple algorithms such as

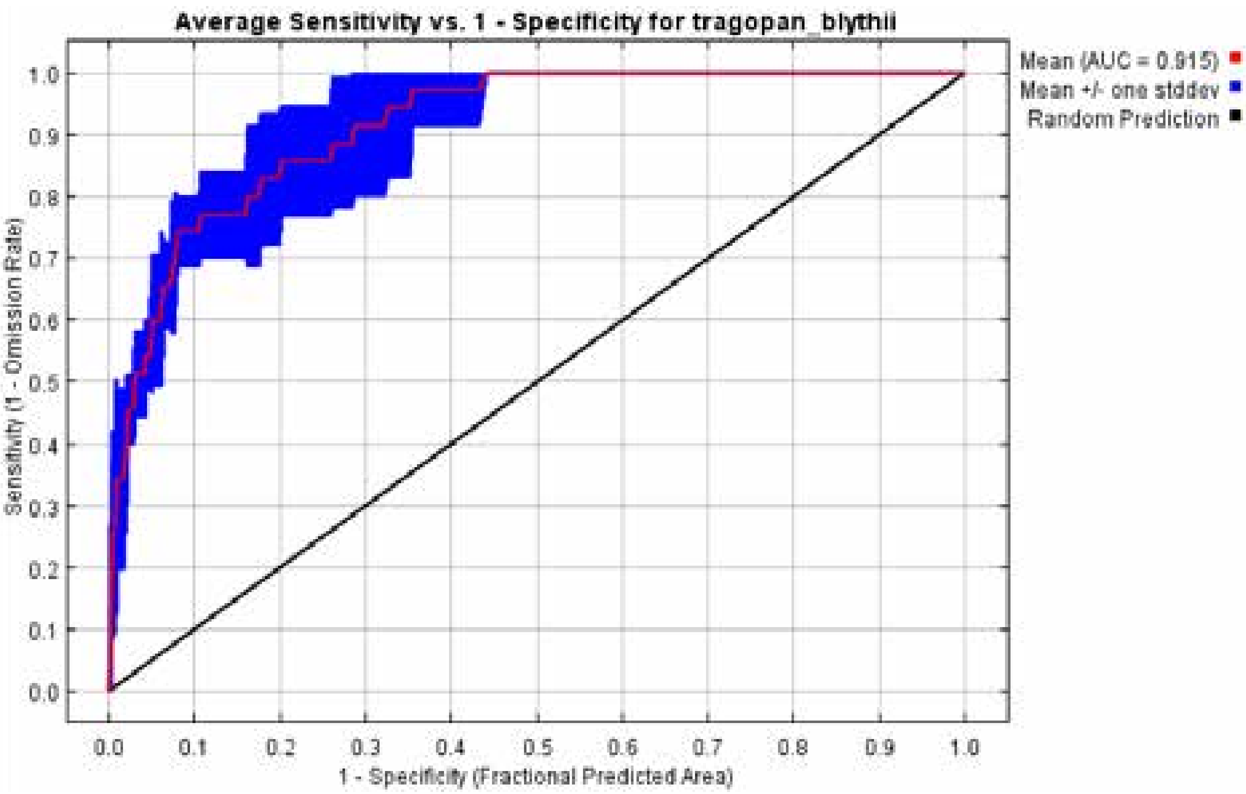


**Figure 4. Area under the receiver operating characteristic Curve (AUC-ROC)**

random forest, generalized linear models, and boosted regression trees (Araújo & New 2007; Marmion et al. 2009). Ensemble approaches reduce uncertainty and improve predictive performance, particularly for rare and elusive species with limited occurrence records (Thuiller et al. 2009; Feng et al. 2019). Such methods have already been applied successfully to forecast habitat shifts of Himalayan pheasants under climate change scenarios (Chhetri et al. 2018; Singh et al. 2020).

Following the reproducibility checklist proposed by Feng et al. (2019), this study recognizes several methodological limitations, including small sample size, potential sampling bias, and reliance on a single modelling algorithm. These factors may influence model transferability and prediction uncertainty (Warren & Seifert 2011; Merow et al. 2013). Future research should, therefore, incorporate ensemble modelling frameworks, bias-corrected occurrence data, and independent validation datasets to enhance robustness and reproducibility (Araújo et al. 2019; Feng et al. 2019; Zurell et al. 2020). Despite these limitations, the present findings provide an important baseline for understanding the climatic and topographic drivers of *T. blythii* distribution and offer valuable guidance for conservation planning and climate-adaptive management strategies.

## CONCLUSION

The study applied the MaxEnt method to predict the suitable habitats of *T. blythii* in the Mehao Wildlife Sanctuary, located in the Lower Dibang Valley of Arunachal Pradesh. The model used 36 occurrence records and 12 environmental variables for the targeted species. The model performance was good. The model predicted only 3.93% of the total area as suitable, which may be due to its restricted distribution range. Besides, the model also predicted about 5% of the area as moderately suitable, which remains to be explored to confirm species occurrence. The suitable areas of *T. blythii* were mostly located in the northern portion of the MWS at altitudes above 1,700 m. The occurrences of the species were most frequently observed at 1,000–2,500 m in the study area. The study area represents a key natural habitat of the vulnerable *T. blythii*. Thus, safeguarding areas recognised as suitable habitats can ensure conservation of *T. blythii* in the long run. Educating local communities on the significance of *T. blythii* can greatly aid such conservation efforts. These findings indicate the need to develop effective strategies for identifying potential habitats, supporting government policies to protect vulnerable species, and reducing human activities like overexploitation, hunting, and deforestation in the preferred habitats of *T. blythii*. The study revealed the potential distribution range of *T. blythii* and laid the groundwork for future research. There is an essential need for initiatives to raise public awareness and build capacity by governmental agencies and NGOs, involving the local communities, to avert further decline in the population of Blyth's Tragopan.

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ARTICLE

# Composition and ecological guild structure of birds at Chaudhary Devi Lal University campus, Haryana, India

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**Abstract:** Documentation of avian diversity is an effective method to monitor the quality of a habitat, along with long-term effects of habitat fragmentation, developmental activities, and urbanization. In the current investigation, the avifauna diversity of the university campus was examined from December 2022 to December 2024. A transect survey was carried out by regular walking on fixed routes in the campus. Eighty-four species from 72 genera, 43 families, and 16 orders were observed. Sixty-six species were resident, five were summer migrants, 12 were winter migrants, and one was a passage migrant. The campus supported 27 (32%) omnivorous, 10 (12%) carnivorous, 31 (37%) insectivorous, six (7%) granivorous, seven (8%) frugivorous, one (1%) nectarivorous, and two (2.4%) piscivorous species. Passerine species had higher relative diversity than non-passerines. Two 'Near Threatened' species were recorded and global population trends were 39 stable, 18 decreasing, 18 increasing, and nine unknown. Conservation efforts, including planting of native trees and preserving green cover on campus, should continue to support avifaunal diversity.

**Keywords:** Avian diversity, conservation, ecosystem, frugivorous, green cover, guilds, insectivore, omnivorous, Passeriformes, threatened, winter migrants.

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**Author contributions:** The authors have made significant contributions to this manuscript. Harkrishan Kamboj and Vivek Goyal designed the study, performed data acquisition and data analysis. Vijay Singh and Vinay Malik performed statistical, and revised the manuscript. Harkrishan Kamboj supervised and finally approved the manuscript.

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## INTRODUCTION

Birds are among the most widespread vertebrates that act as sensitive bioindicators while playing a dynamic role in interconnecting various food chains in aquatic as well as terrestrial habitats (Abd 2019; Byju et al. 2024). An abundance of avifaunal diversity contributes to the development of the biotic community within the ecosystems. Birds also serve as monitors to examine the long-term effects of both habitat fragmentation and habitat loss (Gupta et al. 2009; Rashiba et al 2022). India harbours approximately 1,364 species of birds that belong to 26 orders, 115 families, and 497 genera, contributing approximately 13.81% of total avian species around the world (Praveen & Jayapal 2024). In Haryana alone, 450 bird species have been documented (Goyal et al. 2014; Rai et al. 2017). Unfortunately, the global decline in bird diversity is a concerning issue, primarily driven by the widespread use of agrochemicals in intensive agricultural practices, impacts of climate change, and habitat loss due to the expanding footprint of urbanization (Kiran et al. 2022; Kumar et al. 2025). According to the IUCN Red List, 1,311 avian species are threatened globally, with 182 of them native to India (IUCN 2024). Avian fauna constitutes a vital component of the biotic community across all ecosystems, contributing significantly to ecological stability and functioning by performing a wide range of essential ecological roles in pollination, seed dispersal, nutrient dispositioning, scavenging, and control of insect pests and rodents (Kumar & Sahu 2019). This highlights the urgent need for conservation efforts in diverse habitats to protect avian biodiversity.

Monitoring avian diversity in educational institutions provides valuable information on the ecological health of the campus, which can be used to launch an awareness drive regarding the conservation of habitat and biodiversity. Unfortunately, these sites are comparatively less considered in studies of avian diversity (Kiran et al. 2022). Although numerous researchers have documented the avian diversity within educational institutions around the world, the studies are limited, as they lack comprehensive and systematic assessments.

Estimation of diversity through a scientific approach is also essential to plan the conservation strategies for threatened avian species in any habitat. Therefore, a comprehensive exploration of avian diversity is the need of the time. Chaudhary Devi Lal University (CDLU) was founded in 2003 and is still in the process of developing its campus, with ongoing construction of buildings, roads, and hostels. The ecosystem of such developing institutes faces tremendous pressure, such as tree cutting for construction activities to make way for new infrastructure. These activities may have an impact on the quality of natural habitats. Therefore, the impacts of these changes on the structure and composition of bird diversity are yet to be fully understood. In general, birds are highly sensitive to such activities and are affected by changes in density and species composition. This has prompted us to make a survey of birds in the campus of this University, as information is lacking. Therefore, we assessed species richness, feeding guild composition and residential status of birds in a rapidly urbanizing university campus to evaluate its ecological role as a refuge habitat.

## MATERIALS AND METHODS

### Study area

The present study was conducted at the University campus of CDLU, Sirsa (29.546°N, 75.044°E), Haryana, India (Figure 1). The campus covers an area of 1.1 km$^2$, which comprises buildings, lawns, trees, grassland with herbs and shrubs, and one water body. Neem *Azadirachta indica*, Peepal *Ficus religiosa*, and Shisham *Dalbergia sissoo* dominate the campus, providing a suitable place and attracting a significant number of avian species. The campus experiences sub-tropical climatic conditions characterized by three distinct seasons: rainy season (July–September), winter season (October–February), and dry hot season (March–June). The campus experiences a high temperature of 48 ± 1 °C during the summer and as low as 3 ± 1 $^o$C in winter, with a usual annual rainfall of 350–400 mm.

### Methodology

We surveyed the avifauna for two years (December 2022 to December 2024), covering all the seasons. This field surveys were conducted on alternate weeks, using the point and line transect method (Gaston 1975 ; Sutherland et al. 2005), mainly during the peak activity times of the birds, i.e., in the morning (0600–1000 h) and evening (1600–1900 h), along with some incidental sightings during day time by walking through fixed routes (transect) to cover the entire campus. Eight linear transects of 200 m (each) were randomly deployed within the campus, with regular count stations at every 20 m intervals along the transect (Archana et al. 2024). Birds in each transect were explored with the help of Nikon Action binoculars (10 × 50) and photographed

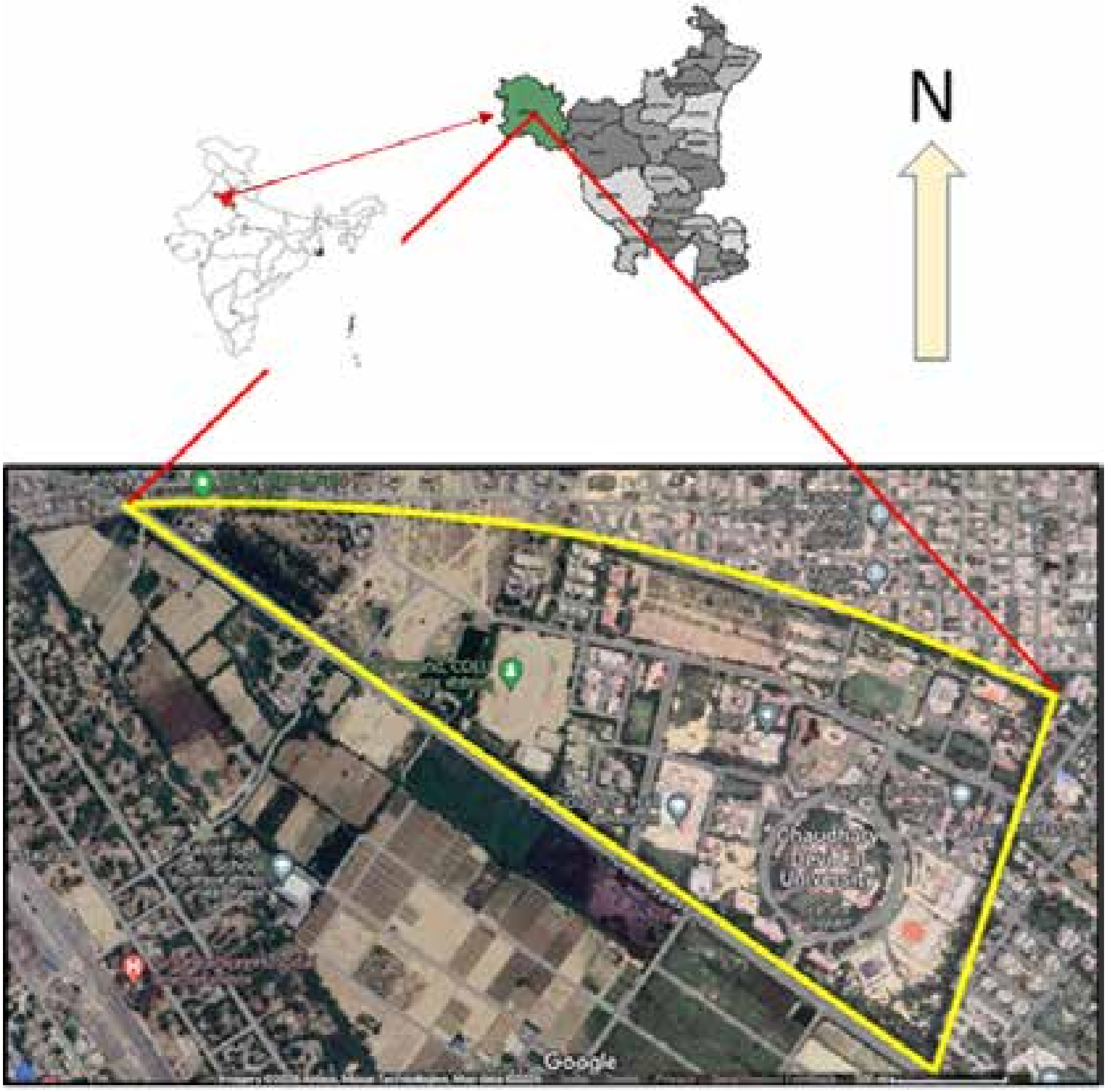


**Figure 1. Location map of study area, Chaudhary Devi Lal University.**

for further identification using Nikon Coolpix P1000 digital Camera. Standard field guides (Ali & Ripley 1983; Grimmett et al. 2014; Kalsi et al. 2019) were also used for birds' identification. The migratory/residential status of the reported bird species was confirmed by adopting the presence or absence method (Grimmett et al. 2014; Kumar et al. 2016). Recorded bird species were classified taxonomically by following Praveen & Jayapal (2024) and IUCN (2024). The abundance status of individual species was assigned depending on the frequency of sightings by following the standard criteria (MacKinnon & Phillipps 1993). The reported species were classified as common (observed on 80–100 % of visits), fairly common (observed on 60–79.9 % of visits), uncommon (observed on 20–59.9 % of visits), and rare (observed on less than 19.9 % of visits). Feeding guilds were determined by directly observing the foraging birds with binoculars and categorized into seven guilds (Omnivorous, Carnivorous, Frugivorous, Granivorous, Insectivorous, Nectarivorous and Piscivorous), and compared with the available literature (Rai & Vanita 2021). The conservation status, including local and global population trends of recorded avian species, was considered according to the latest IUCN Red List (2024). Further, RDi (relative diversity index) for bird families was determined following the standard formula as per Torre-Cuadros et al. (2017

$$RDi = \frac{\text{Number of species in a family}}{\text{Total number of species}} \times 100$$

## RESULT AND DISCUSSION

A total of 84 species belonging to 72 genera, 43 families, and 16 orders (Table 1) were observed. The dominant order was Passeriformes (42 species), followed by Coraciiformes and Pelecaniformes (5 each), Charadriiformes, Columbiformes, Piciformes, Cuculiformes (4 each), and Gruiformes (3) (Figure 2). Tree habitat supported the highest biodiversity, followed by grassland, water body, garden, and buildings. Rock Dove *Columba livia* was the most dominant urban-adapted species, followed by Yellow-footed Green Pigeon *Treron phoenicopterus*, Jungle Babbler *Argya striata*, Red-wattled Lapwing *Vanellus indicus*, and Silver Bill *Euodice malabarica*.

Our observations align with findings from other areas, where order Passeriformes is the most prevalent avian taxon (Mathibalan et al. 2026). This dominance is attributed to their ability to occupy a wide range of habitats and capacity to consume diverse food sources (Goyal et al. 2014; Rai et al. 2017; Rai & Vanita 2021; Qing-Ming et al. 2021). Diversity and richness of avian species in any ecosystem are also influenced by various factors like vegetation, availability of food, roosting sites, number of fruiting trees, degree of noise pollution, human interference, and predation (Hossain & Aditya 2016; Chiawo et al. 2018). Analysis of relative diversity (RDi) revealed that the family Muscicapidae is the most diverse group with the greatest RDi value (7.14) and six species, followed by Sturnidae (5 species), Motacillidae, Columbidae and Cuculidae (4 species) respectively (Figure 3). Similar to our observation, Muscicapidae was also reported as a highly diverse family at the Campus of Bangalore University (Rajashekara & Venkatesha 2017).

We observed two 'Near Threatened' species: Alexandrine Parakeet *Psittacula eupatria* and Black-headed Ibis *Threskiornis melanocephalus*. Regarding residential status, 66 species were resident, five were summer migrants, 12 winter migrants, and one a passage migrant (Table 1) (Figure 4). All the migratory species are common to the earlier recorded studies on the migratory species at Ottu Lake, Sirsa, Haryana (Goyal et al. 2014; Rai & Vanita 2021). A similar pattern has also been reported by Sailo et al. (2019) at the Mizoram University campus, where the number of winter visitors was highest among migratory birds. In our investigation, the campus supported 27 (32 %) omnivorous, 10 (12%) carnivorous, 31 (37%) insectivorous, 6 (7.1%) granivorous, 7 (8.3%) frugivorous, 1 (1.2%) nectarivorous, and 2 (2.4%) piscivorous birds (Figure 5). The high number of insectivorous and omnivorous species indicates the campus provides abundant insects and varied food assets including seeds, grains, nuts, floral buds, fruits, nectar, and non-insect invertebrates. Hence, better conservation strategies should be adopted to conserve the campus ecosystem and avian diversity as well.

Passerine species dominated non-passerines in terms of relative diversity. Further analysis, in accordance with IUCN 2024 (Red List), revealed that 39 species have stable, 18 decreasing, 18 increasing, and nine unknown global population trends (Figure 6). Twenty-one species are found to be common, 25 are fairly common, seven are uncommon, and 31 are rare (Figure 7). Appropriate conservation planning is crucial for maintaining the diversity of rare species in a particular area of campus. The number of rare species in the current study area is approximately half of the number of rare species (60) reported by Rai & Vanita (2021) at Ottu Lake, Sirsa. Comparison between global population trends and local abundance status showed that three species, namely Rock Dove, Eurasian Thick Knee *Burhinus oedicnemus* and Rufous Treepie *Dendrocitta vagabunda*, with decreasing population at the global scale (as per the IUCN Red List), were present abundantly in the campus, most probably due to the presence of suitable environmental conditions and abundance of food resources.

The reported avian diversity indicates that the campus ecosystem is healthy for avian fauna and also comparable with the earlier investigations conducted at various educational institutions situated in different regions of India (Table 2). For instance, Kiran et al. (2022) recorded 101 bird species that belong to 17 orders, 43 families, and 86 genera at agricultural lands and the campus of CCS Haryana Agricultural University, Hisar. Similarly, Rajashekara & Venkatesha (2017) reported 106 bird species belonging to 68 genera at the campus of Bangalore University. Devi et al. (2012) also reported 109 species under 44 families at Guwahati University campus. Seventy-seven bird species that belong to 35 families were reported in a previous investigation at the campus of Shri Krishna University, Chhatarpur (M.P), India (Shivhare et al. 2022). The current observation also supports that despite the limited area, the university campus harbors significant avian diversity when compared with the previous investigations made in this locality. This is comparable with the avian diversity observed at Ottu lake, Sirsa, Haryana, with an area of 950 acres and a depth of 15 feet, harbors total of 114 avian species belonging to 18 orders, 47 families and 91 genera (Rai & Vanita 2021). Additionally, Goyal et al. (2014) also reported 64 migratory bird species at the same lake, comprising 44 genera, 27 families, and nine

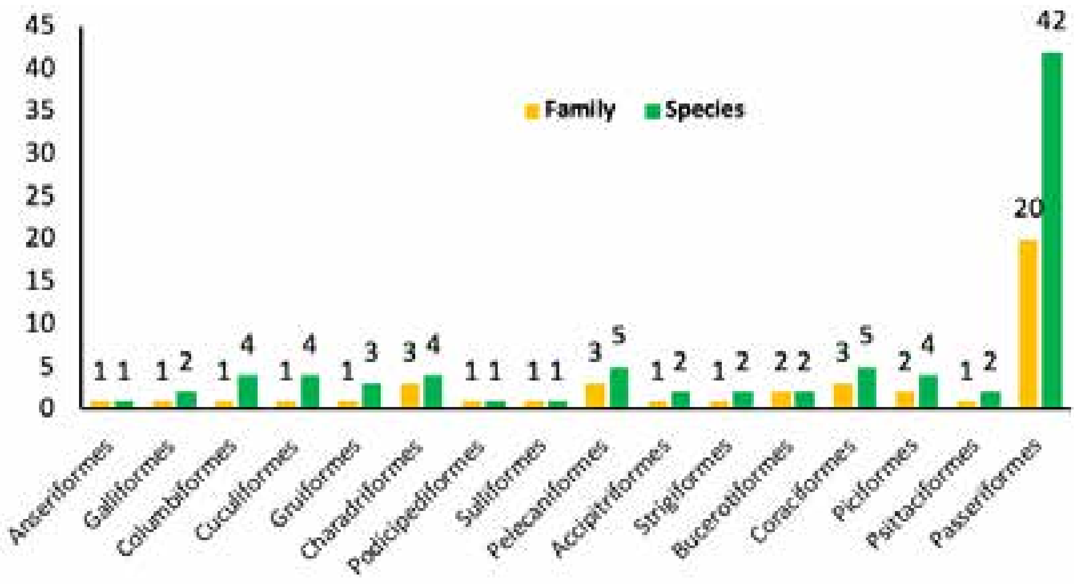


Figure 2. Order wise status of avian family at Chaudhary Devi Lal University.

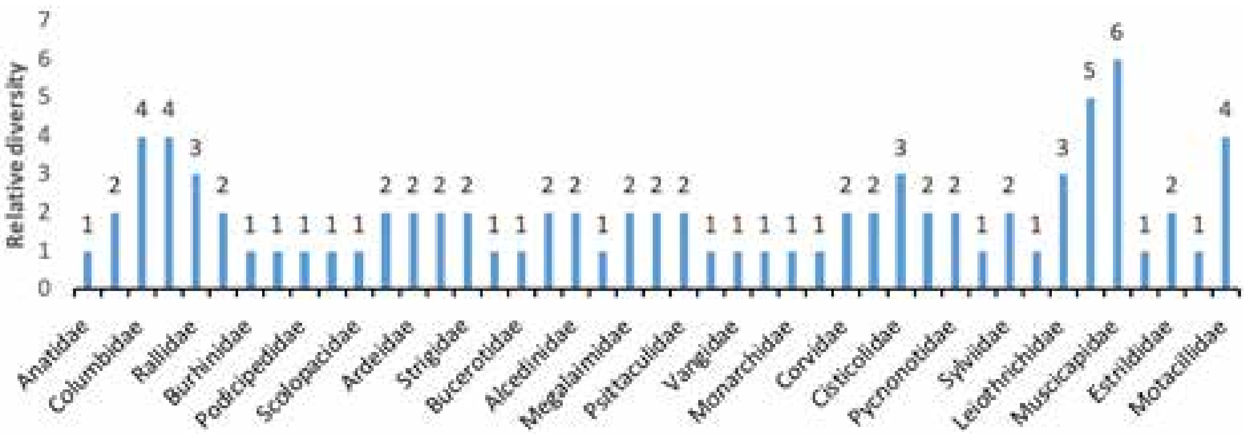


Figure 3. Relative species diversity among recorded avian families at Chaudhary Devi Lal University.

orders.

The rich avifauna diversity at this campus area can be attributed to the availability of a variety of food niches. However, the study also identified several moderate to low-level threats to avian diversity on the campus. These include limited water availability in the summer season, dusty storms in the month of May–July, that damage or destroy a significant number of both nests and nesting trees, predation of chicks by stray dogs and the presence of undeveloped land lacking suitable nesting trees. Although the campus authority has undertaken a large-scale plantation drive in the monsoon season (July–August 2025), planting more than 3,000 saplings across the premises, these require time to mature into fully developed trees capable of providing adequate nesting and foraging habitats. Therefore, additional tree plantation initiatives, effective management of stray dog populations, and increased awareness among students and staff could substantially help mitigate these threats and support the conservation of avian diversity on the campus.

## CONCLUSION

Usually, urbanization leads to a decline in species diversity, favoring only a few urban-adapted species. This study highlights the significance of green spaces and habitat diversity within the institution for the conservation of avian fauna and the maintenance

**Table 1. Guild, status, and composition of avian diversity recorded at the campus of Chaudhary Devi Lal University, Sirsa.**

| | Common name | Scientific name | Guild | IUCN Red List 2024 | Residential status | Abundance status | Global trends |
|---|---|---|---|---|---|---|---|
| **Order 1** | **Anseriformes** | | | | | | |
| **1.1 Family** | **Anatidae (RDi value 1.19)** | | | | | | |
| 1 | Indian Spot-billed Duck | *Anas poecilorhyncha* | Omnivorous | LC | R | C | D |
| **Order 2** | **Galliformes** | | | | | | |
| **2.1 Family** | **Phasianidae (RDi value 2.38)** | | | | | | |
| 2 | Grey Francolin | *Ortygornis pondicerianus* | Omnivorous | LC | R | FC | S |
| 3 | Black Francolin | *Francolinus francolinus* | Omnivorous | LC | R | RA | S |
| **Order 3** | **Columbiformes** | | | | | | |
| **3.1 Family** | **Columbidae (RDi value 4.76)** | | | | | | |
| 4 | Rock Dove | *Columba livia* | Granivorous | LC | R | C | D |
| 5 | Eurasian Collared Dove | *Streptopelia decaocto* | Granivorous | LC | R | FC | I |
| 6 | Laughing Dove | *Spilopelia senegalensis* | Granivorous | LC | R | C | S |
| 7 | Yellow-footed Green Pigeon | *Treron phoenicopterus* | Frugivorous | LC | R | FC | I |
| **Order 4** | **Cuculiformes** | | | | | | |
| **4.1 Family** | **Cuculidae (RDi value 4.76)** | | | | | | |
| 8 | Greater Coucal | *Centropus sinensis* | Carnivorous | LC | R | C | S |
| 9 | Pied Cuckoo | *Clamator jacobinus* | Insectivorous | LC | SM | RA | S |
| 10 | Asian Koel | *Eudynamys scolopaceus* | Omnivorous | LC | SM | C | S |
| 11 | Common Hawk-Cuckoo | *Hierococcyx varius* | Insectivorous | LC | SM | RA | S |
| **Order 5** | **Gruiformes** | | | | | | |
| **5.1 Family** | Rallidae **(RDi value 3.57)** | | | | | | |
| 12 | Common Moorhen | *Gallinula chloropus* | Omnivorous | LC | R | C | S |
| 13 | Grey-headed Swamphen | *Porphyrio poliocephalus* | Omnivorous | LC | R | RA | U |
| 14 | White-breasted Waterhen | *Amaurornis phoenicurus* | Omnivorous | LC | R | C | U |
| **Order 6** | **Charadriformes** | | | | | | |
| **6.1 Family** | **Charadriidae (RDi value 2.38)** | | | | | | |
| 15 | Yellow-wattled Lapwing | *Vanellus malabaricus* | Insectivorous | LC | R | FC | S |
| 16 | Red-wattled Lapwing | *Vanellus indicus* | Insectivorous | LC | R | C | U |
| **6.2 Family** | Burhinidae **(RDi value 1.19)** | | | | | | |
| 17 | Eurasian Thick-knee | *Burhinus oedicnemus* | Omnivorous | LC | R | FC | D |
| **6.3 Family** | **Recurvirostridae (RDi value 1.19)** | | | | | | |
| 18 | Black-winged Stilt | *Himantopus himantopus* | Carnivorous | LC | R | C | I |
| **Order 7** | **Podicipediformes** | | | | | | |
| **7.1 Family** | **Podicipedidae (RDi value 1.19)** | | | | | | |
| 19 | Little Grebe | *Tachybaptus ruficollis* | Carnivorous | LC | R | UC | D |
| **Order 8** | **Suliformes** | | | | | | |
| **8.1 Family** | **Phalacrocoracidae (RDi value 1.19)** | | | | | | |
| 20 | Little Cormorant | *Microcarbo niger* | Piscivore | LC | R | C | U |
| **Order 9** | **Pelecaniformes** | | | | | | |
| **9.1 Family** | **Scolopacidae (RDi value 1.19)** | | | | | | |
| 21 | Wood Sandpiper | *Tringa glareola* | Insectivorous | LC | WM | FC | S |
| **9.2 Family** | **Threskiornithidae (RDi value 2.38)** | | | | | | |
| 22 | Black-headed Ibis | *Threskiornis melanocephalus* | Carnivorous | NT | R | RA | D |
| 23 | Red-naped Ibis | *Pseudibis papillosa* | Carnivorous | LC | R | FC | D |

| | Common name | Scientific name | Guild | IUCN Red List 2024 | Residential status | Abundance status | Global trends |
|---|---|---|---|---|---|---|---|
| **9.3 Family** | **Ardeidae (RDi value 2.38)** | | | | | | |
| 24 | Black-crowned Night Heron | *Nycticorax nycticorax* | Carnivorous | LC | R | UC | D |
| 25 | Cattle Egret | *Ardea ibis* | Carnivorous | LC | R | C | I |
| **Order 10** | **Accipitriformes** | | | | | | |
| **10.1 Family** | **Accipitridae (RDi value 2.38)** | | | | | | |
| 26 | Oriental Honey Buzzard | *Pernis ptilorhynchus* | Insectivorous | LC | R | RA | D |
| 27 | Shikra | *Tachyspiza badia* | Carnivorous | LC | R | FC | S |
| **Order 11** | **Strigiformes** | | | | | | |
| **11.1 Family** | **Strigidae (RDi value 2.38)** | | | | | | |
| 28 | Indian Scops-Owl | *Otus bakkamoena* | Insectivorous | LC | R | RA | S |
| 29 | Spotted Owlet | *Athene brama* | Carnivorous | LC | R | FC | S |
| **Order 12** | **Bucerotiformes** | | | | | | |
| **12.1 Family** | **Upupidae (RDi value 1.19)** | | | | | | |
| 30 | Eurasian Hoopoe | *Upupa epops* | Insectivorous | LC | R | FC | D |
| **12.2 Family** | **Bucerotidae (RDi value 1.19)** | | | | | | |
| 31 | Indian Grey Hornbill | *Ocyceros birostris* | Frugivorous | LC | R | FC | S |
| **Order 13** | **Coraciiformes** | | | | | | |
| **13.1 Family** | **Meropidae (RDi value 2.38)** | | | | | | |
| 32 | Asian Green Bee-eater | *Merops orientalis* | Insectivorous | LC | SM | C | I |
| 33 | Blue-cheeked Bee-eater | *Merops persicus* | Insectivorous | LC | SM | RA | S |
| **13.2 Family** | **Alcedinidae (RDi value 2.38)** | | | | | | |
| 34 | White-throated Kingfisher | *Halcyon smyrnensis* | Omnivorous | LC | R | C | I |
| 35 | Pied Kingfisher | *Ceryle rudis* | Piscivore | LC | R | UC | U |
| **13.3 Family** | **Coraciidae (RDi value 1.19)** | | | | | | |
| 36 | Indian Roller | *Coracias benghalensis* | Omnivorous | LC | R | RA | I |
| **Order 14** | **Piciformes** | | | | | | |
| **14.1 Family** | **Megalaimidae (RDi value 2.38)** | | | | | | |
| 37 | Coppersmith Barbet | *Psilopogon haemacephalus* | Frugivorous | LC | R | RA | I |
| 38 | Brown-headed Barbet | *Psilopogon zeylanicus* | Frugivorous | LC | R | RA | S |
| **14.2 Family** | **Picidae (RDi value 2.38)** | | | | | | |
| 39 | Eurasian Wryneck | *Jynx torquilla* | Insectivorous | LC | WM | RA | D |
| 40 | Black-rumped Flameback | *Dinopium benghalense* | Insectivorous | LC | R | FC | S |
| **Order 15** | **Psittaciformes** | | | | | | |
| **15.1 Family** | **Psittaculidae (RDi value 2.38)** | | | | | | |
| 41 | Alexandrine Parakeet | *Psittacula eupatria* | Frugivorous | NT | R | RA | D |
| 42 | Rose-ringed Parakeet | *Psittacula krameri* | Frugivorous | LC | R | C | I |
| **Order 16** | **Passeriformes** | | | | | | |
| **16.1 Family** | **Campephagidae (RDi value 1.19)** | | | | | | |
| 43 | Small Minivet | *Pericrocotus cinnamomeus* | Insectivorous | LC | R | RA | D |
| **16.2 Family** | **Vangidae (RDi value 1.19)** | | | | | | |
| 44 | Common Woodshrike | *Tephrodornis pondicerianus* | Insectivorous | LC | R | RA | S |

| | Common name | Scientific name | Guild | IUCN Red List 2024 | Residential status | Abundance status | Global trends |
|---|---|---|---|---|---|---|---|
| **16.3 Family** | **Dicruridae (RDi value 1.19)** | | | | | | |
| 45 | Black Drongo | *Dicrurus macrocercus* | Insectivorous | LC | R | FC | U |
| **16.4 Family** | **Monarchidae (RDi value 1.19)** | | | | | | |
| 46 | Indian Paradise-Flycatcher | *Terpsiphone paradisi* | Insectivorous | LC | R | RA | S |
| **16.5 Family** | **Laniidae (RDi value 1.19)** | | | | | | |
| 47 | Long-tailed Shrike | *Lanius schach* | Carnivorous | LC | WM | RA | U |
| **16.6 Family** | **Corvidae (RDi value 2.38)** | | | | | | |
| 48 | Rufous Treepie | *Dendrocitta vagabunda* | Omnivorous | LC | R | FC | D |
| 49 | House Crow | *Corvus splendens* | Omnivorous | LC | R | UC | S |
| **16.7 Family** | **Alaudidae (RDi value 2.38)** | | | | | | |
| 50 | Indian Bushlark | *Plocealauda erythroptera* | Omnivorous | LC | R | RA | S |
| 51 | Crested Lark | *Galerida cristata* | Omnivorous | LC | R | RA | D |
| **16.8 Family** | Cisticolidae **(RDi value 3.57)** | | | | | | |
| 52 | Common Tailorbird | *Orthotomus sutorius* | Omnivorous | LC | R | RA | S |
| 53 | Ashy Prinia | *Prinia socialis* | Insectivorous | LC | R | RA | S |
| 54 | Plain Prinia | *Prinia inornata* | Insectivorous | LC | R | FC | S |
| **16.9 Family** | **Hirundinidae (RDi value 2.38)** | | | | | | |
| 55 | Wire-tailed Swallow | *Hirundo smithii* | Insectivorous | LC | R | C | I |
| 56 | Streak-throated Swallow | *Petrochelidon fluvicola* | Insectivorous | LC | R | C | I |
| **16.10 Family** | **Pycnonotidae (RDi value 2.38)** | | | | | | |
| 57 | Red-vented Bulbul | *Pycnonotus cafer* | Frugivorous | LC | R | C | I |
| 58 | White-eared Bulbul | *Pycnonotus leucotis* | Omnivorous | LC | R | RA | D |
| **16.11 Family** | **Phylloscopidae (RDi value 1.19)** | | | | | | |
| 59 | Common Chiffchaff | *Phylloscopus collybita* | Insectivorous | LC | WM | FC | S |
| **16.12 Family** | **Sylviidae (RDi value 2.38)** | | | | | | |
| 61 | Lesser Whitethroat | *Curruca curruca* | Omnivorous | LC | WM | RA | S |
| 60 | Blyth's Reed- warbler | *Acrocephalus dumetorum* | Insectivorous | LC | WM | FC | I |
| **16.13 Family** | **Zosteropidae (RDi value 1.19)** | | | | | | |
| 62 | Indian White-eye | *Zosterops palpebrosus* | Insectivorous | LC | R | UC | D |
| **16.14 Family** | **Leiothrichidae (RDi value 3.38)** | | | | | | |
| 63 | Large Grey Babbler | *Argya malcolmi* | Omnivorous | LC | R | FC | S |
| 64 | Jungle Babbler | *Argya striata* | Omnivorous | LC | R | C | S |
| 65 | Common Babbler | *Argya caudata* | Omnivorous | LC | R | FC | S |
| **16.15 Family** | **Sturnidae (RDi value 5.95)** | | | | | | |
| 66 | Rosy Starling | *Pastor roseus* | Omnivorous | LC | PM | RA | U |
| 67 | Indian Pied Starling | *Gracupica contra* | Omnivorous | LC | R | RA | I |
| 68 | Brahminy Starling | *Sturnia pagodarum* | Omnivorous | LC | WM | RA | U |
| 69 | Common Myna | *Acridotheres tristis* | Omnivorous | LC | R | FC | I |
| 70 | Bank Myna | *Acridotheres ginginianus* | Omnivorous | LC | R | RA | I |
| **16.16 Family** | **Muscicapidae (RDi value 7.14)** | | | | | | |

| | Common name | Scientific name | Guild | IUCN Red List 2024 | Residential status | Abundance status | Global trends |
|---|---|---|---|---|---|---|---|
| 71 | Indian Robin | *Copsychus fulicatus* | Insectivorous | LC | R | C | S |
| 72 | Oriental Magpie-Robin | *Copsychus saularis* | Omnivorous | LC | R | RA | S |
| 73 | Bluethroat | *Luscinia svecica* | Omnivorous | LC | WM | FC | S |
| 74 | Red-breasted Flycatcher | *Ficedula parva* | Insectivorous | LC | WM | FC | I |
| 75 | Black Redstart | *Phoenicurus ochruros* | Insectivorous | LC | WM | FC | I |
| 76 | Brown Rock Chat | *Oenanthe fusca* | Insectivorous | LC | R | C | S |
| **16.17 Family** | **Nectariniidae (RDi value 1.19)** | | | | | | |
| 77 | Purple Sunbird | *Cinnyris asiaticus* | Nectarivorous | LC | R | C | S |
| **16.18 Family** | Estrildidae **(RDi value 2.38)** | | | | | | |
| 78 | Indian Silverbill | *Euodice malabarica* | Granivorous | LC | R | RA | S |
| 79 | Scaly-breasted Munia | *Lonchura punctulata* | Granivorous | LC | R | RA | S |
| **16.19 Family** | **Passeridae (RDi value 1.19)** | | | | | | |
| 80 | House Sparrow | *Passer domesticus* | Granivorous | LC | R | UC | D |
| **16.20 Family** | **Motacillidae (RDi value 4.76)** | | | | | | |
| 81 | Western Yellow Wagtail | *Motacilla flava* | Insectivorous | LC | WM | UC | D |
| 82 | White-browed Wagtail | *Motacilla maderaspatensis* | Insectivorous | LC | R | FC | S |
| 83 | White Wagtail | *Motacilla alba* | Insectivorous | LC | WM | FC | S |
| 84 | Paddy Field Pipit | *Anthus rufulus* | Insectivorous | LC | R | RA | S |

IUCN status: LC—Least Concerned, NT—Near Threatened | Resident status: R—Resident, SM—Summer Migrant, WM—Winter Migrant | Abundance status: RA—Rare, FC—Fairly Common, C—Common, UC—Uncommon | Global Trends: S—stable, I—Increasing, D—Decreasing, U—Unknown.

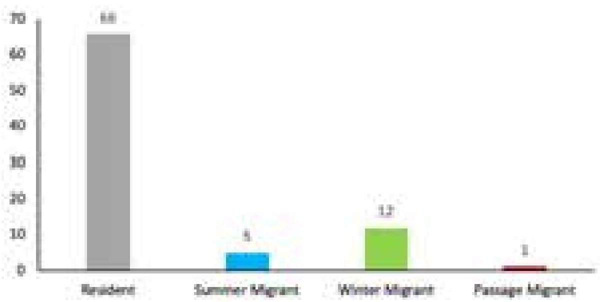


**Figure 4. Residential status of different avian species recorded at Chaudhary Devi Lal University.**

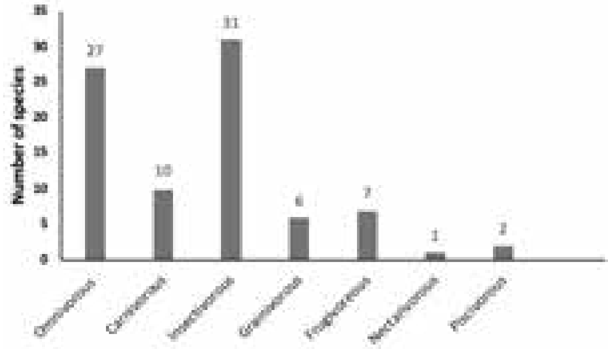


**Figure 5. Guild status of reported bird species in Chaudhary Devi Lal University.**

of ecological balance. It also underscores the global importance of protecting such habitats, which serve as safe havens and food niches for a wide variety of bird species. The adjoining areas of this campus are rapidly losing greenery due to construction activities, including the establishment of a medical college and other developmental projects; however, the CDLU campus itself is progressing in the opposite direction, and efforts are being directed toward enhancing its green cover. Specifically, during the monsoon season (July–August), large-scale tree plantation drives are being organized across the campus. Such initiatives are expected to play a crucial role in conserving habitats and sustaining food resources for local bird populations. Further action plan involves mitigation of threats, long-term monitoring of avian diversity through active student participation, focusing on species density, habitat utilization, seasonal variations in abundance, and aspects of nesting and breeding ecology, thereby contributing valuable insights into bird conservation and ecosystem management.

**Table 2. Avian diversity reported at different educational institutes of India.**

| Educational Institute | Area surveyed | Avian species reported | Time frame | Region | Key findings | References |
|---|---|---|---|---|---|---|
| CCS Haryana Agricultural University Campus, Hisar | ------- | 101 | 2 Years | Hisar, Haryana, India | 101 bird species belonging to 17 orders and 43 families. Order Passeriformes most dominating | Kiran et al. 2022 |
| Kurukshetra University, Kurukshetra, Haryana, India | 160 hectares | 92 | 3 Years, 9 Months | Kurukshetra, Haryana, India | 92 bird species belonging to 37 families. Order Passeriformes most dominating | Gupta et al. 2009 |
| Bangalore University Campus, Bengaluru, India | 445.15 hectares | 106 | 2 Years | Bengaluru, India | 106 bird species belonging to 42 families and 68 genera | Rajashekara & Venkatesha 2017 |
| Gauhati University Campus, Jalukbari, Assam, India | 195.87 hectares | 109 | 3 Years | Jalukbari, Assam, India | 109 bird species belonging to 42 families | Devi et al. 2012 |
| Indian Institute of Technology Guwahati Campus, Assam, India | 280 hectares | 152 | 3 Years | Guwahati, Assam, India | 152 bird species belonging to 14 orders and 50 families | Rathod & Bhaduri 2022 |
| Shri Krishna University Campus, Chhatarpur (M.P), India | 40 hectares | 77 | 6 Months | Chhatarpur (M.P), India | 77 bird species belonging to 35 families | Shivhare et al. 2022 |
| Durgapur Government College Campus, West Bengal, India | 12 hectares | 106 | 7 years | West Bengal | 106 bird species belonging to 47 families | Adhurya et al. 2023 |

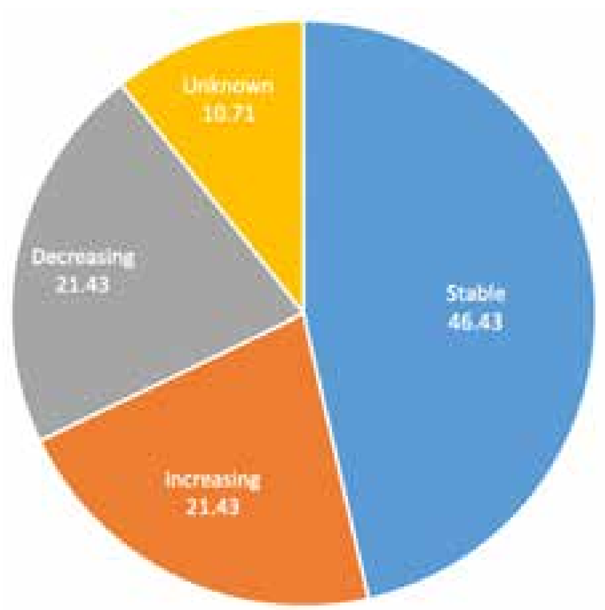


**Figure 6. Global population trend of avian species reported at campus of Chaudhary Devi Lal University (IUCN 2024).**

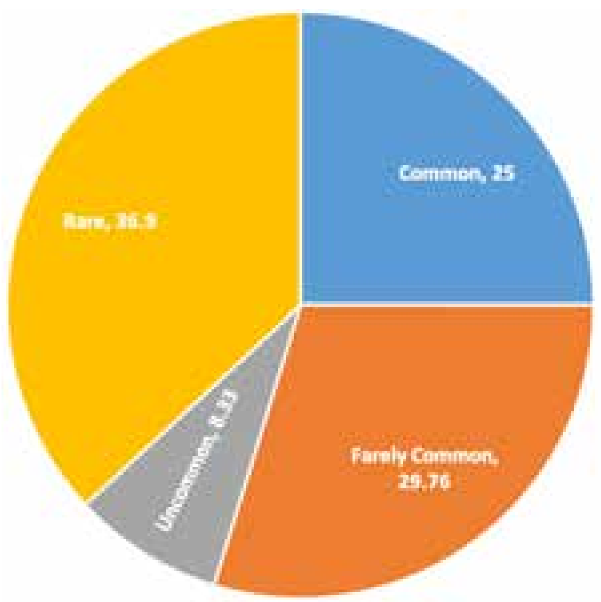


**Figure 7. Abundance status of avian species at Chaudhary Devi Lal University.**

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ARTICLE

# New record of two natricine snakes, *Hebius gilhodesi* (Wall, 1925) and *Herpetoreas davidi* Nguyen et al., 2024 (Reptilia: Squamata: Colubridae), from India

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**Abstract:** Two natricine snakes, *Hebius gilhodesi* and *Herpetoreas davidi*, are reported for the first time from India based on mitochondrial DNA and morphological data. This study extends the northwestern-most distribution of *H. gilhodesi* by 107 km and *H. davidi* by 577 km, both of which were thus far known only from adjacent Myanmar. Additionally, a detailed description of the hemipenial morphology of *H. gilhodesi* is provided.

**Keywords:** Arunachal Pradesh, keelback, Mizoram, morphology, Myanmar, natural history, northeastern India, phylogeny, range extension.

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**Competing interests:** The authors declare no competing interests.

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**Author contributions:** SD conducted field work, studied specimens and prepared the manuscript draft. BB conducted field work, did the phylogenetic analyses and reviewed the manuscript. AD conceptualized the work, conducted field work and reviewed the manuscript.

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## INTRODUCTION

The natricine snake genus *Hebius* Thompson, 1913, currently represents over 50 species, widely distributed throughout eastern and southeastern Asia (Gao et al. 2024; Li et al. 2026; Uetz et al. 2026). In India, this genus is represented by seven species (Basfore et al. 2024; Uetz et al. 2026), namely: *H. clerki* (Wall, 1925); *H. khasiensis* (Boulenger, 1890); *H. lacrima* Purkayastha & David, 2019; *H. modestus* (Günther, 1875); *H. parallelus* (Boulenger, 1890); *H. taronensis* (Smith, 1940); and *H. venningi* (Wall, 1910). Recently, Bohra et al. (2025) resurrected *H. gilhodesi*, which was synonymised under *H. khasiensis* by Wall (1926). *Hebius gilhodesi* is currently known from the type locality, Hutung in Bhamo District and Alangdunhku in Putao District of Myanmar (Bohra et al. 2025).

Another natricine snake genus *Herpetoreas* Günther, 1860, is represented by nine species, distributed across the foothills of western and eastern Himalaya, including northeastern Pakistan, northern & northeastern India, Nepal, Bhutan, southwestern China, Bangladesh, and Myanmar (Ren et al. 2022). In India, five species of this genus have been reported (Basfore et al. 2024; Nguyen et al. 2024; Uetz et al. 2026), namely: *H. murlen* Lalremsanga, Bal, Vogel & Biakzula, 2022; *H. pealii* (Sclater, 1891); *H. platyceps* (Blyth, 1855); *H. sieboldii* Günther, 1860; and *H. xenura* (Wall, 1907). Among these five species, *H. murlen* and *H. pealii* are endemic to northeastern India. Recently, Nguyen et al. (2024) described *Herpetoreas davidi* from southwestern Myanmar, which is known only from the type locality Rakhine Yoma Elephant Sanctuary.

During the herpetological surveys in northeastern India, some unidentified populations of natricine snakes were encountered that did not fit the definitions of taxa known from India. Phylogenetic analyses and morphological data suggest two populations from Arunachal Pradesh are *H. gilhodesi* and one from Mizoram is *H. davidi* which are reported herein as the first record from India.

## MATERIALS AND METHODS

### Sample collection and fixation

Specimens of natricine snakes were hand-collected from Arunachal Pradesh, Meghalaya, and Mizoram in northeastern India during 2021 and 2023. Collected samples were euthanized using Tricaine Methanesulfonate (MS222) and fixed in 3% formalin. Prior to fixation, liver tissue was collected and stored in molecular-grade ethanol for DNA extraction. Collected specimens were registered and deposited at the Wildlife Institute of India, Dehradun.

### DNA extraction and phylogenetic analyses

Genomic DNA was extracted from liver tissue samples stored in absolute ethanol at –20 °C, using the DNeasy (Qiagen) blood and tissue kit. Cytochrome b (Cyt-b) gene (~ 1100 base pairs) was amplified and sequenced using the primers L14910 (5'-GACCTGTGATMTGAAAACCAYCGTTGT-3') and H16064 (5'-CTTTGGTTTACAAGAACAATGCTTTA-3') (Burbrink et al. 2000). Polymerase chain reaction (PCR) condition followed was initial denaturation at 95 °C for 5 min, followed by 35 cycles of denaturation at 95 °C for 45 s, annealing at 54 °C for 45 s, and extension at 72 °C for 55 s. The final extension was at 72 °C for 10 min. Bidirectional sequences were manually checked using CHROMAS v.2.6.6 software (http://technelysium.com.au/wp/chromas) and aligned using ClustalW (Thompson et al. 1994) with default prior settings implemented in MEGA v.7 (Kumar et al. 2016). We checked for unexpected stop codons by translating the sequence to amino acids in MEGA v.7. The new sequences generated in this study were aligned with 49 sequences downloaded from GenBank (Benson et al. 2007), and *Amphiesma stolatum* was used as an outgroup (Appendix 1). Maximum likelihood (ML) analysis was performed using the GUI version of the IQ-TREE (Nguyen et al. 2015), implemented in PhyloSuite (Zhang et al. 2020). The dataset was partitioned by codon position. The ModelFinder (Kalyaanamoorthy et al. 2017) was used to find the best-fitting models. The best fit models suggested by ModelFinder were Partition 1: TN+F+I+G4, Partition 2: HKY+F+I, Partition 3: TIM+F+G4. We also performed a Bayesian inference (BI) analysis using the program MrBayes 3.2 (Ronquist et al. 2012) implemented in PhyloSuite (Zhang et al. 2020). We used PartitionFinder v1.1.1 (Lanfear et al. 2012) with default settings to find the best-fit model of sequence evolution for the same dataset used for ML analysis. The best fit models suggested by PartitionFinder were Partition 1: HKY+I+G, Partition 2: HKY+I, Partition 3: GTR+G. Four separate runs were set up, each with eight Markov chains, initiated from random trees and allowed to run for 10 million generations, sampling every 1,000 generations. Analyses were terminated when the standard deviation of the split frequencies was less than 0.001, the first 25% of trees were discarded as burn-in, and trees were constructed using a 50%

majority consensus rule. We obtained the ESS values using TRACER v1.6 (Rambaut et al. 2018) and confirmed greater than 200 for the priors. Support for the internal branches for the ML and BI was quantified using 10,000 pseudoreplicates (ultrafast bootstrap UFB) and posterior probability (PP), respectively. The resulting tree was edited in Figtree v.1.4.4 (Rambaut 2018). Uncorrected pairwise distances (p–distances) were calculated in MEGA v7.1 with pairwise deletion of missing data and gaps.

**Morphological examination**

Morphological measurements and terminologies followed Das et al. (2021) as mentioned in the following: snout-vent length (SVL); tail length (TL); head length (HL): distance between posterior edge of last supralabial and tip of the snout; head width (HW): at angle of jaws; head depth (HD): height at the occipital region; eye diameter (ED): horizontal diameter; eye to nostril distance (EN): anterior corner of eye to posterior edge of nostril; eye to snout distance (ES): anterior corner of eye to tip of snout; interorbital distance (IO): measured at the anterior corner of orbit. All linear measurements, except SVL and TL, were taken using Mitutoyo digital callipers (accuracy 0.01 mm). The SVL and TL were measured using a thread and metal scale. We also counted head and body scales as follows: SL: number of supralabials; IL: number of infralabials; SL-E: number of supralabials entering orbit; PreO: numbers of preocular; PostO: number of postocular; Tmp: number of temporals; PVS: number of preventrals; DSR: dorsal scales row at one head length behind neck, at midbody, and one head length before vent; VS: number of ventrals; AN: anal plate divided or entire; SC: number of subcaudals. Ventral scale counts and hemipenial descriptions followed Dowling (1951); Dowling & Savage (1960) respectively. Abbreviation used are WII-ADR: Wildlife Institute of India Abhijit Das Reptile collection.

## RESULTS

**Phylogenetic analyses**

Both ML and BI analyses yielded nearly similar tree topologies (Figures 1 & 2). The newly collected materials (WII-ADR1792, WII-ADR1793, WII-ADR1800, WII-ADR3303, WII-ADR3320) from Namdapha Tiger Reserve, Gandhigram, and Kamlang Tiger Reserve in Arunachal Pradesh (Figure 3) clustered with the published sequences of *Hebius gilhodesi* from Myanmar. The genetic divergence of these newly collected samples from northeastern India and samples from Myanmar is 2.2–3.2 % in the Cyt-b gene. One specimen (WII-ADR1051) collected from Ngengpui Wildlife Sanctuary, Mizoram (Figure 3) nested with the published type sequences of *Herpetoreas davidi* from Myanmar (Figures 1 & 2). The genetic divergence between these two samples is 0.7% in the Cyt-b gene.

**Morphology**

The specimens from Arunachal Pradesh (WII-ADR1792, WII-ADR1793, WII-ADR1800, WII-ADR3303, WII-ADR3320) (Images 1 & 2) were referred to *Hebius gilhodesi* based on the following set of morphological characters: 1) dorsal scale rows 19: 19: 17; 2) scales are moderately keeled; 3) dorsal scale rows reduce from 19–17 between 91$^{st}$–97$^{th}$ ventrals in males and between 84$^{th}$–89$^{th}$ ventrals in females where the third and fourth dorsal scale rows fuse; 4) ventrals 142–148; 5) subcaudals 71–103; 6) nine supralabials, generally fourth to sixth supralabials enter the orbit; 7) dorsally dark brown, a very faint, rusty brown dorsolateral stripe from the neck to the tip of the tail, interrupted by buff spots.

The specimen (WII-ADR1051) (Image 3) from Mizoram was referred to *Herpetoreas davidi* based on the following set of characters: 1) small body size, 490 mm; 2) 19: 19: 17 dorsal scale rows, scales strongly keeled; 3) ventrals 153; 4) subcaudals undivided; 5) nine supralabials; 6) a white sagittal line just behind the parietal present; 7) head dorsally rusty brown; 8) dorsum light to dark brown with a dorsolateral series of white spots from nape to base of the tail; 9) ventral surface creamish or off white with dark spots along the lateral edge of each ventral and subcaudal scales.

Thus, this study reports two Myanmar natricine snakes *Hebius gilhodesi* and *Herpetoreas davidi* for the first time from India (Figure 3) based on phylogenetic and morphological data. Morphological descriptions of newly collected specimens of the two species from India are given below.

***Hebius gilhodesi* (Wall, 1925)**

(Table 1; Figure 1–3; Images 1, 2)

**Materials examined (n = 5):** adult male (WII-ADR1793), adult female (WII-ADR1792) and subadult female (WII-ADR1800) collected from Gandhigram (27.26514° N, 96.93704° E, elevation 1,115 m), Changlang District, Arunachal Pradesh, India on 17–19 September 2022 by Abhijit Das, Bitupan Boruah, Naitik G. Patel; adult male (WII-ADR3320) collected from Kamlang Tiger

**Table 1. Morphometric and meristic data of newly collected *Hebius gilhodesi* and *Herpetoreas davidi* from India, with available data. Bilateral characters are given in right and left order separated by "/"; "n" denotes samples size, "-" indicates data not provided, and "*" measurement/ counts incomplete because of tail missing.**

| | *Hebius gilhodesi* | | | | | | | *Herpetoreas davidi* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Voucher specimen | WII-ADR1793 | WII-ADR3320 | WII-ADR1800 | WII-ADR1792 | WII-ADR3303 | Bohra et al. 2025 (n = 15) | | WII-ADR1051 | Nguyen et al. 2024 (n = 2) | |
| Sex | Male | Male | Female | Female | Female (juvenile) | Male | Female | Female | Male | Female |
| SVL | 370 | 410 | 250 | 370 | 170 | 288–368 | 156–435 | 490 | 292–384 | 259–482 |
| TL | 145 | 210 | 105 | 190 | 80 | 152–181 | 68–183 | 140* | 126–168 | 115–178 |
| HL | 14.80 | 14.50 | 11.30 | 15.80 | 8.90 | 13.4–16.4 | 13.1–17.9 | 21.15 | - | - |
| HW | 8.55 | 8.0 | 5.88 | 8 | 7.70 | 3.2–4.1 | 3.2–4.2 | 10 | - | - |
| HD | 8.60 | 6.10 | 4.68 | 5.85 | 3.50 | - | - | 7.46 | - | - |
| ED | 2.56 | 2.60 | 2.18 | 2.61 | 1.85 | 2.2–2.9 | 2.5–2.9 | 3.26 | - | - |
| E-N | 2.52 | 2.45 | 1.78 | 2.52 | 1.47 | 2.3–2.9 | 2.4–3.3 | 3.14 | - | - |
| E-S | 4.45 | 4.25 | 3.10 | 4.20 | 2.50 | 3.2-4.1 | 3.2–4.2 | 5.21 | - | - |
| IN | 2.85 | 2.90 | 2.10 | 2.75 | 1.79 | - | - | 3.35 | - | - |
| IO | 4.40 | 4.25 | 3.32 | 4.07 | 2.82 | - | - | 5 | - | - |
| PVS | 2 | 2 | 1 | 2 | 3 | - | - | 2 | - | - |
| VS | 145 | 148 | 146 | 142 | 147 | 144–153 | 143–151 | 153 | 154–156 | 151–155 |
| SC | 71, 72 | 99, 100 | 86, 87 | 93, 92 | 102, 103 | 99–111 | 87–98 | 59* | 97–99 | 97–100 |
| DSR | 19: 19: 17 | 19: 19: 17 | 19: 19: 17 | 19: 19: 17 | 19: 19: 17 | 19:19:17 | 19:19:17 | 19: 19: 17 | 19: 19: 17 | 19: 19: 17 |
| SL | 10, 9 | 9, 9 | 8, 9 | 9, 9 | 9, 9 | 9, rarely 8 | 9 | 8, 8 | 9 | 9 |
| SL-E | 5, 6, 7/ 4, 5, 6 | 4, 5, 6/ 4, 5, 6 | 3, 4, 5/ 4, 5, 6 | 4, 5, 6/ 4, 5, 6 | 4, 5, 6/ 4, 5, 6 | 4-6, rarely 4, 5 | 4, 5, 6 | 4, 5/ 3, 4, 5 | 4–6 | 4–6 |
| IL | 10/10 | 10/10 | 9/ 10 | 10/ 10 | 10/ 10 | 10 | 10, rarely 11 | 10/ 10 | 9 or 10 | 9 or 10 |
| Tmp | 2+2/ 2+2 | 1+2/1+2 | 1+1 / 1+1 | 1+1/ 1+1 | 1+1/ 1+1 | 1+1, rarely 2+1 | 1+1, rarely 2+1 | 2+2/ 2+1 | 1+2 or 2+2 | 1+2 or 2+2 |
| PreO | 1/1 | 1/1 | 1/1 | 2/2 | 1/1 | 1, rarely 2 | 1, rarely 2 | 1/1 | 1 | 1 |
| PostO | ¾ | 3/3 | 3/3 | 3/3 | 3/3 | | 3, rarely 2 | 3/2 | 3 | 3 |
| AN | Divided | Divided | Divided | Divided | Divided | Divided | Divided | Divided | Single | Single |

reserve (27.69583° N, 96.44585° E, elevation 1,205 m), Lohit District, Arunachal Pradesh, India on 19 July 2023 by Abhijit Das, Jason D. Gerard and Rajiv N.V.; juvenile female (WII-ADR3303) collected from Kamala Valley (27.46127° N, 96.42569° E, elevation 645 m), Namdapha Tiger Reserve, Changlang District, Arunachal Pradesh, India on 2 June 2023 by Abhijit Das, Sourav Dutta, Jason D. Gerard and Rajiv N.V. (Figure 3).

**Description of new Indian material (Image 1)**

A moderate sized snake, SVL 370–410 mm in males and 250–370 mm in females. Body subcylindrical, widest at midbody, slightly tapering anteriorly and posteriorly; tail moderately long, TL/SVL= (0.39–0.51) in males and TL/SVL= (0.42–0.51) in females. Head moderately distinct from neck, longer than wide, HW/HL = (0.55–0.57) in males and HW/HL= (0.50–0.52) in females; snout nearly rounded, gradually sloping towards the tip; nostril visible from dorsal aspect; rostral almost hidden from dorsal aspect, only posterior border is slightly visible; internasal paired, as long as broad; prefrontal wider than long, laterally extended towards loreal; frontal posteriorly pointed, longer than broad, anteriorly wide, slightly longer than the supraocular; supraocular elongated, widest at posterior part; parietals long, anteriorly wide, posterior margin extends at the level of more than half of the last supralabial length. In lateral view tip of snout acute; rostral partially visible; nostril horizontally elliptical, laterally placed, closer to snout than to orbit; nasal divided by a vertical slit, posterior nasal larger than anterior one, in contact with first and second supralabials; loreal region slightly concave; loreal single, sub-rectangular, dorsally widely contacting with prefrontal, and below in contact with second and third supralabials; in WII-ADR1793, loreal in contact with third and fourth supralabials; generally a single preocular

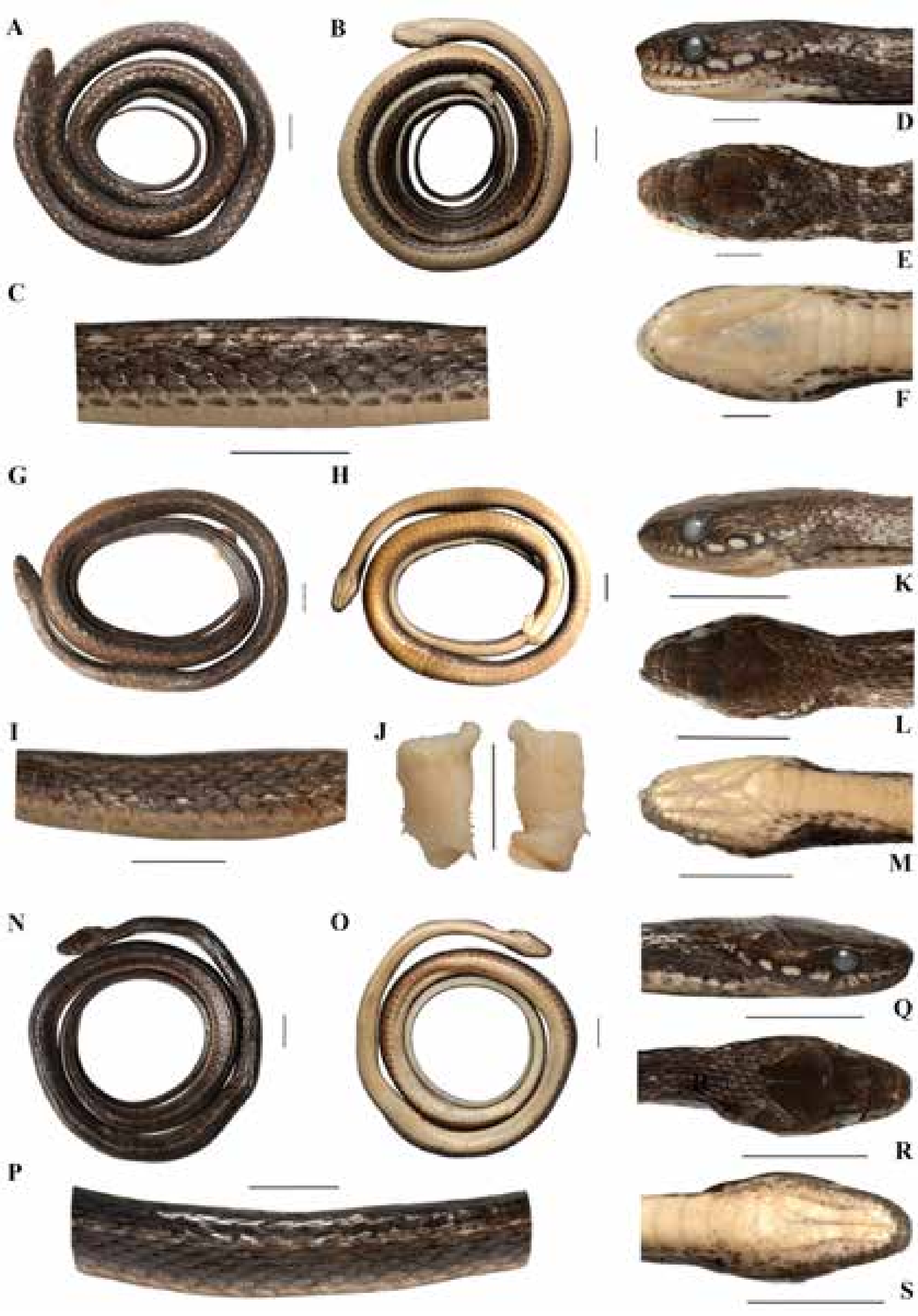


**Image 1. Newly collected specimens of *Hebius gilhodesi* in preserved condition, from India. A–F—WII-ADR3320 | A—dorsal view of full body | B—ventral view of full body | C—closeup of dorsal scales of midbody | D—lateral side of head | E—dorsal side of head | F—ventral side of head | G–M—WII-ADR1793 | G—dorsal view of full body | H—ventral view of full body | I—closeup of midbody dorsal scales | J—sulcate and asulcate view of hemipenis | K—lateral side of head | L—dorsal side of head | M—ventral side of head | N–S—WII-ADR1792 | N—dorsal view of full body | O—dorsal view of full body | P—closeup of midbody dorsal scales | Q—lateral side of head | R—dorsal side of head | S—ventral side of head. Scale bar—10 mm. © A. Das, B. Boruah & S. Dutta.**

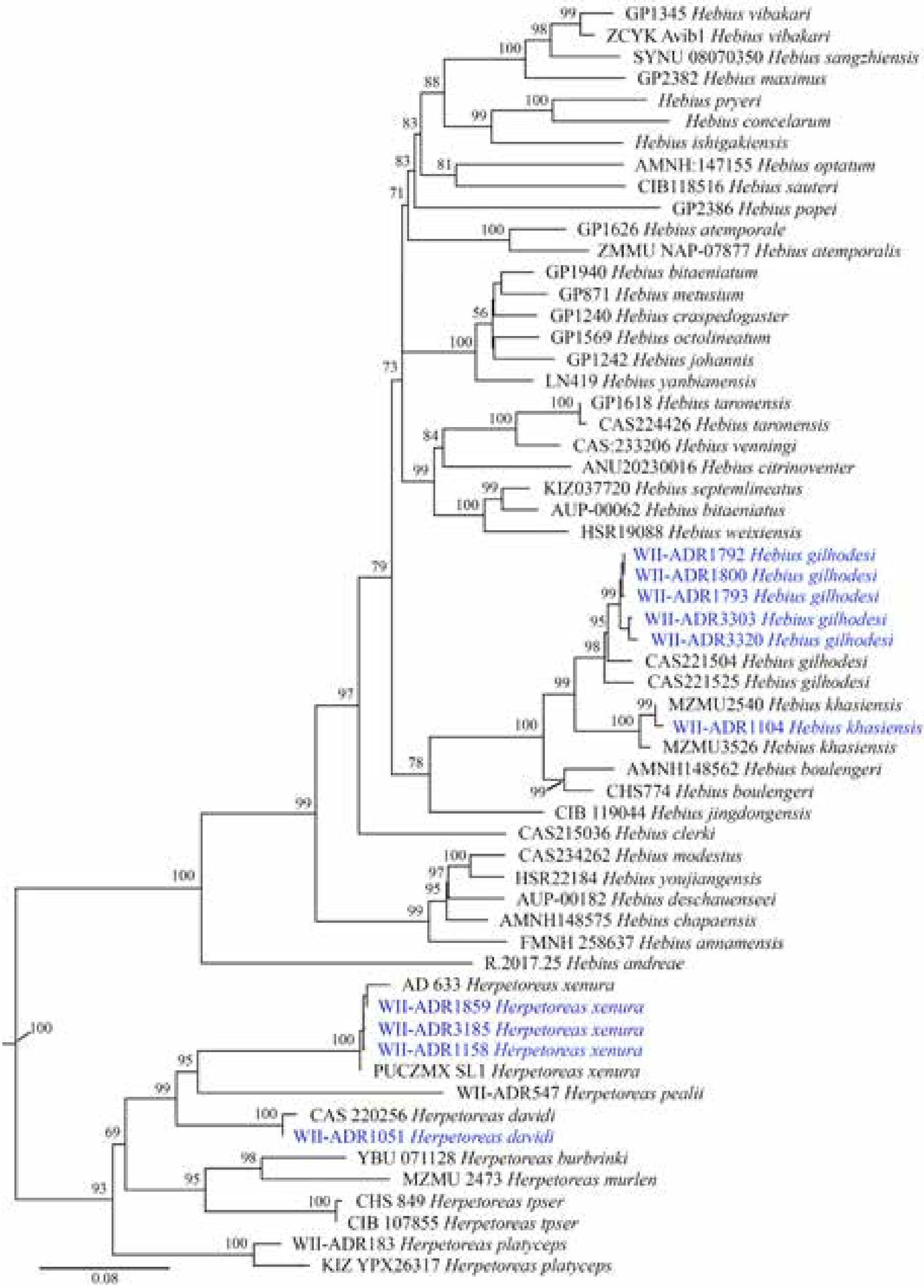


**Figure 1. Maximum likelihood phylogeny of *Hebius* spp. and *Herpetoreas* spp. based on the Cyt-b gene, showing clustering of sequenced Indian specimens of *H. gilhodesi* and *H. davidi* reported here. DNA Sequences generated in this study are in blue colour.**

present, but in WII-ADR1792 two preoculars present; preocular vertically elongated, dorsally wide, below in contact with fourth supralabial, in WII-ADR1793, preocular in contact with fifth supralabial; eye large with rounded pupil; orbit semi-circular, orbital diameter less than snout length; three postoculars, topmost postocular largest and widely connected to parietal, middle postocular connected to anterior temporal, and third postocular posteriorly connected to anterior temporal and below in contact with sixth and seventh supralabials, in WII-ADR1793, the bottom postocular in contact with seventh and eighth supralabials; anterior temporal single but two in WII-ADR1793; anterior temporal narrow and elongated; two posterior temporals on each side; 8–10 supralabials, first one smallest, wider than tall; second to fourth supralabials taller than wide, equal in size, and usually fourth to sixth supralabials connected to eye, but in WII-ADR1800 and WII-ADR1793 the third to fifth supralabials and fifth to seventh supralabials connected to eye on the left side respectively; seventh to ninth supralabials wider than tall, eighth supralabial largest among all; mental subtriangular, much wider than long; 10 infralabials on each side, nine on left side of WII-ADR1800, first to fifth infralabials in contact with first pair of genials, first pair in midline contact; second pair smallest, second to fourth infralabials taller than wide, fifth infralabial largest among all; anterior genials short and elongated; posterior genials long and posteriorly oblique, anteriorly separated from each other by two small scales and posteriorly separated by a pair of enlarged scales.

Dorsal scales narrow and posteriorly nearly pointed, arranged in 19: 19: 17 rows; dorsal scales moderately keeled, except those on first row, which are feebly keeled or nearly smooth on anterior body; apical pits absent; dorsal scales closer to the vent comparatively large; all dorsal scale rows on tail moderately keeled; 145–148 ventrals in males and 142–147 in females; 1–3 preventrals, anterior most preventral separated from posterior pair of genials by one pair of enlarged scales; subcaudals divided, 71–100 in males and 86–100 in females. Morphometric and meristic data of the newly collected specimens in this study are provided in Table 1.

Dorsal scales reduction varies among the four individuals as follows:

WII-ADR3320 (Male): $19 \frac{3+4(95)}{-} 18 \frac{-}{3+4(97)} 17$

WII-ADR1793 (Male): $19 \frac{-}{3+4(91)} 18 \frac{3+4(93)}{-} 17$

WII-ADR1792 (Female): $19 \frac{-}{3+4(84)} 18 \frac{3+4(86)}{-} 17$

WII-ADR1800 (Female): $19 \frac{-}{3+4(87)} 18 \frac{3+4(89)}{-} 17$

**Hemipenis**

Organ short, thin and unilobed; extended up to the level of fourth to fifth subcaudals. The organ with a slightly extended apical tip on left side of the organ; organ entirely covered with small spines from base to apical tip on both sulcate and asulcate side; sulcate side with few enlarged spines at mid-base, and a large basal hook present at proximal part of truncus; sulcus spermaticus single, shallow (deep in WII-ADR1793) and simply oblique, extending to inner side of right apical tip; sulcal lip almost indistinct; apical necked area smooth.

**Colouration in preservative**

Head on dorsal aspect light brown, pale rusty brown towards parietals, scattered with small dark spots throughout (Image 1); laterally cream coloured and posteriorly light brown; supralabials cream coloured up to sixth scale and bordered with dark brown on posterior and lower edge of each scale, rest are white on middle and surrounded by broad dark brown colour; enlarged white spots on supralabials continue to nape; in WII-ADR1792, these two stripes are disconnected; a short and narrow faint whitish stripe on posterior dorsal aspect of head. Dorsum on anterior one third dark greyish, vertebral scales dark greyish, scales towards lateral side pale reddish-brown with greyish tinge; each dorsal scale scattered with tiny cream-coloured speckles; a faint dorsolateral stripe along the body, interrupted by buff spots; tail dorsally dark greyish-brown. Ventral aspect of head pale cream-coloured, infralabials mottled with dark brown on outer edge; on ventral side, anterior part of body pale cream-coloured and posteriorly whitish; tail ventrally whitish; each ventral and subcaudal scales has distinct or indistinct dark brown spots along the lateral side.

**Colouration in life (Image 2)**

Nearly the same as in preserved condition. Head dorsally and laterally light or dark brown, mottled with dark brown and black throughout; supralabials cream coloured or whitish with dark edge; on each side, white

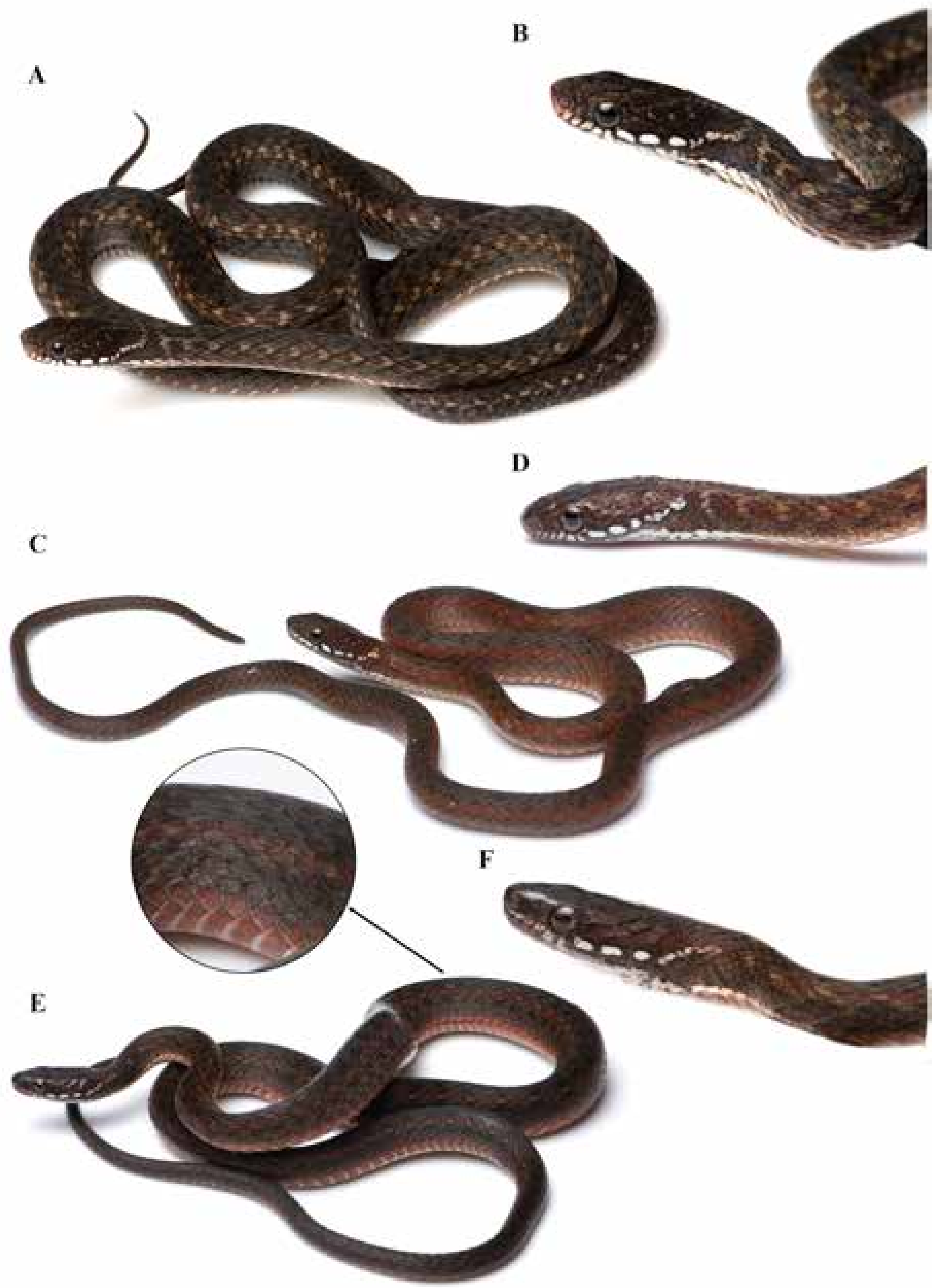


**Image 2. *Hebius gilhodesi* in life from India: A–B—WII-ADR3320 | A—full body in dorsolateral view | B—closeup of head | C–D—WII-ADR1793 | C—full body in dorsolateral view | D—closeup of head | E–F—WII-ADR1792 | E—full body in dorso-lateral view | F—closeup of head. © A. Das; edited by S. Dutta.**

spots on the supralabials continue to the nape; pupil entirely dark with light outer margin; iris light golden brown. Dorsum reddish or dark brown, mottled with dark spots throughout; a very faint, rusty brown dorsolateral stripe from the neck to the tip of the tail, interrupted by prominent or obscure buff spots. Each ventral and subcaudal scale has dark spots along the lateral edge.

**Natural history and distribution**

We recorded *H. gilhodesi* along the edge of small streams with shallow water in Gandhigram and at Kamala Valley in Namdapha Tiger Reserve, and in Kamlang Tiger Reserve, Arunachal Pradesh, India between 1900–2200 h. The forest type at the locality was tropical evergreen and semievergreen. The forest floor was covered with ferns and shrubs. Other reptile species such as *Pseudoxenodon macrops*, *Ptyctolaemus namdaphaensis,* and *Sphenomorphus* sp. were recorded at that location. We also observed anurans such as *Nasutixalus jerdonii*, *Raorchestes orientalis*, G*racixalus patkaiensis, Xenophrys* sp., and *Kurixalus naso* in this locality.

***Hepetoreas davidi*** **Nguyen, Lalremsanga, Biakzuala & Vogel, 2024**

(Table 1; Figure 1–3; Image 3)

**Material examined (n = 1):** adult female (WII-ADR1051) collected from Ngengpui Wildlife Sanctuary (22.48498° N, 92.75653° E, elevation 215 m), Lawngtlai District, Mizoram, India on 7 September 2021 by Abhijit Das, Bitupan Boruah, Naitik G. Patel, and Samuel Lalronunga.

**Description of new Indian material (Image 3)**

Body and tail subcylindrical, widest at mid body, substantially narrower towards neck, and slightly tapering towards vent; tail moderately long (incomplete) (TL/SVL = 0.2*). Head moderately distinct from neck and longer than broad (HW/HL = 0.4); head widest at posterior axis of jaw, slightly tapering before mandibular joint; rostral nearly hidden as seen from above, only posterior border slightly visible; internasal paired, slightly wider than its height; two prefrontals, laterally extended towards loreal; frontal much longer than its width, slightly longer than supraocular, anteriorly broad; parietals elongated, widest at anterior part; in lateral view, parietal region anteriorly flattened, from frontal to internasal slightly elevated; tip of snout acute in lateral view; rostral partially visible in lateral aspect; nostril small and vertically elliptical, laterally oriented, closer to snout tip than to eye; nasal divided by a vertical slit; loreal region narrowly concave; a single loreal on each side, sub-rectangular in shape, widely contact to prefrontal above, and below to second supralabial; single preocular, vertically elongated, dorsally wide; eye large, with rounded pupil, orbit horizontally elliptical, eye diameter less than snout length (ED/SL= 0.5); three postocular on right and two on left, topmost one largest; two anterior temporal, narrow and elongated, two posterior temporal on right and single on left; eight supralabials on each side, first six supralabials taller than wide, seventh and eighth wider than tall, first supralabial smallest and in contact with nasal, second supralabial connected to post nasal and loreal, third supralabial connected to preocular and slightly entering to orbit; fourth and fifth below eye, widely entering to orbit, fifth supralabial posteriorly in contact with lower postocular; and sixth in contact with second and third postocular and lower anterior temporal; seventh supralabial largest and widely connected to lower anterior and posterior temporals; eighth supralabial posteriorly narrow; mental much wider than long; 10 infralabials on each side, first to fifth in contact with first pair of genials; first infralabials in mid line contact; second infralabial smallest; second to fourth taller than the wide; fifth infralabial largest; anterior genials shorter than posterior paired; posterior genials elongated and posteriorly oblique.

Dorsal scales strongly keeled, except the first row, keels are posteriorly serrated, arranged in 19: 19: 17 rows; first dorsal row large and feebly keeled on anterior body, posteriorly moderately keeled; topmost third and fourth rows on dorsum slightly narrow and pointed than those on bellow; tail scales strongly keeled; 153 ventral and two preventrals; anterior most preventral separated from posterior pair of genials by a pair of small scales; subcaudal scales single, 59 in number (incomplete).

Dorsal scale reduction: $19 \frac{4+5(96)}{-} 18 \frac{-}{3+4(98)} 17$

**Colouration in preservative**

Head dorsally rusty brown, mottled with tiny dark spots, posteriorly darker; supralabials cream-coloured with irregular dark brown patches; a whitish stripe running behind eye to above nape on each side and medially connected on nape; an indistinct, narrow, white streak on posterior part of head; dorsum dark brown; first dorsal scale row predominantly cream coloured; each dorsal scales marked with tiny cream coloured spackles; a series of white spots from nape to base of the tail dorsolaterally present. Ventral surface of head and body cream-coloured; anterior infralabials with dark brown spots; tail ventrally whitish; ventral and

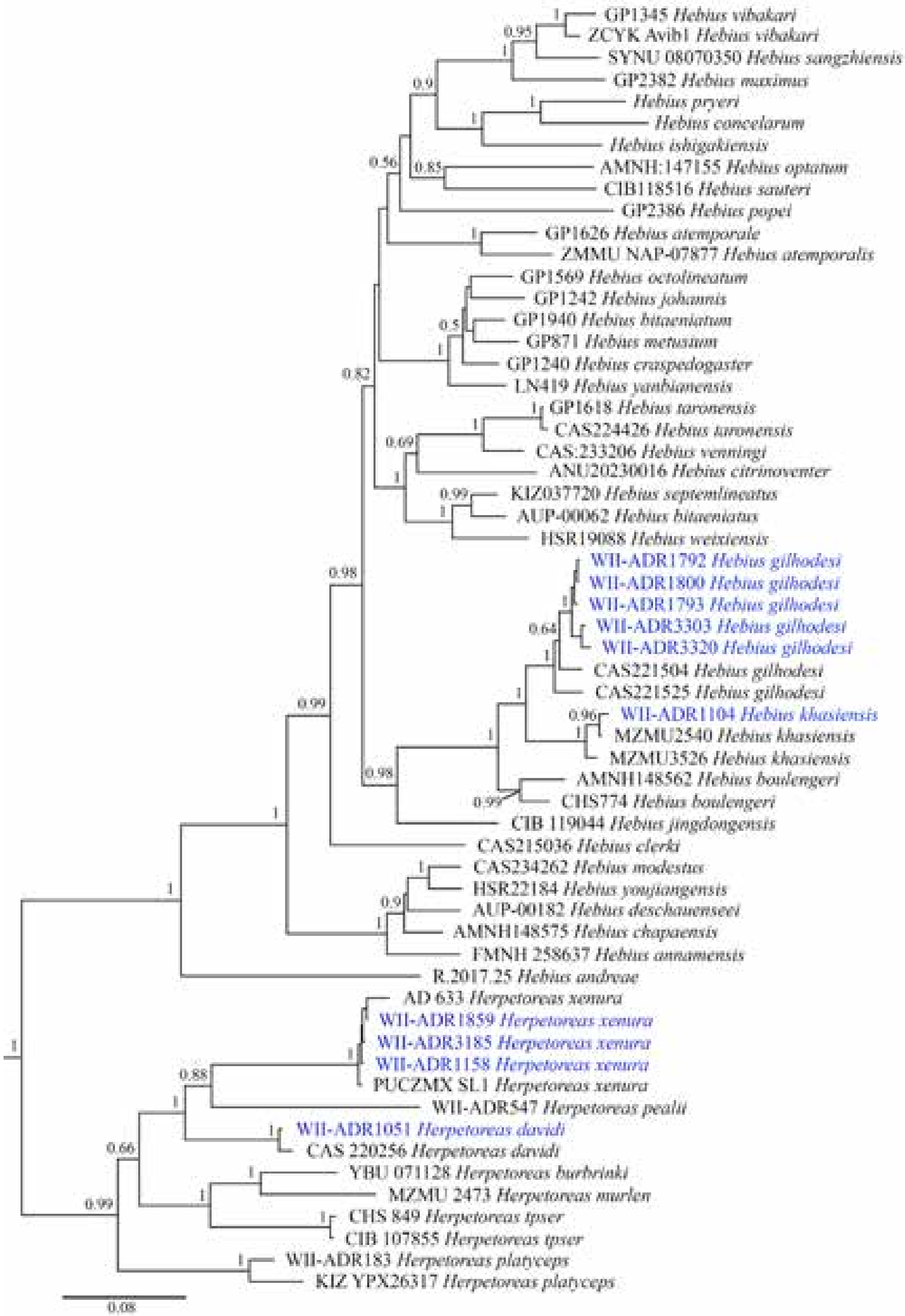


**Figure 2. Bayesian phylogeny of *Hebius* spp. and *Herpetoreas* spp. based on the Cyt-b gene, showing clustering of sequenced Indian specimens of *H. gilhodesi* and *H. davidi* reported here. Posterior probability values <0.5 are not shown in the figure. DNA sequences generated in this study are in blue colour.**

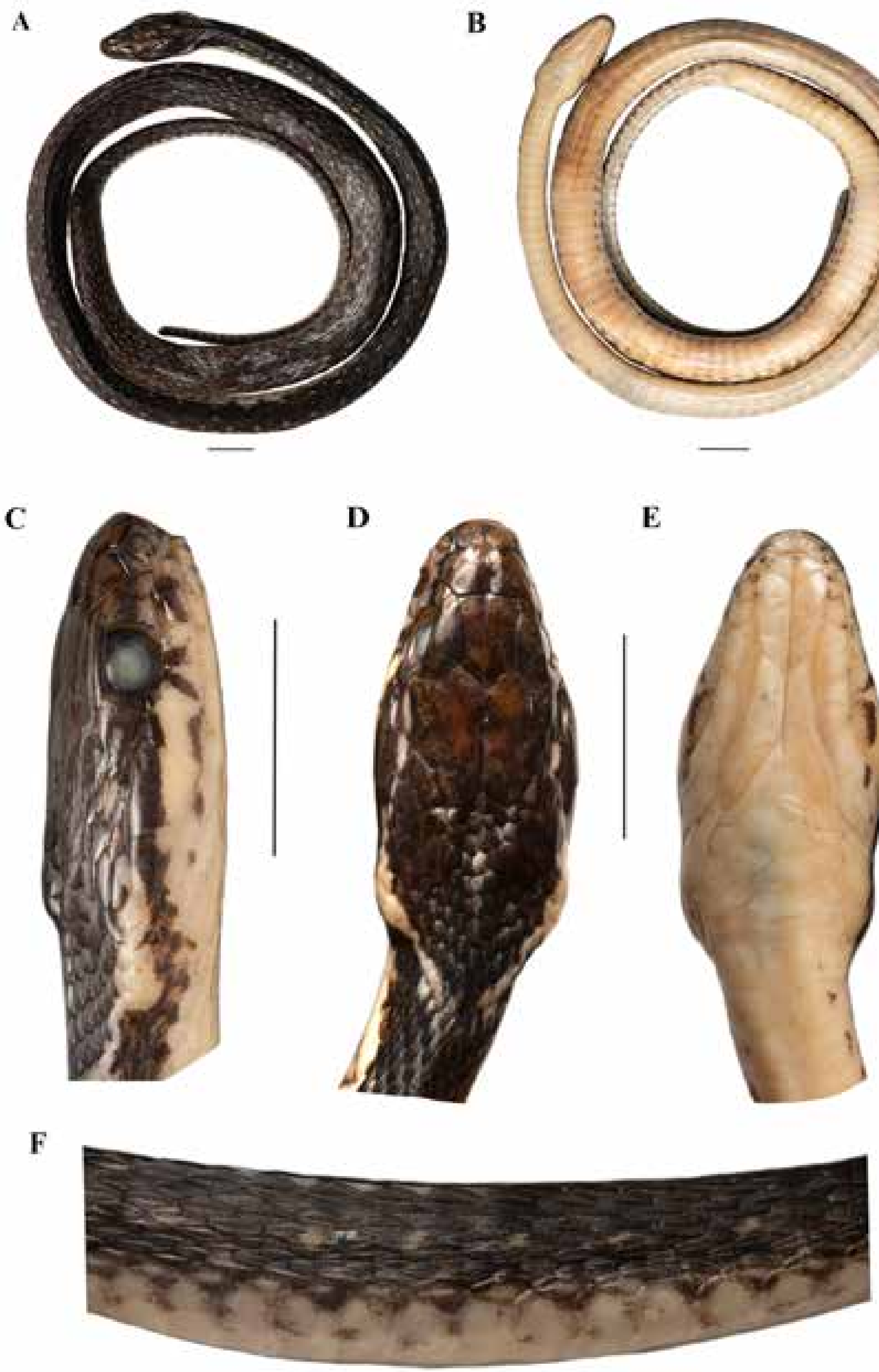


**Image 3. Newly collected *Herpetoreas davidi* specimen (WII-ADR1051) from India: A—dorsal view of full body | B—full body ventral view | C—lateral view of head | D—dorsal view of head | E—ventral view of head | F—keeled scales at mid body. Scale bar—10 mm. © A. Das; edited by S. Dutta.**

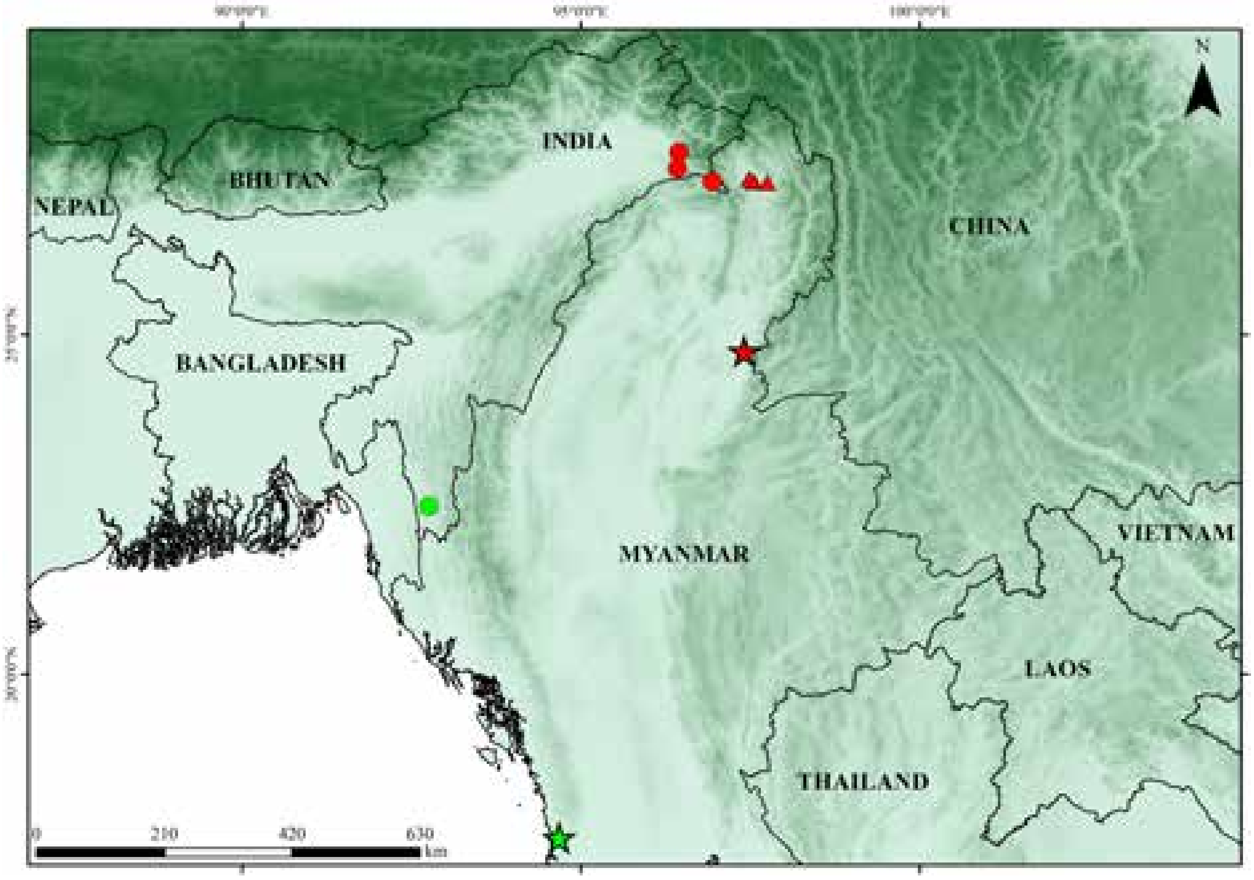


**Figure 3. Map showing distribution of *Hebius gilhodesi* (in red) and *Herpetoreas davidi* (in green). Type localities are shown with star, previous records with triangle (*H. gilhodesi*) and new records from India with circle.**

subcaudals scales with obscure dark spots along lateral aspect.

### Natural history and distribution

We recorded the species among the leaf litter at the edge of a small stream in Ngengpui Wildlife Sanctuary, Mizoram, India at around 09.30 h. Forest type at the locality was lowland evergreen forest. We observed *Tropidophorus assamensis*, *Sphenomorphus* sp., *Dendrelaphis* sp. at the same locality. Anurans such as *Limnonectes khasianus*, *Ingerana borealis* were observed along the stream where the individual of *Hepetoreas davidi* was recorded.

## DISCUSSION

Northeast India falls under Tibeto-Yunanese / Indo-Chinese biogeographic zones and is known to have a rich and unique snake diversity (Das 1996; Das et al. 2009; Malsawmdawngliana et al. 2022; Basfore et al. 2024). In the past as well as in more recent years, several new records of snakes have been reported in India from the northeastern region (Captain & Patel 1998; David et al. 2001; Mohapatra et al. 2010; Biakzuala et al. 2024; Gerard et al. 2024; Ray et al. 2025).

*Hebius gilhodesi* recently revalidated by Bohra et al. (2025), and was previously known only from a few localities in northernmost Myanmar. The present study reported this species from Namdapha Tiger Reserve and Kamlang Tiger Reserve of Arunachal Pradesh, India. This record extends the western and northwestern distribution limit of the species by 103 km and 107 km (areal distance) respectively from the closest locality of the species in Kachin state, Myanmar. The new locality records of this species are 280–339 km northwest of the type locality, Huton, Bhamo District, Myanmar. With this new record, the number of species of the genus *Hebius* in India now gets raised to eight.

It is observed that the following morphological characters in the newly collected specimens of *H. gilhodesi* which are incongruent with that of previous literature. According to Wall (1925), the dorsolateral stripe of *H. gilhodesi* starts from neck and extends up to vent, in all the examined specimens this stripe extended to the tip of the tail. Bohra et al. (2025) mentioned that *H. gilhodesi* lacks dorsolateral stripes but has a series of spots whereas in all the examined specimens of *H. gilhodesi,* including the subadult, it was observed that light reddish or rusty brown dorsolateral stripes on which the buff-coloured spots are arranged. This stripe remains visible even in preserved condition. Notably, Wall (1925) also stated a reddish dorsolateral stripe is present in all examined specimens. Furthermore, the holotype of *H. gilhodesi* depicted in Bohra et al. (2025) (Figure 11A, page 487) clearly shows the presence of dorsolateral stripe. Bohra et al. (2025) reported scale reduction involving the fourth and fifth row which does not correspond to the original description by Wall (1925). This data of both adult male and female specimens (n = 4) are consistent with Wall (1925) where the third and fourth rows are involved in the reduction. In addition to this, the dorsal scale row reduction is observed among our newly collected materials. The first reduction of dorsal scale rows (19–18) in males was found at 91st–95th ventral and in females at 84th–87th ventral. The second reduction (18–17) was found at 93rd–97th ventral in males and at 86th to 89th ventral in females. Thus, the reduction in females is more anterior in trunk position compared to males. However, this reduction is due the merging of third and fourth dorsal scale rows, which is consistent in all the specimens. This intraspecific variation of dorsal scale reduction has also been previously recorded in the species belonging to other Indian colubrid genera such as *Ahaetulla* and *Oligodon* (Deepak et al. 2019; Mirza et al. 2021).

*Herpetoreas davidi* was originally described from the Rakhine Yoma Elephant Sanctuary, in Myanmar. In the present study, it is reported that this species from the southern part of Mizoram, which represents a range extension of 577 km (areal distance) northwestern from the type locality. This disjunct distribution could be a result of sampling gap. Further sampling along Indo-Myanmar border may reveal unknown localities of this species. With this new record, the number of species of the genus *Herpetoreas* increased to six in India. Previously, Nguyen et al. (2025) reported this species at an elevation range 120–175 m. The present study recorded this species from Ngengpui Wildlife Sanctuary at an elevation of 215 m, representing the highest elevation known for the species to date.

The minor morphological variations mirror the mild genetic divergences noted in Indian vs. Myanmar specimens of *H. gilhodesi*. The Indian specimen of *H. davidi* was much more congruent with the type series in morphology and genetics. Ironically, the geographic distances between the known Myanmar distributions and the new Indian records were lesser for the more divergent *H. gilodesi* than *H. davidi*. It remains to be tested if the sample size being larger for the Indian material of *H. gilodesi* than *for H. davidi,* may be a reason for this discordance in intra-specific variation patterns. The new distribution records in recent years from northeastern India, including these two new records of natricine snakes highlights the urgent need of extensive faunal surveys in this region.

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**Appendix 1. Details of the DNA sequences (Cyt-*b*) used in this study.**

| Species | Locality | Voucher no. | Accession number | Reference |
|---|---|---|---|---|
| *Hebius vibakari* | Liaoning, China | GP1345 | KJ685676 | Bohra et al. 2025 |
| *Hebius vibakari* | Eastern Asia | ZCYK Avib1 | LC640368 | Bohra et al. 2025 |
| *Hebius sangzhiensis* | Hunan, China | SYNU 08070350 | MK340763 | Bohra et al. 2025 |
| *Hebius maximus* | Sichuan, China | GP2382 | KJ685696 | Bohra et al. 2025 |
| *Hebius pryeri* | Kagoshima, Japan | NA | AB989126 | Bohra et al. 2025 |
| *Hebius concelarus* | Okinawa, Japan | NA | AB989268 | Bohra et al. 2025 |
| *Hebius ishigakiensis* | Okinawa, Japan | NA | AB989292 | Bohra et al. 2025 |
| *Hebius optatum* | Vinh Phuc, Vietnam | AMNH147155 | KJ685662 | Bohra et al. 2025 |
| *Hebius sauteri* | Guangdong, China | CIB118516 | OP937178 | Bohra et al. 2025 |
| *Hebius popei* | Guizhou, China | GP2386 | KJ685697 | Bohra et al. 2025 |
| *Hebius atemporalis* | Guangdong, China | GP1626 | KJ685680 | Bohra et al. 2025 |
| *Hebius atemporalis* | Vietnam | ZMMU NAP-07877 | OK315813 | Bohra et al. 2025 |
| *Hebius bitaeniatus* | Guangxi, China | GP1940 | KJ685688 | Bohra et al. 2025 |
| *Hebius metusia* | Sichuan, China | GP871 | KJ685707 | Bohra et al. 2025 |
| *Hebius craspedogaster* | Guizhou, China | GP1240 | KJ685672 | Bohra et al. 2025 |
| *Hebius johannis* | Guizhou, China | GP1242 | KJ685673 | Nguyen et al. 2024 |
| *Hebius octolineatus* | Yunnan, China | GP1569 | KJ685678 | Nguyen et al. 2024 |
| *Hebius yanbianensis* | China | LN419 | OR215499 | Bohra et al. 2025 |
| *Hebius taronensis* | Myanmar | GP1618 | KJ685679 | Nguyen et al. 2024 |
| *Hebius taronensis* | Myanmar | CAS224426 | OK315828 | Bohra et al. 2025 |
| *Hebius venningi* | Kachin, Myanmar | CAS233206 | KJ685670 | Bohra et al. 2025 |
| *Hebius citrinoventer* | Yingjiang, China | ANU20230016 | PP472750 | Bohra et al. 2025 |
| *Hebius septemlineatus* | China | KIZ037720 | MZ570486 | Bohra et al. 2025 |
| *Hebius bitaeniatus* | Thailand | AUP-00062 | OK315816 | Bohra et al. 2025 |
| *Hebius weixiensis* | Lijiang, Yunnan, China | HSR19088 | OQ085074 | Bohra et al. 2025 |
| *Hebius gilhodesi* | Gandhigram, Changlang, Arunachal Pradesh, India | WII-ADR1792 | PZ160968 | This Study |
| *Hebius gilhodesi* | Gandhigram, Changlang, Arunachal Pradesh, India | WII-ADR1800 | PZ160970 | This Study |
| *Hebius gilhodesi* | Gandhigram, Changlang, Arunachal Pradesh, India | WII-ADR1793 | PZ160969 | This Study |
| *Hebius gilhodesi* | Kamala Valley, Namdapha Tiger Reserve, Arunachal Pradesh, India | WII-ADR3303 | PZ160971 | This Study |
| *Hebius gilhodesi* | Glaw lake, Kamlang Tiger Reserve, Arunachal Pradesh, India | WII-ADR3320 | PZ160972 | This Study |
| *Hebius gilhodesi* | Kachin state, Myanmar | CAS221504 | KJ685668 | Bohra et al. 2025 |
| *Hebius gilhodesi* | Kachin state, Myanmar | CAS221525 | KJ685669 | Bohra et al. 2025 |
| *Hebius khasiensis* | Sailam, Aizawl, Mizoram, India | MZMU2540 | PQ288048 | Bohra et al. 2025 |
| *Hebius khasiensis* | Phuldungsei, Dampa Tiger Reserve, Mizoram, India | WII-ADR1104 | PZ160963 | This Study |
| *Hebius khasiensis* | Mairang, Eastern West Khasi hills, Meghalaya, India | MZMU3526 | PQ288047 | Bohra et al. 2025 |
| *Hebius boulengeri* | Ha Giang, Vietnam | AMNH148562 | KJ685664 | Bohra et al. 2025 |
| *Hebius boulengeri* | China | CHS774 | MK201520 | Bohra et al. 2025 |
| *Hebius jingdongensis* | Jingdong, China | CIB 119044 | OR285310 | Bohra et al. 2025 |
| *Hebius clerki* | Nujiang, Yunnan, China | CAS215036 | KJ685666 | Bohra et al. 2025 |
| *Hebius modestus* | Yunnan, China | CAS234262 | KJ685671 | Bohra et al. 2025 |
| *Hebius youjiangensis* | Guanxi, China | HSR22184 | OQ085073 | Bohra et al. 2025 |
| *Hebius deschauenseei* | Thailand | AUP-00182 | OK315827 | Bohra et al. 2025 |
| *Hebius chapaensis* | Ha Giang, Vietnam | AMNH148575 | KJ685665 | Bohra et al. 2025 |

| Species | Locality | Voucher no. | Accession number | Reference |
|---|---|---|---|---|
| *Hebius annamensis* | Laos | FMNH 258637 | OK315812 | Bohra et al. 2025 |
| *Hebius andreae* | Laos | R.2017.25 | MK253674 | Bohra et al. 2025 |
| *Herpetoreas xenura* | Narpuh Wildlife Sanctuary, Meghalaya, India | WII-ADR3185 | PZ160965 | This Study |
| *Herpetoreas xenura* | Teirei, Dampa Tiger Reserve, Mizoram, India | WII-ADR1158 | PZ160966 | This Study |
| *Herpetoreas xenura* | Mizoram, India | PUCZMX SL1 | MN993850 | Nguyen et al. 2024 |
| *Hepetoreas pealli* | Poba Reserve Forest, Arunachal Pradesh, India | WII-ADR547 | MT571586 | Das et al. 2020 |
| *Hepetoreas davidi* | Gawa, Rakhine, Myanmar | CAS 220256 | OK315830 | Nguyen et al. 2024 |
| *Hepetoreas davidi* | Ngengpui Wildlife Sanctuary, Mizoram, India | WII-ADR1051 | PZ160967 | This Study |
| *Hepetoreas burbrinki* | Tibet, China | YBU 071128 | GQ281781 | Nguyen et al. 2024 |
| *Hepetoreas murlen* | Mizoram, India | MZMU2473 | ON204025 | Nguyen et al. 2024 |
| *Hepetoreas tpser* | Tibet, China | CHS849 | MK201567 | Nguyen et al. 2024 |
| *Hepetoreas tpser* | Medog, Tibet, China | CIB107855 | OM313292 | Nguyen et al. 2024 |
| *Hepetoreas platyceps* | Uttarakhand | WII-ADR183 | MT571587 | Das et al. 2020 |
| *Hepetoreas platyceps* | Gyirong, Tibet, China | KIZ YPX26317 | MW111464 | Nguyen et al. 2024 |
| *Amphiesma stolatum* | Ha Giang, Vietnam | CAS215037 | KJ685667 | Guo et al. 2014 |

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ARTICLE

# Diversity and distribution pattern of geometrid moths (Insecta: Lepidoptera: Geometridae) along the altitudinal gradient, Kumaun Himalaya, India

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**Abstract:** Altitudinal gradients are frequently used to study Lepidoptera diversity. The study site, situated in the Munsiari Subdivision of Pithoragarh District, Kumaun Himalaya, was divided into transects along the altitudinal gradient, each 200 m wide, spanning elevations from 1,200–4,000 m. In each transect, a minimum of five sampling plots were established. Furthermore, the study area was divided into five broad zones based on vegetational cover. Moths were collected using automated light traps between 1900 h and 2300 h. The specimens were identified using the available literature and following standard protocols. Indicator species analysis was carried out as per Dufrêne & Legendre. The present paper deals exclusively with the status and altitudinal distribution pattern of the Geometridae moths. Zone II, lying between 1,800–2,600 m, harboured highest species richness (98 species), as well as abundance (4,686 individuals), while the least species richness was encountered in Zone III. In terms of species diversity across the subfamilies, Ennominae comprised 93 species, followed by Larentiinae (49), Geometrinae (14), Sterrhinae (4), and Desmobathrinae (1). In terms of distribution, 23 species, restricted to just one transect and exhibiting distribution for one month, could be categorised as highly specialized, while two species—*Euphyia subangulata* and *Eustroma melancholicum venipicta* (Larentiinae)—exhibiting distribution throughout the altitudinal gradient, along with an additional 23 species (all Ennominae) exhibiting presence across five or more transects, could be defined as generalists. Both categories are considered 'indicator species.'

**Keywords:** Alpine, ecotone, environmental factor, habitat, indicator species, light trap, specialists, species richness, transects, western Himalaya.

**सार:** ऊँचाई के आधार पर होने वाले परिवर्तन (आल्टिट्यूडिनल ग्रेडिएंट) का उपयोग प्रायः लेपिडोप्टेरा की विविधता के अध्ययन के लिए किया जाता है। अध्ययन क्षेत्र, जो मुनस्यारी उपखंड (जिला , पिथौरागढ़, कुमाऊं हिमालय) में स्थित है, को ऊँचाई के अनुसार ट्रांसेक्टों में विभाजित किया गया। प्रत्येक ट्रांसेक्ट की चौड़ाई 200 मीटर थी तथा यह 1,200–4,000 मीटर की ऊँचाई तक फैला हुआ था। प्रत्येक ट्रांसेक्ट में कम से कम पाँच नमूना प्लॉट स्थापित किए गए। इसके अतिरिक्त, अध्ययन क्षेत्र को वनस्पति आवरण के आधार पर पाँच प्रमुख क्षेत्रों (ज़ोन) में बाँटा गया। पतंगों का संग्रह सायं 7:00 बजे से रात्रि 11:00 बजे तक स्वचालित प्रकाश फंदों की सहायता से किया गया। नमूनों की पहचान उपलब्ध साहित्य और मानक विधियों के अनुसार की गई। संकेतक प्रजाति विश्लेषण Dufrêne & Legendre की विधि के अनुसार किया गया। यह शोधपत्र विशेष रूप से Geometridae कुल के पतंगों की स्थिति तथा ऊँचाई के अनुसार उनके वितरण पैटर्न पर केंद्रित है। ज़ोन II (1,800–2,600 मीटर) में सर्वाधिक प्रजाति समृद्धि (98 प्रजातियाँ) तथा अधिकतम संख्या (4686 व्यक्तियों) दर्ज की गई, जबकि न्यूनतम प्रजाति समृद्धि ज़ोन III में पाई गई। उपपरिवार स्तर पर, Ennominae में 93 प्रजातियाँ, इसके बाद Larentiinae में 49, Geometrinae में 14, Sterrhinae में 4 तथा Desmobathrinae में 1 प्रजाति दर्ज की गई। वितरण के आधार पर, 23 प्रजातियाँ केवल एक ही ट्रांसेक्ट तक सीमित थीं और केवल एक माह तक ही पाई गईं, जिन्हें अत्यधिक विशिष्ट (विशेषज्ञ) श्रेणी में रखा जा सकता है। वहीं, दो प्रजातियाँ–*Euphyia subangulata* तथा *Eustroma melancholicum venipicta*—पूरे ऊँचाई क्षेत्र में पाई गईं। इसके अतिरिक्त, 23 अन्य प्रजातियाँ (सभी Ennominae) पाँच या उससे अधिक ट्रांसेक्टों में उपस्थित रहीं, जिन्हें सामान्यवादी श्रेणी में रखा जा सकता है। इन दोनों श्रेणियों को संकेतक प्रजातियाँ माना गया है।

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**Author contributions:** Both authors contributed to the study. NSL: Field work, formal analysis of the raw data, review, and manuscript writing (original draft). CSN: Conceptualization, methodology, formal analysis, supervision, and editing of the draft.

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## INTRODUCTION

Moths and butterflies belong to the insect order Lepidoptera, characterized by two pairs of scale-covered wings, and, in most groups, reduced mandibles. Butterflies are primarily day-flying and usually brightly coloured, while most moths are nocturnal and tend to be more cryptically coloured. Currently, approximately 158,000 Lepidoptera species have been reported worldwide; new discoveries are made each year, and the actual total is estimated to range 300,000–400,000 (Kristensen et al. 2007). Even though butterflies are relatively better known than moths, the latter, outnumber the butterflies by at least 10 to one (Hill et al. 2021). Moths are a significant component of terrestrial ecosystems as herbivores and pollinators, and they also play a role in nutrient cycling; therefore, disturbances to their natural habitats, primarily due to anthropogenic activities, affect their population dynamics (Lomov et al. 2006). In fact, on account of their sensitivity towards habitat change, moths have been recently targeted as 'indicator species' that reflect upon habitat changes, such as forest fragmentation, land-use patterns, deforestation, and regeneration (Ricketts et al. 2001; Enkhtur et al. 2017). In terms of distribution and habitat preferences, moths exhibit both narrow and wide distributions. Both narrow, highly niche specialized (confined to 200–400 m breadth segments), and widely distributed – the generalists, could act as ecological indicators; for any change in their availability or numbers would relate to habitat change or its quality. The distribution of moths across an altitudinal gradient, thus, provides an opportunity to study the range of their distribution pattern, the diversity – both richness and abundance, and relate these with the above-ground vegetation profile, as well as the anthropogenic disturbance. Moreover, any depletion in numbers, as well as the availability of specialist moths in particular, could be monitored, since moths exhibit 'assemblages' that are easy to monitor.

Variation in moth diversity along altitudinal gradients can be an effective way to study the effects of climate change on ecological communities (Kitching et al. 2011). Forested elevational gradients representing sets of adjacent climates are excellent tools for such studies; encompassing, in a small geographical area, a range of environmental factors that shift predictably (Rahbek 2005; Fiedler & Beck 2008; Fischer et al. 2011; Kitching et al. 2011). For example, it is well established that for every 100 m increase in elevation, the temperature decreases by approximately 0.6 °C (Jacobson 2005). Concomitantly, a set of other biotic-abiotic factors, for example, mean annual temperature, precipitation change, and others, too, shift in concert, inclusive of soil physico-chemical properties (Strong et al. 2011), along elevational gradients (Stevens 1992; Kessler et al. 2001; Lomolino 2001; Foster 2010).

Understanding how moth assemblages change along the altitudinal gradient is therefore important for assessing likely future changes in diversity, for example, climate change (Doran et al. 2003). It will also allow us to observe the current distributions of different species, and make predictions about how they would respond to climate change based on their current climatic envelopes, thereby leading us to identify species (indicator species), which would then be used to monitor future range shifts (Kitching & Ashton 2014; Nakamura et al. 2016). Moths are ideal as 'Indicator species' for use in climate monitoring, since (i) they are sensitive to environmental variables, and (ii) their herbivorous life histories bind them invariably to larger community-level shifts (Schulze et al. 2001). Other features, like their being easy to sample in large numbers (principally, making use of automated light traps), giving strong statistical power, and their being relatively well known taxonomically (Holloway 1985ab–1997) make them ideal species to monitor climate change.

An elevational change of just 200 m drives significant changes in moth assemblage composition, particularly for forest-inhabiting moths (Ashton et al. 2016); these changes have considerable implications for conservation under climate change scenarios. Because moths, as herbivores, are closely linked to the availability of appropriate larval host plants, this could lead to a mismatch between the upward movement of herbivores and their host plants when host plants respond more slowly and track climatic envelopes (Rehm 2014). To understand how species respond to climate change, we need to generate baseline data on their current distributions. By examining species distributions and investigating how their altitudinal ranges are driven by environmental variables across altitudes, we will be better able to predict how these species may respond to further climate warming.

Many recent studies on altitude-diversity patterns have been conducted in tropical systems, including studies of moths (e.g., Axmacher et al. 2004; Brehm et al. 2007; Beck & Chey 2008; Fiedler et al. 2008; Beck & Kitching 2009). Comparable data regarding methods and studies are conspicuously lacking for the temperate moths. Consequently, little is known about the altitudinal diversity patterns of temperate taxa, and information on the seasonal variation in these patterns is scarce (Summerville & Crist 2003). Also, as concerns India, most studies related to the diversity and distribution of moths along the altitudinal gradient are restricted to tropical or sub-temperate regions (Axmacher et al. 2004; Beck & Chey 2008; Beck & Kitching 2009; Ashton et al. 2016), with an exception (Dey et al. 2015) conducted across four protected areas within the state of Uttarakhand. Further, only one single attempt (Sanyal et al. 2017) has addressed the 'indicator properties' of moth assemblages in assessing habitat quality. The present study aims to address this gap. Further, most, if not all, studies on moths are relegated to macromoths, and micromoths, if any, remain mostly unexplored. This fact becomes all the more obvious when it concerns studies in the sub-alpine and alpine zones of the Himalaya, which remain unexplored. However, one positive outcome of such a scenario is that the likelihood of discovering entirely new species or documenting their presence increases, as evidenced by the present study.

Geometrid moths occur in large numbers and have a wide elevational distribution, making them an ideal group for studies along elevational transects (Toko et al. 2023). Their sensitivity to habitat alteration and climate variation, as reflected in their distribution patterns, makes them a valuable bioindicator of environmental change (Scoble 1992; Choi 2006; Ashton et al. 2011; Alonso-Rodrigue et al. 2017; Enkhtur et al. 2020). Approximately 24,000 species of Geometridae have been described worldwide (Brehm et al. 2005). The present study thus examines (i) the diversity of the family Geometridae, and (ii) indicator species vis-à-vis the spatial distribution of each individual species, along the elevational gradient.

## MATERIALS & METHODS

The study site (Figure 1), situated in Munsiari Subdivision, Pithoragarh District, Kumaun Himalaya, between 30.111°–30.144° N and 80.254°–80.304° E, extending from base 1,200 m to 4,000 m, was divided along the altitudinal gradient into transects, measuring 200 m in breadth. In each transect, a minimum of five sampling plots were established, spaced at least 20 m apart, ensuring that a light device (UV light source) did not impede the other light device. Light traps were set using a light-sensitive solar-powered lantern. Solar light traps remained an effective tool for insect collection; they are fully automatic, switch on at night, and are absolutely safe to handle. The solar light trap was positioned at a right angle in relation to the direction of movement of the sun during daytime, for charging the battery to a maximum, so that it lasts for the complete duration (4 h) of the insect trap. Since temporal distribution remained one component of the study (though not included in the present manuscript), moth collections, in each transect, were carried out on average between 2–3 days per month, compounding to 10–15 days for the complete duration of the study of five months, annually, and replicated for two years.

The study area was further divided into five zones (I–V) based on vegetational cover and other features, such as interspersed habitat types and anthropogenic disturbance. Moths were collected using automated light traps, between 1900 h and 2300 h. The collected specimens were then pinned and partially spread according to standard techniques (Krogmann et al. 2010). The specimens were sorted into morphospecies and identified using the available literature, following standard protocols (Haruta 2000; Scoble & Hausmann 2007). The identification of moth specimens was based entirely on morphological features, following the BOLD system of taxonomy for moths of India, Nepal, and Borneo (Ratnasingham & Hebert 2007). The identified species were further classified into families, subfamilies, and genera.

Characteristic moth species restricted to specific transect/s were identified across the altitudinal gradient using the indicator species analysis (Dufrêne & Legendre 1997). For the calculation of the indicator value, abundance figures of each species confined either to a single or two belt transects were selected (since species spread out across more than two transects had a p-value greater than 0.01). Species with indicator values greater than 70% produced from ISA were regarded as good indicators for each habitat, while those with the Indicator Value lying between 50–70 % were regarded as detector species, i.e., as a detector of a change in habitat (McGeoch et al. 2002). At each level of cluster (species group), indicator values (Ind. Val.) and their associated *p*-values for all moth species were calculated. We selected species with an indicator value greater than 70%. The Bray-Curtis similarity index was calculated as per Bray & Curtis (1957). Lastly, the data analysis was conducted using Past 4.17 and Excel Stat. The correlation coefficient between species richness and the altitudinal gradient was calculated using Pearson's (1895) method.
While Zone I can be classified as sub-temperate or warm-temperate, the subsequent zones are classified as temperate or cool-temperate, sub-alpine, timberline,

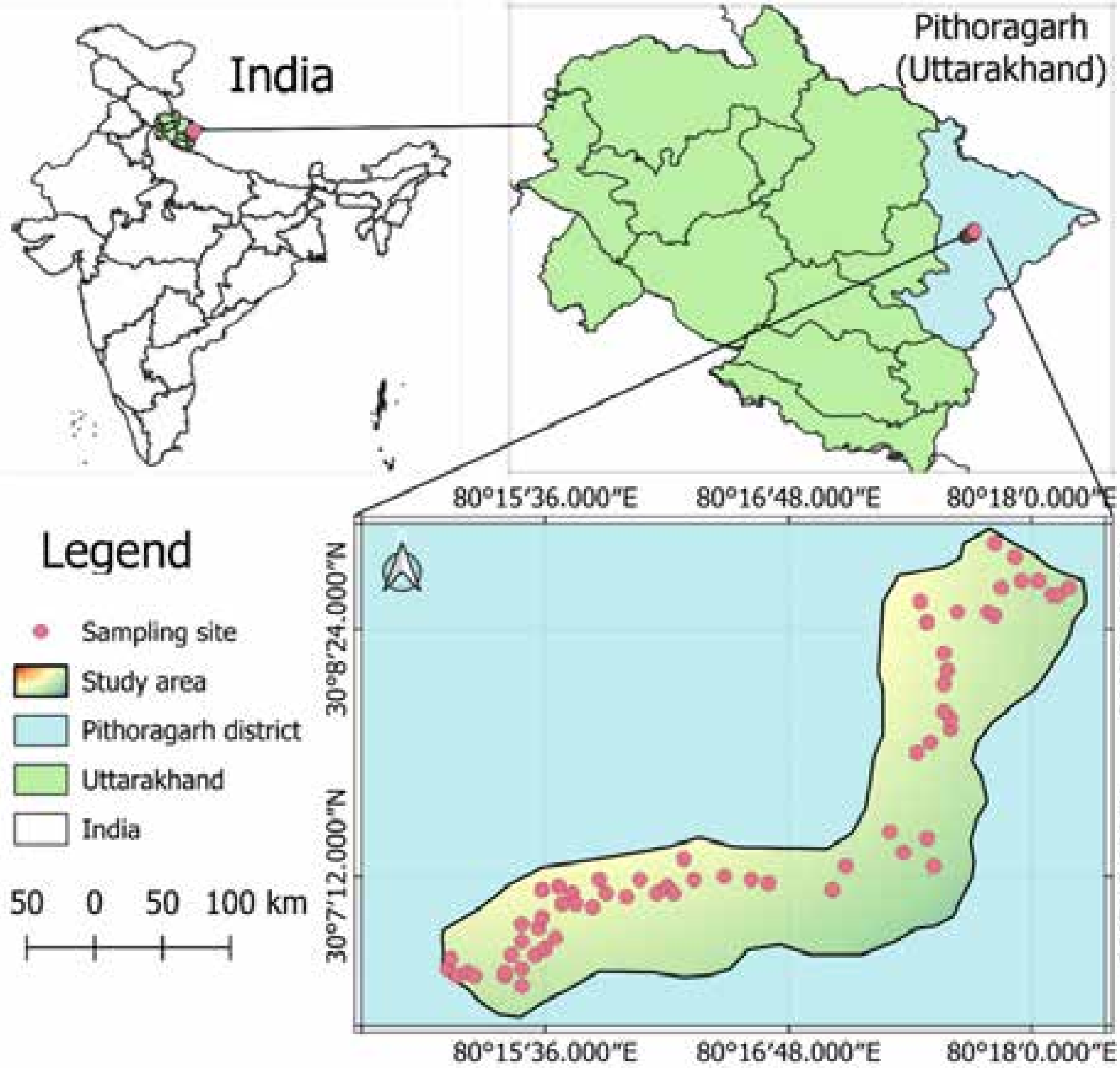


**Figure 1. The study site: red dots represent the sampling sites of different altitudinal transects.**

and alpine, respectively. Because the altitudinal range was extensive, changes in vegetation profiles across the altitudinal gradient were also observed, as were ecotones. The dominant plant species were *Quercus* spp., *Rhododendron* spp., *Alnus nepalensis*, *Neolitsea umbrosa*, and *Acer*; the was characterized by *Betula utilis*, while the alpine meadow was dominated by herbaceous species.

## RESULTS

A total of five subfamilies, representing 99 genera, and 161 species were collected. The maximum species richness (98) and abundance (4,686 ind.) were encountered in zone II (1,800–2,600 m), followed by zone I (68 species and abundance 2,586 ind.) (Table 1). Species abundance declined with altitude; it increased rapidly in zone V (Table 1). The subfamily Ennominae exhibits the highest species richness, represented by 93 species (58% of the total, Figure 2), with the highest diversity encountered in the mid-altitudinal zone (1,800–2,400 m), and with transects at 2,200–2,400 m exhibiting the maximum diversity (58 species), followed by steady decline with an increase in altitude (Figure 3). The most dominant genera include *Arichanna* (7 spp.), followed by *Cleora* (4 spp.), *Opisthograptis* (4 spp.), and *Psyra* (4 spp.). The genera, *Abraxas*, *Alcis*, *Biston*, *Dalima*,

**Table 1. A brief statement of the five different zones, and their habitat description.**

| Altitudinal zone | Altitude (m) | Species | Species abundance | Temperature (°C) | Humidity (%) | Habitat description |
|---|---|---|---|---|---|---|
| Zone- I (warm temperate forest) | 1200–1800 | 68 | 2586 | 21.19 ± 0.26 | 63.81 ± 1.12 | Mixed forest, dominated by *Engelhardtia spicata* Lesch. ex-Blume and *Quercus leucotrichophora* A.Camus, with interspersed *Rhus punjabensis*. J.L.Stewart ex Brandis; and characterized by riverine ecosystem on its lower end, and interspersed grass-dominant patches. |
| Zone- II (Cool temperate forest) | 1800–2600 | 98 | 4686 | 19.99 ± 0.19 | 67.22 ± 0.90 | Mixed forest, dominated by *Quercus leucotrichophora* A. Camus and *Rhododendron arboreum* Sm., with interspersed *Alnus nepalensis* D.Don, *Neolitsea umbrosa* (Nees) Gamble., *Acer pseudoplatanus* L., and *Q. semecarpifolia* Sm. towards the upper reaches. The forest is marked by interspersed grass habitats and agricultural land |
| Zone- III (Timberline Forest) | 2600–3000 | 35 | 1098 | 18.08 ± 0.27 | 70.33 ± 0.25 | Mixed forest, dominated by *Q. semecarpifolia* and *R. arboreum* Sm., and further marked by *R. barbatum*. and *Acer acuminatum* Wall. ex D.Don, towards upper reaches. This zone is disturbed, characterized by lopping and removal of grass cover. |
| Zone- IV (Sub-alpine forest) | 3000–3400 | 41 | 606 | 15.70 ± 0.85 | 72.81 ± 0.27 | Ecotone, marked out by treeline and alpine meadow. The treeline is dominated by *Acer acuminatum* Wall. ex D.Don., *R. barbatum, R. campanulatum* D.Don. The tree line is marked by a steep slope and is dominated by grass cover |
| Zone- V (Alpine meadow) | 3400–4000 | 46 | 1118 | 11.69 ± 0.95 | 78.02 ± 0.75 | Alpine meadow, characterized by herbaceous vegetation, with few individuals of *R. campanulatum*. |

*Medasina*, and *Ourapterix*, are represented by three species each. Ennominae is followed by Larentiinae (49 species, and 31.05% dominance, Figure 2); exhibiting dominancy in the high-altitudinal zone (2,800–4,000m, Figure 3). Important genera include *Euphyia* (6 spp.), *Photoscotosia* (5 spp.), *Entipheria* (5 spp.), *Eustroma* (4 spp.), and *Eupithecia* (2 spp.). The subfamily Geometrinae did not exhibit a consistent altitudinal gradient pattern, although it comprises 14 species (9% dominance, Figure 2) and is restricted to 2,800 m in distribution (Figure 3). *Pachyodes* was the dominant genus, with three species. The subfamily Sterrhinae was confined to the lower and mid-altitudinal zones (1,200–2,600 m) and comprised four species (Genera 3, Figure 2). Desmobathrinae was represented by a single species, distributed across three transects (2,000–2,600 m, Figure 3).

The Bray-Curtis Similarity Index (Bray & Curtis 1957) between the distribution pattern and species richness, along the altitudinal gradient, shows that the subfamily Ennominae exhibits maximum diversity at 1,600–2,400 m, and is represented throughout the altitudinal gradient; while Larentiinae exhibits maximum diversity at 3,400–3,600 m, as well as reciprocates Ennominae in its wide distribution, while the rest of the three subfamilies- Desmobathrinae, Geometrinae, and Sterrhinae, are restricted in distribution (Figure 4). Pearson correlation analysis revealed a significant negative relationship between altitude and the species richness of Ennominae ($r = -0.597$, $p = 0.024$),

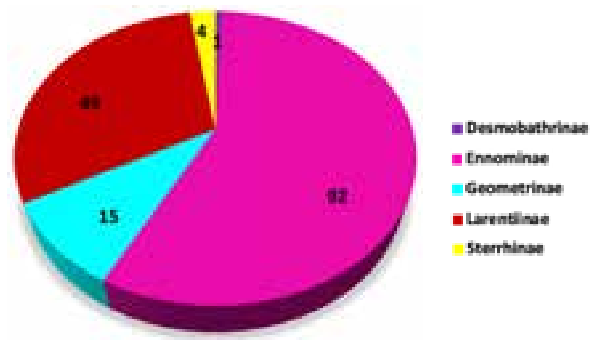


**Figure 2. Geometrid species diversity within subfamilies.**

Geometrinae ($r = -0.545$, $p = 0.044$), and Sterrhinae ($r = -0.684$, $p = 0.007$). In contrast, Larentiinae exhibits a strong positive correlation with altitude ($r = 0.730$, $p = 0.003$), indicating an increase in species richness with elevation (Brehm et al. 2007). Desmobathrinae show no significant correlation with altitude ($r = 0.290$, $p = 0.320$), likely due to their extremely low and rare occurrence across the altitudinal gradient (Table 3).

Across transects and the altitudinal gradient, many species exhibit restricted distributions or highly specialized niches. These include 17 species restricted to just one transect, 37 species restricted to just two transects, totalling 54 species, which could be categorised as highly specialized, while two species—*Euphyia subangulata* and *Eustroma melancolicum venipicta* (Larentiinae)—exhibited distribution throughout the

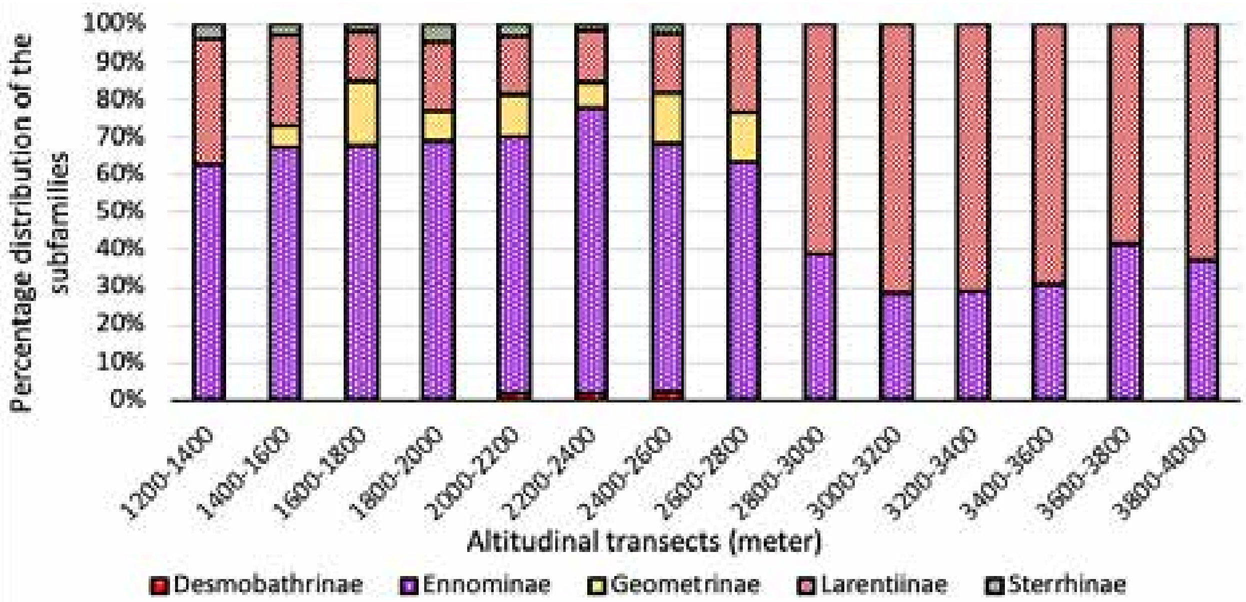


**Figure 3. Distributional pattern of each geometrid subfamily along the altitudinal gradient.**

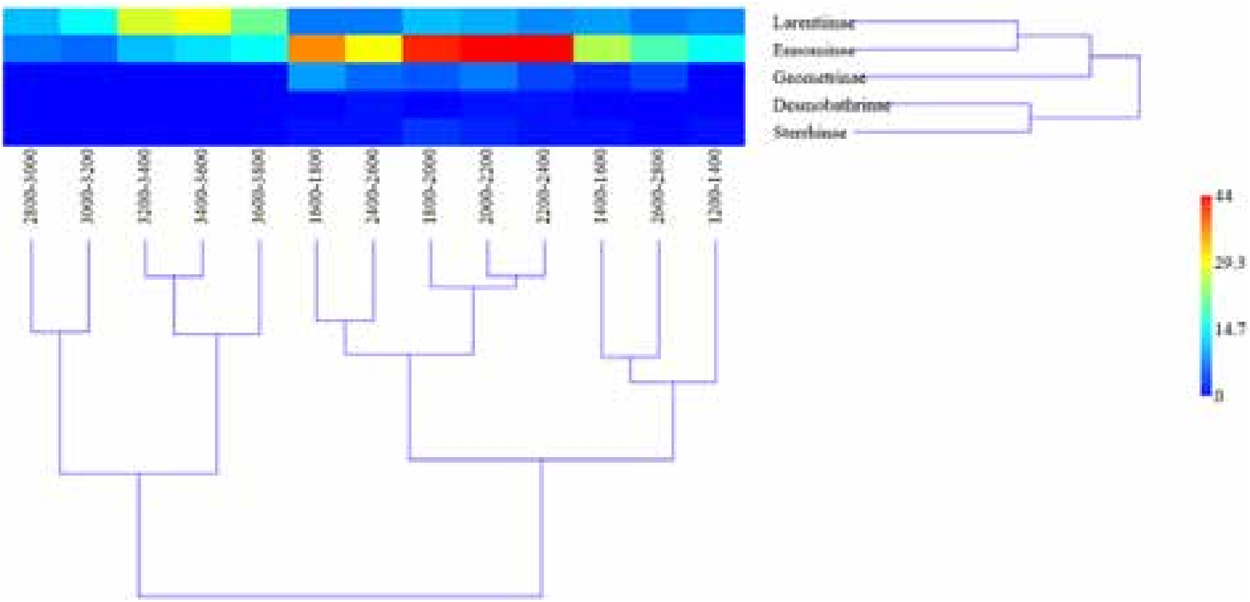

**Figure 4. Bray-Curtis similarity index between distribution pattern and species richness, along the altitudinal transects. The subfamilies are distinguished by different colour scales, highlighting their diversity and their wide distribution within the broad study area.**

altitudinal gradient. However, in terms of relative distribution, the subfamily Ennominae, represented by 23 species and present across five or more transects, outperforms other families, principally Larentiinae. This is because these species are mostly polyphagous and hence relatively more widely distributed (Lindström et al. 1994).

The indicator values range 53.33–100 %. However, the indicator value of a species was compounded with the *p*-value, which in the present study, should be less than 0.01. Of the 23 species analyzed, 13 exhibited high indicator values (70–100 %) and were therefore categorized as good indicator species, indicating a strong association with specific habitat conditions. The remaining 10 species, exhibiting moderate indicator values of 50–70 %, were classified as detector or early-

**Table 2. Distribution profile of individual species along the altitudinal gradient.**

| | Species | Distribution of species across the transects* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **Subfamily Desmobathrinae (01)** | | | | | | | | | | | | | | | |
| 1 | *Ozola* sp. | | | | | ■ | ■ | ■ | ■ | | | | | | |
| **Subfamily Ennominae (93)** | | | | | | | | | | | | | | | |
| 2 | *Abaciscus tristis* Butler, 1889 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 3 | *Abraxas permutans* Wehrli, 1931 | | | | | | | | | ■ | ■ | ■ | ■ | | |
| 4 | *Abraxas praepiperata* Wehrli, 1935 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 5 | *Abraxas* sp. | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 6 | *Alcis paraclarata* Sato, 1993 | | ■ | ■ | ■ | | | | | | | | | | |
| 7 | *Alcis praevariegata* Prout, 1929 | | | | ■ | ■ | ■ | ■ | | | | | | | |
| 8 | *Alcis variegata* Moore, 1888 | | | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 9 | *Anonychia grisea* Butler, 1883 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 10 | *Anonychia lativitta* Moore, 1888 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 11 | *Arichanna furcifera* Moore, 1888 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 12 | *Arichanna flavinigra* Hampson, 1907 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 13 | *Arichanna interplagata* Guenee, 1857 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 14 | *Arichanna sparsa* Butler, 1890 | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 15 | *Arichanna tramesata* Moore, 1867 | | | ■ | ■ | ■ | | | | | | | | | |
| 16 | *Arichanna* sp. 1 | | | | | | | | | | | | ■ | ■ | ■ |
| 17 | *Arichanna* sp. 2 | | | | | | | | | | | | ■ | ■ | ■ |
| 18 | *Blepharoctenucha virescens* Butler, 1880 | | | | | | | | ■ | ■ | | | | | |
| 19 | *Biston bengaliaria* Guenee, 1858 | ■ | ■ | | | | | | | | | | | | |
| 20 | *Biston falcata* Warren, 1893 | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 21 | *Biston sionitibetica* Warren, 1941 | | | | | | | | ■ | | | | | | |
| 22 | *Cabera quadrifasciaria* Packard, 1873 | | ■ | ■ | | | | | | | | | | | |
| 23 | *Cassyma deletaria* Moore, 1888 | | | | ■ | ■ | ■ | | | | | | | | |
| 24 | *Chiasmia cymatodes* Wehrli, 1932 | | | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 25 | *Chiasmia* sp. | | | | | | ■ | ■ | ■ | ■ | | | | | |
| 26 | *Chorodna vulpinaria* Moore, 1867 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 27 | *Cleora alienaria* Walker, 1860 | | | | | ■ | ■ | ■ | ■ | ■ | | | | | |
| 28 | *Cleora fraternal* Moore, 1888 | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| 29 | *Cleora* sp. 1 | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 30 | *Cleora* sp. 2 | | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 31 | *Corymica pryeri* Butler, 1878 | | | ■ | ■ | ■ | | | | | | | | | |
| 32 | *Corymica spatiosa* Prout, 1925 | ■ | | | | | | | | | | | | | |
| 33 | *Dalima apicata* Moore, 1868 | | | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 34 | *Dalima schistacearia* Moore, 1868 | | | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 35 | *Dalima truncataria* Moore, 1868 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 36 | *Deinotrichia scotosiaria* Warren, 1893 | | | | | | | | | ■ | ■ | ■ | | | |
| 37 | *Euclidiodes meridionalis* Wallengren, 1860 | | | | | | | | ■ | ■ | | | | | |
| 38 | *Epigynopteryx* sp. | | | | | ■ | ■ | ■ | | | | | | | |
| 39 | *Erebabraxas metachromata* Walker, 1862 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 40 | *Erebomorpha fulgurita* Walker, 1860 | | | | | ■ | | | | | | | | | |
| 41 | *Eutoea heteroneurata* Guenee, 1858 | | | | | | ■ | ■ | ■ | | | | | | |

| | Species | Distribution of species across the transects* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 42 | *Fascellina plagiata* Walker, 1866 | | | ■ | ■ | ■ | | | | | | | | | |
| 43 | *Gareus* sp. | | ■ | | | | | | | | | | | | |
| 44 | *Harutalcis vialis* Moore, 1888 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 45 | *Hirasa scripturaria* Walker, 1866 | | | | | ■ | ■ | | | | | | | | |
| 46 | *Hyalinetta circumflexa* Kollar, 1848 | | | | | ■ | ■ | ■ | | | | | | | |
| 47 | *Hypephyra cyanargentea* Wehrli, 1925 | | | ■ | ■ | ■ | | | | | | | | | |
| 48 | *Hypochrosis amaurospila* Yazaki, 1995 | | | | | ■ | ■ | ■ | | | | | | | |
| 49 | *Lassaba albidaria* Walker, 1866 | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| 50 | *Lomographa vestaliata* Guenee, 1857 | | | ■ | ■ | | | | | | | | | | |
| 51 | *Loxaspilates hastigera* Butler, 1889 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 52 | *Luxiaria amasa* Butler, 1878 | | | | ■ | ■ | ■ | | | | | | | | |
| 53 | *Medasina albidaria* Walker, 1866 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 54 | *Medasina combustaria* Walker, 1866 | | | ■ | | | | | | | | | | | |
| 55 | *Medasina* sp. | ■ | ■ | | | | | | | | | | | | |
| 56 | *Micronidia simpliciata* Moore, 1868 | | | | | ■ | ■ | ■ | | | | | | | |
| 57 | *Mimomiza cruentaria* Moore, 1867 | | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 58 | *Menophra nigrifasciata* Hampson, 1891 | | | | | ■ | ■ | | | | | | | | |
| 59 | *Menophra* sp. | | | | | | | ■ | ■ | ■ | | | | | |
| 60 | *Odontopera kanchia* Moore, 1883 | | | | | | ■ | | | | | | | | |
| 61 | *Odontopera* sp. | | | | | | | ■ | | | | | | | |
| 62 | *Ophthalmitis cordularia* Swinhoe, 1893 | | | ■ | ■ | | | | | | | | | | |
| 63 | *Opisthograptis luteolata* L., 1758 | | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 64 | *Opisthograptis tridentifera* Moore, 1888 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 65 | *Opisthograptis rumiformis* Hampson, 1902 | | | | | | | | | | | | ■ | ■ | ■ |
| 66 | *Opisthograptis sulphurea* Butler, 1880 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 67 | *Orthofodonia* sp. 1 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 68 | *Orthofodonia* sp. 2 | | | | | | | | | | ■ | ■ | ■ | ■ | |
| 69 | *Ourapteryx clara* Butler, 1880 | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| 70 | *Ourapteryx consociata* Inoue, 1993 | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| 71 | *Ourapteryx sambucaria* L. 1758 | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| 72 | *Oxymacaria penumbrata* Warren, 1896 | | | | ■ | ■ | | | | | | | | | |
| 73 | *Paradarisa consonaria* Hübner, 1799 | | ■ | ■ | | | | | | | | | | | |
| 74 | *Paraleptomiza bilinearia* Leech, 1897 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| 75 | *Parectropis subflava* Bastelberger, 1909 | | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 76 | *Percnia belluaria* Guenee, 1858 | | | | | | ■ | ■ | ■ | ■ | | | | | |
| 77 | *Percnia foraria* Guenee, 1858 | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| 78 | *Plagodis inustaria* Moore, 1868 | | | | | | | ■ | ■ | | | | | | |
| 79 | *Plutodes costatus* Butler, 1886 | | ■ | | | | | | | | | | | | |
| 80 | *Pseudomiza cruentaria* Moore, 1867 | | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 81 | *Pseudopanthera himalayica* Kollar, 1848 | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| 82 | *Psilalcis conspicuata* Moore, 1888 | ■ | ■ | ■ | | | | | | | | | | | |
| 83 | *Psyra angulifera* Walker, 1867 | | | | | | | ■ | | | | | | | |
| 84 | *Psyra cuneata* Walker, 1860 | | | | ■ | ■ | ■ | | | | | | | | |
| 85 | *Psyra falcipennis* Yazaki, 1994 | | | | | | ■ | | | | | | | | |

| | Species | Distribution of species across the transects* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 86 | *Psyra spurcataria* Walker, 1863 | | ■ | ■ | ■ | | | | | | | | | | |
| 87 | *Racotis petrosa* Butler, 1879 | | | | | | | | | | | | | ■ | |
| 88 | *Scioglyptis externaria* Walker, 1866 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 89 | *Sirinopteryx rufivinctata* Walker, 1862 | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| 90 | *Stenorumia ablunata* Guenee, 1858 | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| 91 | *Stenorumia duplicilinea* Hampson, 1895 | | | | | | | | | | | ■ | ■ | ■ | |
| 92 | *Tanaoctenia haliaria* Walker, 1861 | ■ | ■ | | | | | | | | | | | | |
| 93 | *Thinopteryx crocoptera* Kollar, 1844 | | | | | | ■ | | | | | | | | |
| 94 | *Xandrames albofasciata* Moore, 1868 | | | ■ | ■ | ■ | | | | | | | | | |
| **Subfamily Geometrinae (14)** | | | | | | | | | | | | | | | |
| 95 | *Chloroglyphica variegata* Butler, 1889 | | | ■ | ■ | | | | | | | | | | |
| 96 | *Chlororithra fea* Butler, 1889 | | | | | | | ■ | | | | | | | |
| 97 | *Comostola minutata* Druce, 1893 | | | ■ | ■ | | | | | | | | | | |
| 98 | *Dichorda* sp. | | | | | | ■ | ■ | ■ | | | | | | |
| 99 | *Gelasma inaptaria* Walker, 1863 | | | ■ | ■ | | | | | | | | | | |
| 100 | *Idiochlora approximans* Warren, 1897 | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 101 | *Lotaphora iridiocolor* Butler, 1880 | | | | | | | ■ | ■ | | | | | | |
| 102 | *Orothalassodes falsaria* Prout, 1912 | | | | | | ■ | ■ | ■ | | | | | | |
| 103 | *Pachyodes erionoma* Swinhoe, 1893 | | | ■ | ■ | ■ | | | | | | | | | |
| 104 | *Pachyodes moelleri* Warren, 1893 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 105 | *Pachyodes ornataria* Moore, 1888 | | | | | ■ | ■ | ■ | ■ | | | | | | |
| 106 | *Pelagodes* sp. 1 | | ■ | ■ | ■ | | | | | | | | | | |
| 107 | *Pelagodes* sp. 2 | | | | ■ | ■ | | | | | | | | | |
| 108 | *Tanaorhinus formosanus* Okano, 1959 | | | ■ | | | | | | | | | | | |
| **Subfamily Larentiinae (49)** | | | | | | | | | | | | | | | |
| 109 | *Agnibesa pictaria brevibasis* Prout, 1938 | | | ■ | ■ | ■ | ■ | | | | | | | | |
| 110 | *Amnesicoma bicolor* Oberthur, 1893 | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ |
| 111 | *Amnesicoma* sp. | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 112 | *Baynia odontata* Prout, 1910 | | | | | | | | | | | | | ■ | ■ |
| 113 | *Colostygia* sp. | | ■ | ■ | ■ | ■ | | | | | | | | | |
| 114 | *Dysstroma* sp. 1 | | | | | | | | | | | ■ | ■ | | |
| 115 | *Dysstroma* sp. 2 | | | | | | | | | | | | | ■ | ■ |
| 116 | *Ecliptopera postpallida* Prout, 1940 | | | | | | | | | | ■ | ■ | ■ | | |
| 117 | *Ecliptopera umbrosaria* Motschulsky, 1861 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 118 | *Elophos* sp. | ■ | ■ | ■ | | | | | | | | | | | |
| 119 | *Entephria caesiata* Denis & Schiffermuller, 1775 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 120 | *Entephria nobiliaria* Herrich-Schaffer, 1852 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 121 | *Entephria* sp. 1 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 122 | *Entephria* sp. 2 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 123 | *Entephria* sp. 3 | | | | | | | | | | ■ | ■ | ■ | | |
| 124 | *Epirrita dilutata* Schiffermuller, 1775 | | | | | | | | | ■ | ■ | ■ | ■ | | |
| 125 | *Epirrita* sp. | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 126 | *Epirrhoe galiata* Denis & Schiffermuller, 1775 | ■ | ■ | ■ | | | | | | | | | | | |
| 127 | *Eupithecia* sp. 1 | | | | | | | | | | ■ | ■ | ■ | ■ | |

| | Species | Distribution of species across the transects* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 128 | *Eupithecia* sp. 2 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| 129 | *Euphyia coangulata* Prout, 1914 | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| 130 | *Euphyia setellata* Warren, 1893 | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ |
| 131 | *Euphyia subangulata* Kollar, 1844 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| 132 | *Euphyia* sp. 1 | | | | | | ■ | ■ | ■ | ■ | | | | | |
| 133 | *Euphyia* sp. 2 | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| 134 | *Euphyia* sp. 3 | | | | | | | | | | | ■ | ■ | ■ | |
| 135 | *Eustroma chalcoptera* Hampson, 1895 | | | | | | | | | | | | ■ | ■ | |
| 136 | *Eustroma melencolicum venipicta* Butler, 1878 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 137 | *Eustroma* sp. 1 | | | | ■ | ■ | ■ | | | | | | | | |
| 138 | *Eustroma* sp. 2 | | | | | | | | | | ■ | ■ | ■ | ■ | |
| 139 | *Heterothera sororcula* Bastelberger, 1909 | | | | | | | | | | | ■ | ■ | ■ | |
| 140 | *Hydrelia bicolorata* Moore, 1868 | | | | | ■ | | | | | | | | | |
| 141 | *Hysterura multifaria* Swinhoe, 1890 | | | | | | | | | | | ■ | ■ | | |
| 142 | *Laciniodes plurilinearia* Moore, 1867 | ■ | ■ | ■ | | | | | | | | | | | |
| 143 | *Laciniodes unistirpis* Butler, 1878 | ■ | ■ | | | | | | | | | | | | |
| 144 | *Lampropteryx otregiata* Metcalf, 1917 | | | | | | | | | | | | ■ | | |
| 145 | *Larentia* sp. | | | | | | | | | | | ■ | ■ | | |
| 146 | *Lobogonodes multistriata* Butler, 1889 | ■ | ■ | | | | | | | | | | | | |
| 147 | *Melanthia alaudaria* Freyer, 1846 | | | ■ | ■ | | | | | | | | | | |
| 148 | *Perizoma bicolor* Warren, 1893 | ■ | ■ | | | | | | | | | | | | |
| 149 | *Pseudopolynesia* sp. | | | ■ | ■ | ■ | | | | | | | | | |
| 150 | *Photoscotosia chlorochrota* Hampson, 1902 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 151 | *Photoscotosia dejeani* Oberthur, 1893 | | | | | | | | | | ■ | ■ | ■ | ■ | |
| 152 | *Photoscotosia indecora* Prout, 1940 | | | | | | | | | | | | ■ | | |
| 153 | *Photoscotosia insularis* Bastelberger, 1909 | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | |
| 154 | *Photoscotosia metachryseis* Hampson, 1896 | | | | | | | | | | | ■ | ■ | ■ | ■ |
| 155 | *Physetobasis dentifascia* Hampson, 1895 | | | | | | ■ | ■ | ■ | | | | | | |
| 156 | *Stamnodes danilovi* Erschoff, 1877 | | | | | | | | ■ | | | | | | |
| 157 | *Stamnodes pauperaria* Eversmann, 1877 | | | | | | | | | ■ | ■ | | | | |
| **Subfamily Sterrhinae (04)** | | | | | | | | | | | | | | | |
| 158 | *Organopoda carnearia* Walker, 1861 | ■ | | | | | | | | | | | | | |
| 159 | *Scopula calcarata* D.S. Fletcher, 1958 | | | | ■ | ■ | ■ | | | | | | | | |
| 160 | *Scopula* sp. | | | | ■ | ■ | | | | | | | | | |
| 161 | *Timandra correspondens* Hampson, 1895 | | | ■ | ■ | ■ | ■ | | | | | | | | |

*1—1200–1400 m | 2—1400–1600 m | 3—1600–1800 m | 4—1800–2000 m | 5—2000–2200 m | 6—2200–2400 m | 7—2400–2600 m | 8—2600–2800 m | 9—2800–3000 m | 10—3000–3200 m | 11—3200–3400 m | 12—3400–3600 m | 13—3600–3800 m | 14—3800–4000 m.

warning species (Table 4). Both these categories of indicator species, however, reflect upon the habitat changes, habitat modification, environmental stress, or successional shifts (Bandyopadhyay 2021).

The highest number of indicator species were recorded from Ennominae subfamily (14 spp.), followed by Larentiinae (7 spp.), Sterrhinae (1 sp.), and Geometrinae (1 sp.) (Table 4). In terms of distribution profiles, a significant number of species (5) were confined to transects, ranging 2,200–2,400 m, followed by four species confined to the transects lying at 1,800–2,000 m; in three transects (1,200–1,400 m, 2,400–2,600 m, and 3,600–3,800 m) each have three spp.; in transects at altitudes of 1,600–1,800 m and 2,600–2,800 m two spp. were recorded from each; and the transect 2,800–3,000 m contain only a single indicator species (Table 4). In terms of the distribution of representative indicator species across the families Geometridae exhibiting species distribution across the whole transect area, from 1,200 m at the bottom to 4,000 m, characteristically is marked by the absence of any indicator species between the six transects lying between 1,400–1,600 m, 2,000–2,200 m, 3,000–3,600 m, and 3,800–4,000 m (Table 4).

Several species (Images 1–7) are reported for the first time from Uttarakhand, most of which belong to the subfamily Ennominae. These include- *Chiasmia cymatodes* Wehrli, 1932, *Cleora alienaria* Walker, 1860, *Dalima apicata* Moore, 1868, *Harutalcis vialis* Moore, 1888, and *Micronidia simpliciata* Moore, 1868; while two species- *Agnibesa pictaria brevibasis* Prout, 1938 and *Physetobasis dentifascia* Hampson, 1895, belong to the Larentiinae. Of greater importance are the two species, Euclidiodes meridionalis Wallengren, 1860, and *Hypochrosis amaurospila* Yazaki, 1995 (Ennominae, Images 8 & 9), reported for the first time from the country.

## DISCUSSION

Changes in subfamily composition of geometrid moths along elevational transects show different patterns of distribution (Brehm & Fiedler 2003). The maximum diversity encountered in zones I and II (altitude 1,200–2,600 m), reflects the findings of Brehm et al. (2003). Also, the finding that Ennominae accounts for the highest proportions at low elevations (1,200–2,800 m), while Larentiinae dominates at higher elevations (2,800–4,000 m), is consistent with Brehm & Fiedler's (2003) findings in the Ecuadorian Andes.

The declining trend in species diversity, along the altitudinal gradient, could be ascribed to open patches and anthropogenic disturbance, principally in zone III, while the other factors could be declining temperature (21.19 ± 0.26 to 11.69 ± 0.95) and concomitant increase in humidity (63.81 ± 1.12 to 78.02 ± 0.75), with altitude (Table 1). The subfamily Ennominae exhibits a strong positive correlation with ambient temperature (r = 0.61) and a negative correlation with humidity (r = -0.57). In contrast, Larentiinae exhibits a strong negative correlation with temperature (r = -0.78), but a strong positive correlation with humidity (r = 0.74). This contrasts with the findings of Colwell & Lees (2000) and Colwell et al. (2004), which indicate that Ennominae exhibits a positive relationship with both humidity and temperature. With respect to Larentiinae, our findings further support those of Colwell & Lees (2000) and Colwell et al. (2004), namely that species diversity within Larentiinae is positively correlated with humidity.

Overall, for Geometridae, a positive correlation with temperature (r = 0.35) and a negative correlation with humidity (r = -0.32) were observed. It would thus be safe to conclude that changes in species diversity, along the altitudinal gradient, are influenced principally by the vegetation cover—tree species as host plants for Ennominae, and subsequently, herbaceous species in the case of Larentiinae. This feature is exemplified by a positive correlation (r = 0.59) between Ennominae and tree diversity, and a negative correlation (r = -0.74) between Larentiinae and tree diversity. The latter exhibit increased diversity with decreased forest cover and increased herbaceous diversity, as also indicated by their distribution pattern (Figure 3).

The marked increase in species richness in zone 2 relative to zone 1 could be attributed to the ecotonal effect between forest cover and species diversity. In zone 1 the ecotonal effect is between forest cover and agricultural patches. This ecotone effect on species diversity across zones III and IV is presumably offset by anthropogenic disturbance, primarily tree lopping and grass removal. On the other hand, the marked increase in species abundance in the alpine zone could be attributed to greater host plant diversity.

Various biotic and abiotic factors shape the diversity and distribution of Geometrid moths, governing species assemblages along elevational and vegetational gradients (Webb et al. 2002; Graham et al. 2009). One of the major factors determining the distribution pattern of moths is the availability of larval host plants. This is especially true for highly specialized species, as exemplified by 54 species restricted to one or two transects (Brehm et al. 2013). At the same time, 32 species, mostly belonging

1. ***Agnibesa pictaria brevibasis*** **Prout, 1938**

2. ***Chiasmia cymatodes*** **Wehrli, 1932**

3. ***Cleora alienaria*** **Walker, 1860**

4. ***Dalima apicata*** **Moore, 1868**

5. ***Harutalcis vialis*** **Moore, 1888**

6. ***Micronidia simpliciata*** **Moore, 1868**

7. ***Physetobasis dentifascia*** **Hampson, 1895**

8. ***Euclidiodes meridionalis*** **Wallengren, 1860**

9. ***Hypochrosis amaurospila*** **Yazaki, 1995**

**Images 1–9. Moths from Pithoragarh District, Kumaon Himalaya. © Narendra Singh Lotani.**

**Table 3. Correlation between species richness and altitudinal gradient.**

| | Subfamilies | Altitudinal transects | | | | | | | | | | | | | | Correlation coefficient | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | *r*-value | *p*-value |
| 1 | Desmobathrinae | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +0.290 | 0.320 |
| 2 | Ennominae | 15 | 25 | 36 | 42 | 44 | 44 | 29 | 19 | 7 | 6 | 11 | 13 | 15 | 10 | -0.597 | 0.024 |
| 3 | Geometrinae | 0 | 2 | 9 | 5 | 7 | 4 | 6 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | -0.545 | 0.044 |
| 4 | Larentiinae | 8 | 9 | 7 | 11 | 10 | 8 | 7 | 7 | 11 | 15 | 27 | 29 | 21 | 17 | +0.730 | 0.003 |
| 5 | Sterrhinae | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.684 | 0.007 |

*__1__—1200–1400 m | **2**—1400–1600 m | **3**—1600–1800 m | **4**—1800–2000 m | **5**—2000–2200 m | **6**—2200–2400 m | **7**—2400–2600 m | **8**—2600–2800 m | **9**—2800–3000 m | **10**—3000–3200 m | **11**—3200–3400 m | **12**—3400–3600 m | **13**—3600–3800 m | **14**—3800–4000 m.

**Table 4. Indicator species of the Geometridae family with their indicator value and significant *p*-value.**

| | Subfamily | Species | Indicator value (%) | p-value | Transect |
|---|---|---|---|---|---|
| 1 | Ennominae | *Biston sionitibetica* Warren, 1941 | 100 | 0.0096 | 2600–2800 m |
| 2 | Ennominae | *Corymica spatiosa* Prout, 1925 | 100 | 0.0099 | 1200–1400 m |
| 3 | Ennominae | *Euclidiodes meridionalis* Wallengren, 1860 | 100 | 0.0096 | 2600–2800 m |
| 4 | Ennominae | *Odontopera kanchia* Moore, 1883 | 100 | 0.0098 | 2400–2600 m |
| 5 | Ennominae | *Psyra falcipennis* Yazaki, 1994 | 100 | 0.0096 | 2200–2400 m |
| 6 | Geometrinae | *Chlororithra fea* Butler, 1889 | 100 | 0.0096 | 2200–2400 m |
| 7 | Larentiinae | *Stamnodes danilovi* Erschoff, 1877 | 100 | 0.0096 | 2400–2600 m |
| 8 | Ennominae | *Gelasma inaptaria* Walker, 1863 | 83.33 | 0.0098 | 1800–2000 m |
| 9 | Ennominae | *Plagodis inustaria* Moore, 1868 | 82.35 | 0.0097 | 2400–2600 m |
| 10 | Ennominae | *Ophthalmitis cordularia* Swinhoe, 1893 | 73.21 | 0.0098 | 1800–2000 m |
| 11 | Larentiinae | *Perizoma bicolor* Warren, 1893 | 73.21 | 0.0099 | 1200–1400 m |
| 12 | Larentiinae | *Baynia odontata* Prout, 1910 | 71.66 | 0.0099 | 3600–3800 m |
| 13 | Larentiinae | *Eustroma chalcoptera* Hampson, 1895 | 70.23 | 0.0098 | 3600–3800 m |
| 14 | Ennominae | *Tanaoctenia haliaria* Walker, 1861 | 69.34 | 0.0098 | 1200–1400 m |
| 15 | Ennominae | *Cabera quadrifasciaria* Packard, 1873 | 68.18 | 0.0099 | 1600–1800 m |
| 16 | Larentiinae | *Melanthia alaudaria* Freyer, 1846 | 66.67 | 0.0099 | 1600–1800 m |
| 17 | Ennominae | *Hirasa scripturaria* Walker, 1866 | 64.71 | 0.0098 | 2200–2400 m |
| 18 | Sterrhinae | *Scopula* sp. | 63.36 | 0.01 | 2200–2400 m |
| 19 | Ennominae | *Eutoea heteroneurata* Guenee, 1858 | 61.52 | 0.0098 | 2200–2400 m |
| 20 | Ennominae | *Lomographa vestaliata* Guenee, 1857 | 59.23 | 0.0096 | 1800–2000 m |
| 21 | Larentiinae | *Stamnodes pauperaria* Eversmann, 1877 | 58.06 | 0.0099 | 2800–3000 m |
| 22 | Larentiinae | *Hysterura multifaria* Swinhoe, 1889 | 53.85 | 0.0096 | 3600–3800 m |
| 23 | Ennominae | *Oxymacaria penumbrata* Warren, 1896 | 53.33 | 0.0096 | 1800–2000 m |

to Ennominae (23 species), exhibiting relatively wider distribution (more than 5 transects, which equals a significant distance of 1 km altitudinally), could be defined as 'polyphagous' and 'generalists.'

The relative greater species richness as well as abundance of moths, predominantly belonging to the subfamily Larentiinae, in the alpine (zone V), compared to immediate sub-alpine zones III and IV, could be ascribed to the fact that species occupying higher elevations have a larger range of tolerances (Brehm et al. 2007), and possess physiological characteristics to comply with the cooler temperatures and affiliation with the host plants that have colonized the upper areas (Brehm et al. 2013). It could be presumed that the Larentiinae moths are better suited to cooler environments than the members of other subfamilies, especially Sterrhinae and Geometrinae (Brehm et al. 2013). The physiological properties, which allow moths of this subfamily to be unusually tolerant of unfavourable conditions, however, remain unknown (Brehm & Fiedler 2003). Furthermore, Larentiinae moths, owing to their relatively weaker body structure compared with other subfamilies, are weak flyers, which might benefit them in predator-free environments (Brehm & Fiedler 2003). Moderate host-plant specificity, as exhibited primarily by Ennominae, coupled with adaptability to cooler temperatures, as exhibited by Larentiinae, broadly describes patterns in species distribution across the altitudinal gradient (Brehm et al. 2013).

The indicator species were confined to a single transect, i.e., within an altitudinal breadth of just 200 m, which makes them not just highly specialized species (in terms of distribution), but more importantly, their niche specificity, relegated to biotic (mostly) and abiotic factors, would necessitate their greater monitoring. Any degradation of the habitat would invariably result in population decline and the loss of these species.

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ARTICLE



# New distribution records and taxonomic studies of ascomycetous fungi *Xylaria* and *Daldinia* (Ascomycota: Xylariales: Xylariaceae) in Karnataka, India

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**Abstract:** The family Xylariaceae represents a diverse assemblage of ascomycetous fungi, widely recognised for their prolific production of secondary metabolites with potent bioactive properties, including antimicrobial, anticancer, and immunomodulatory compounds. A mycological survey was conducted from June 2023 to August 2024 across various ecological niches in Karnataka, India, to document the diversity of Xylariaceae. Extensive morphological, anatomical, and taxonomic investigations led to the identification of 16 fungal taxa distributed across two genera: *Daldinia* (3 species), *Xylaria* (12 species) and *Sphaeria* (1 species). The species of *Daldinia* were confirmed as *D. childiae* J.D.Rogers & Y.M.Ju, *D. concentrica* (Bolton) Ces. & De Not., and *D. eschscholtzii* (Ehrenb.) Rehm, while the *Xylaria* taxa included *X. curta* Fr., *X. carpophila* (Pers.) Fr., *X. castorea* Berk., *X. cornu-damae* (Schwein.) Berk., *X. apiculata* Cooke, *X. ellisii* Tanney, Seifert & Y.M.Ju, *X. frustulosa* (Berk. & M.A.Curtis) Cooke, *X. hypoxylon* (L.) Grev., *Sphaeria kegeliana* Lév., *X. longipes* Nitschke, *X. nigripes* (Klotzsch) Cooke, *X. polymorpha* (Pers.) Grev., *X. telfairii* (Berk.) Sacc., These species were predominantly found colonizing decayed wood, lignified stumps, and decomposing leaf litter. Notably, *D. childiae*, *X. curta*, *X. ellisii*, *X. frustulosa*, *X. kegeliana* are reported for the first time in Karnataka, whereas *X. telfairii* and *X. cornu-damae* constitute new records for India. This study significantly enhances our understanding of the taxonomy, systematics, and biogeography of Xylariaceae in the Indian subcontinent, providing valuable insights into their classification, substrate preferences, and ecological distribution.

**Keywords:** Fungal diversity, morphological survey, morphological taxonomy, secondary metabolites, substrate specificity, wood decay fungi.

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**Author contributions:** BKS: Conceptualised, filed survey, investigated, developed data, analysed, and wrote the manuscript. NPK: Revised and edited the manuscript, analysed and validated the data, instructed and supervised the whole process. AMK: Filed survey, host identification, manuscript reviewed and validated.

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## INTRODUCTION

Ascomycota, a large taxonomic group of fungi, encompasses numerous genera that play crucial roles in forest ecosystems. Xylariaceae is a diverse and ecologically important family within the Ascomycota (Suwannasai et al. 2023). The family Xylariaceae, belonging to the phylum Ascomycota, includes approximately 85 genera and over 1,300 species worldwide (Patel & Krishnappa 2017). Among these, *Xylaria* and *Daldinia* species are particularly significant, as they contribute to the decomposition of wood and organic matter (Rogers 1979). Most representatives of the genus *Xylaria* are considered saprophytes, though they may exhibit varying degrees of parasitism, typically associated with stems and leaves and less frequently with fruits (Canon et al. 2019). *Xylaria* species associated with termite nests are predominantly found in Africa and Asia, particularly in regions dominated by the termite species from the subfamily Macrotermitinae (Wangsawat et al. 2021). Despite their ecological importance, many xylariaceous fungi remain poorly understood, especially in the underexplored Western Ghats, a biodiversity hotspot, despite known ascomycete numbers having nearly doubled in recent years (Karun & Sridhar 2015). The present study focuses on the diversity, distribution, taxonomy, and substrate specificity of *Xylaria* and *Daldinia* within the eco-regions, including the Western Ghats of Karnataka, India.

## MATERIALS AND METHODS

### Sample collection

Fieldwork was conducted from June 2023 to August 2024 across a range of forest ecosystems with diverse climatic conditions, including moist and dry deciduous forests, scrublands, wetlands, and arid to semi-arid regions in the districts of Davanagere, Bengaluru, Kodagu, Shivamogga, and Chikkamagaluru in Karnataka (Figure 1). Fungal specimens were collected in sterile, zip-lock bags and transported to the laboratory for analysis. The morphological features of Xylariaceae members were carefully examined and documented, followed by the drying and preservation of each specimen individually in plastic bags.

### Morphological characterization

Transverse sections of fungal specimens were prepared and mounted in lactophenol, cotton blue, and stained with iodine reagent to observe the features of perithecia, asci, and ascospores. A 5–10% potassium hydroxide (KOH) solution was used to soften the fungal tissues; after rinsing with water using a dropper or pipette, the KOH was replaced with the appropriate stains. Morphological characteristics of all specimens were examined under a light microscope equipped with a Canon EOS 600D camera (Nagadesi 2018; Bharath et al. 2025). Measurements were recorded, and species were identified using standard taxonomic literature. (Dennis 1956, 1957, 1958; Thind & Waraitch 1969; Martin 1970; Thind & Dargan 1975, 1978, 1979; Kar & Gupta 1978; Dargan 1980; Rogers et al. 1987, 1988).

## RESULTS

A total of 144 fungal samples were collected from various eco-regions and biodiversity hotspots of Karnataka, among which 16 fungal taxa were identified, including three species of *Daldinia,* one species of *Sphaeria* and twelve species of *Xylaria*. Comprehensive morphological and anatomical analyses confirmed the identity of three *Daldinia* species as *D. childiae D. concentrica,* and *D. eschscholtzii.* The 12 *Xylaria* species were identified as *X. curta*, *X. carpophila*, *X. castorea*, *X. cornu-damae*, *X. apiculata*, *X. ellisii*, *X. frustulosa*, *X. hypoxylon*, *X. longipes*, *X. nigripes*, *X. polymorpha*, *X. telfairii*, and one *S. kegeliana.* These taxa were found inhabiting various substrates, including living trees, decayed wood, stumps, organic-matter-rich soil, and leaf litter, across different locations in Karnataka (Table 1). Significantly, this study reports *D. childiae, X. curta*, *X. ellisii*, *X. frustulosa*, and *S. kegeliana* for the first time from Karnataka, whereas *X. telfairii* and *X. cornu-damae* are documented as new records for India. These findings provide new insights into the diversity and distribution of Xylariaceae in the region, contributing to the broader understanding of their taxonomy and systematics.

The collected specimens have been submitted to the Museum, Department of Botany in St. Joseph's University, Bengaluru, with accession numbers such as SJCCBOT031, SJCCB032, SJCCB033, SJCCB034, SJCCB038, SJCCB039, SJCCB041, SJCCB042, SJCCB043, SJCCB044, SJCCB048, SJCCB049, SJCCB053, SJCCB065, SJCCB055, and SJCCB066 accordingly. These sixteen species have been described and illustrated based on their morphological and anatomical features, along with their substrate records.

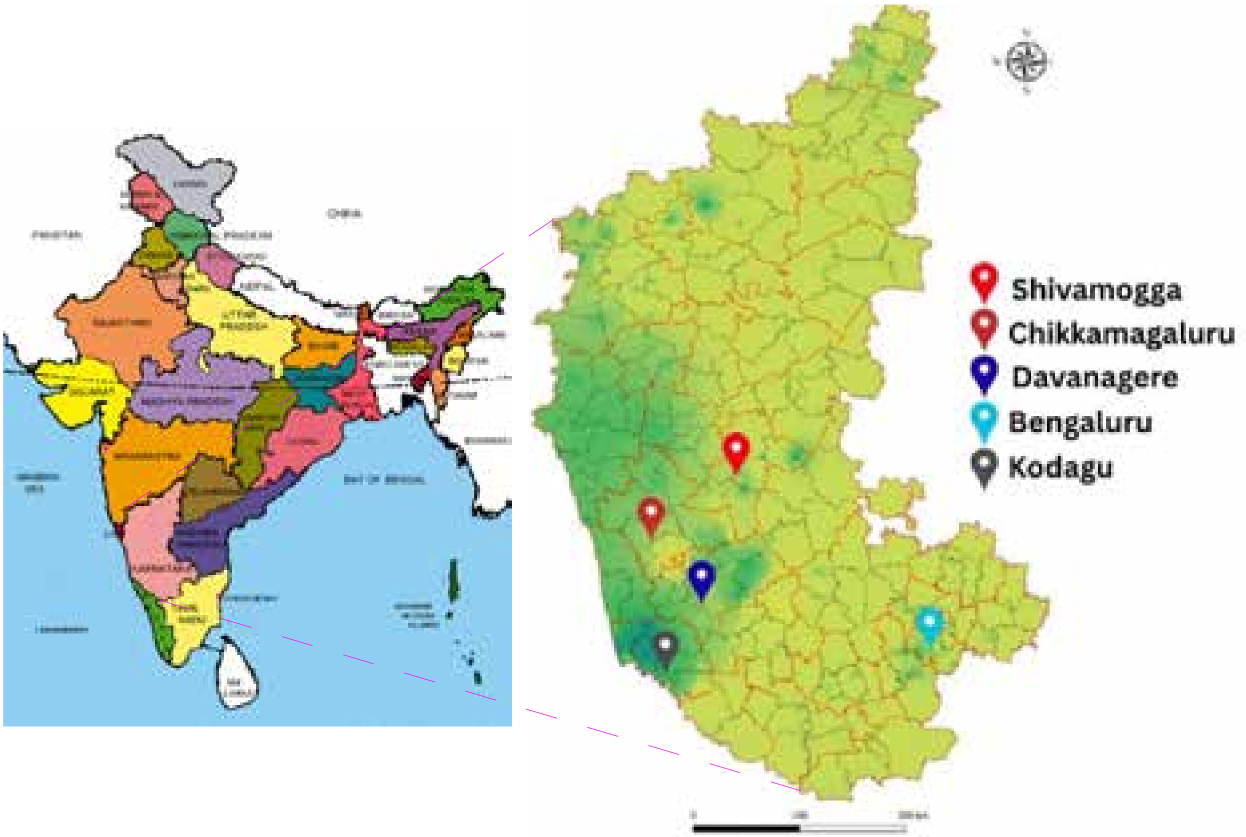


**Figure 1. Map of Karnataka showing sampling districts.**

**Taxonomy**

***Daldinia concentrica*** **(Bolton) Ces. & De Not., 1863**

The fruit bodies are 3–7 cm in diameter; brown, turn black and dense as they mature; sessile, broadly attached to the host, smooth, hard, and solitary, with a cushion-shaped, rounded appearance. Surface becomes cracked over time, revealing reddish-brown granules beneath. Spore-bearing surface consists of tiny perithecia embedded within the outer layer of the fruiting body. Flesh arranged in concentric layers, with slightly papillate ostioles. Asci cylindrical; ascospores dark brown to black, elliptical to fusiform, unicellular, with rounded ends, approximately 5–7 × 11–16 µm

**Specimens examined:** India, Karnataka, Lalbagh, Bengaluru, forest area, on dead and decayed wood of *Eucalyptus* tree, leaf litter, decayed twigs, decayed stumps, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 12.948 °N & 77.588 °E, 5 August 2024, Bharath Kumar S. Acc. no.SJCCB065.

***Daldinia childiae*** **J.D. Rogers & Y.M. Ju, 1999 (Image 1)**

Fruit bodies about 0.8–2.5 cm wide, found in clusters on the dead wood of the Eucalyptus tree; nearly globose to hemispherical to irregularly shaped; greyish-white to pinkish-brown in colour, become greyish to blackish in colour. Conidia may appear as a whitish mass. The surface of a mature carbon ball appears finely dotted, with minute bumps. Perithecia are present just below the surface of the fruiting body. Alternating light and darker-coloured concentric zones are present when cut vertically. Ascospores are brown to black, unicellular, ellipsoid, with rounded ends, approximately 8.5–9 × 4.5–5 µm in diameter.

**Specimens examined:** India, Karnataka, Bannerugatta, Bengaluru, forest area, on decayed dead and decayed wood of *Eucalyptus* tree, leaf litter, decayed twigs, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.032 °N & 77.563 °E, 5 August 2024, Bharath Kumar S. Acc. No SJCCB055.

***Daldinia eschscholtzii*** **(Ehrenb.) Rehm, 1904**

The fruiting body exhibits considerable variability, ranging from hemispherical to placentiform shapes. It is sessile, solitary, short, stout, and smooth, measuring

**Table 1. Morphological and habitat data of *Xylaria* and related fungal species.**

| | Species | Substrate | Stroma shape and colour | Co-ordinates | References |
|---|---|---|---|---|---|
| 1 | *Xylaria apiculata* | Bark of the Mahogany tree, decayed stumps, | Black in colour, pale coating, splits into vertical strations. 0.5–2.5 cm | 14.166° N 75.033° E | **Pande et al. (**2012) |
| 2 | *X. carpophila* | Dead and Decayed wood of Silver Oak tree | Long, slender, and cylindrical to oval in shape. 5.5–7.5 cm, ending in a rounded to pointed apex. white, yellow to off-white | 13.690° N 75.245° E | Swapna et al. (2008) |
| **3** | *X. castorea* | Decayed wood of *Samanea saman*, Ficus tree stumps | Solitary, unbranched, flattened to cylindrical, broadly Spathulate, tip acute to round, glabrous, brown to blackish brown in colour, 3.6 × 1–2 cm | 14.3742° N 74.81142° E | **Pande et al. (**2012) |
| 4 | *X. cornu- damae* | Decayed wood, bark of *Acacia nilotica* | Grey to black to pimply, little large, branched, cylindrical young stage dusty whitish covering, surface powdery, 3.6 × 0.6 cm | 14.364° N 74.884° E | New to the study area |
| 5 | *X. curta* | Leaf litter, decayed twigs, and stumps | Initially dark brown, they become much darker as they mature. External texture is rough and wrinkled, ranging in colour from black to golden brown, 3–6.5 cm | 14.034° N 75.934° E | New to the study area |
| 6 | *X. ellisisii* | Soil surface, leaf litter, decayed twigs | Solitary, branched once, cylindrical to spathulate, apices broadly rounded, 3.5–5.6 × 0.8–1.1 cm. Surface irregularly flattened to wrinkled, frequently cracked, and black in colour, | 14.641° N 75.531° E | New to the study area |
| 7 | *X. frustulosa* | Decayed wood, Bark of *Samanea saman* | Gregarious to confluent, semi-circular to irregular, flattened to pulvinate, dark brown in colour, 0.6–1.5 × 2–3.5 cm. | 14.748° N 75.541° E | New to the study area |
| 8 | *X. hypoxylon* | Base of the Tamarind tree and decayed bark | Slender, sub-cylindrical to strap-shaped, and branched at the tip. Black colour on the lower side and a powdery white tip, 6–8 cm. | 14.354° N 75.467° E | Karun & Sridhar (2015) |
| 9 | *X. kegeliana* | Soil surface, leaf litter, decayed twigs | Stroma 7–10 × 0.6 cm, creamish white in colour with black dotted lines, with a cracked, rough surface. | 13.333° N 75.251° E | New to the study area |
| 10 | *X. longipes* | Decayed wood of *Acacia nilotica* | Club-shaped form and a short stipe. Tough and tapering to a rounded apex. At maturity, greyish-brown, turning black with age, and becomes crackly and scaly. 3.8 × 0.2–1.5 cm | 13.313° N 75.737° E | Karun & Sridhar (2015) |
| 11 | *X. nigripes* | Decayed wood, bark, and leaf litter | Long, slender, and cylindrical, tapering to a club shape at the top. Smoky white to greyish-white but turns black, becoming crackly and scaly with age, 8–13.5 cm. | 13.162° N 75.857° E | Karun & Sridhar (2015) |
| 12 | *X. polymorpha* | Decayed wood of a Silver Oak tree | Dark brown in colour, club-shaped with blunt, narrowed, whitish to black tips, varies from pale grey to dark black, finely dusted, swollen at top to bottom, finely wrinkled 4.5–8 × 0.5–1.4 cm | 13.137° N 75.606° E | Karun & Sridhar (2015) |
| 13 | *X. telfairii* | Soil surface, leaf litter, decayed twigs | Cylindrical with rounded apices, unbranched, solitary, measuring about 2.4–3.5 × 0.9–1.4 cm thick, the stipe is black in colour, surface copper to cinnamon brown in colour, smooth. | 12.947° N, 77. 585° E | New to the study Area |
| 14 | *Daldinia concentrica* | Dead and decayed wood of the Eucalyptus tree | They are brown and turn black and dense as they mature, sessile, hard, and solitary, with a cushion-shaped, rounded appearance. The surface becomes cracked over time, with reddish-brown granules beneath. 3–7 cm | 12.948° N 77.588° E | Swapna et al. (2008) |
| 15 | *D. eschscholtzii* | Decayed Teak wood bark | The fruiting body has hemispherical to placentiform shapes. It is sessile, solitary, short, stout, and smooth, 2–5 cm, brown to black in colour. With age, the surface becomes varnished and develops granules. | 13.012° N 77.570° E | Chutulo & Chalannavar (2020) |
| 16 | *D. childiae* | Dead and decayed wood of the Eucalyptus tree | Fruiting body is nearly globose to hemispherical, and some are often irregularly shaped. Greyish white to pinkish brown in colour, at maturity, the fruiting body becomes greyish to blackish in colour, 0.8–2.5 cm. | 13.032° N 77.563° E | New to the study area |

2–5 cm in diameter, with a brown to black colouration. As it ages, the surface becomes varnished and develops granules. The perithecia are small and tubular, featuring prominent internal zones with alternating light and dark concentric rings, and are dark brown in colour. The ascospores are brown to black, unicellular, ellipsoid, with rounded ends, measuring approximately 9–10 × 5–6 µm in diameter.

**Specimens examined:** India, Karnataka, Lalbagh, Bengaluru, forest area, observed on decayed *Teak* wood, bark, stumps, leaf litter, decayed twigs, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.012 °N & 77.570 °E, collected on 5 August 2024 by Bharath Kumar S. Acc. no.SJCCB065

***Xylaria apiculata*** **Cooke, 1879**

The fruiting bodies are slender and relatively small compared to other species, ranging from 0.5–2.5 cm in length and 0.3–0.4 cm in width. The fertile fruiting bodies


**Image 1. *Daldinia childiae*: A–C—fruiting body attached to the host, individual fruiting body | D—fruiting body shows dots | E—concentric zones (10X) | F&G—Perithecia (40X) | H&I—different sizes and shapes of spores (100X). © Bharath Kumar S.**

are black, with a pale coating on the upper surface that splits into vertical striations. The interior tissues are white and softer than the black outer coating, while the stipes are often densely tomentose. Mature stromata are unbranched. The perithecia are globose, measuring 0.4–0.5 mm in diameter, with very finely papillate ostioles.

The stipe is small compared to the spore-bearing fruiting body, swelling in the centre. The ascospores are brown, unicellular, ellipsoid, and have broadly rounded ends, measuring 15–20 × 6–9 µm in diameter.

**Specimens examined:** India, Karnataka, Sagara, Shivamugga, forest area, observed on bark of *Mahogany* tree, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.166 °N & 75.033 °E, collected on 14 November 2023 by Bharath Kumar S. Acc. no. SJCCBOT031.

***Xylaria carpophila*** **(Pers.) Fr., 1849**

The fruiting bodies are long, slender, and cylindrical, with some branched and others unbranched, extending to a fertile portion that is cylindrical to oval in shape. They measure up to 5.5–7.5 cm in length, ending in a rounded to pointed apex. The texture is rough. When young, they are initially white, becoming yellow to off-white as they mature. The apical tip is rusty and yellow to off-white, and rounded. The perithecia are mammiform with papillate ostioles. The ascospores are pale yellow to pale brown, measuring up to 8–9 × 18–21 µm in diameter, and have a slightly bean-shaped structure.

**Specimens examined:** India, Karnataka, Thirthahalli, Shivamugga, forest area, observed on dead and decaying wood of the Silver oak tree, stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.690 °N & 75.245 °E, collected on 14 November 2023 by Bharath Kumar S. Acc. no. SJCCBOT032.

***Xylaria castorea*** **Berk., 1855**

Fruiting body solitary to gregarious, unbranched, flattened to cylindrical, clavate, broadly spathulate, tip acute to round, entire stromata fertile, glabrous, plane to slightly enlarged, sessile, brown to blackish brown in colour, surface splitting into distinct plates, measuring up to 3–6 × 1–2 cm diam. Perithecia are

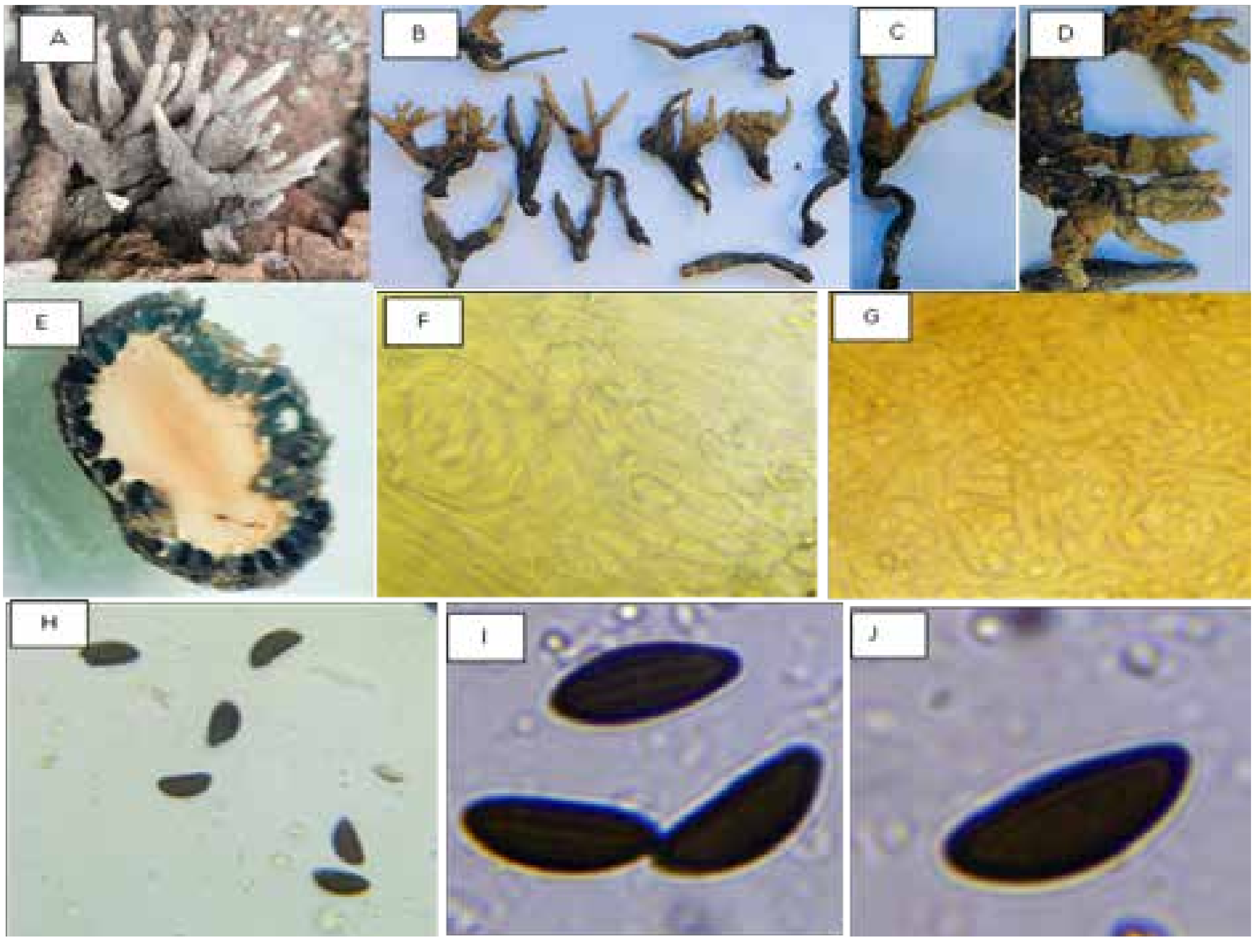


**Image 2. *Xylaria cornu-damae*: A—fruiting body attached to the host | B—individual fruiting body | C&D—mature fruiting body | E—Perithecia (10X) | F&G—internal tissue (100X) | H–J—different size and shape of spores (100X). © Bharath Kumar S.**

completely immersed, 5–7 µm. Asci cylindrical, 8-spored. Ascospores are elliptical, equilateral to nearly symmetric, dark brown in colour, measuring up to 9.5–13 × 5.5–6.5 µm in diameter.

**Specimens examined:** India, Karnataka, Ranganathapura, Shivamugga, forest area, observed on decayed wood of *Albizia saman*, ficus tree stumps, leaf litter, decayed twigs, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.374 °N & 74.811 °E, collected on 14 November 2023 by Bharath Kumar S. Acc. no. SJCCBOT033.

***Xylaria cornu-damae*** **(Schwein.) Berk., 1873 (Image 2)**

The fruiting body is found on decaying wood of heartwood stumps. Fruiting body grey to black, pimply, little large, branched, cylindrical, young stage dusty whitish covering, surface powdery, often with whitish remains of the powdery coating of the grey to black, measuring up to 3.6 × 0.6 cm in diameter. Interior flesh white, and tough, perithecia at maturity fruiting body more are less spherical, just below the surface measuring about 45–50 × 3–5.5 µm with a long stipe. Asci 8-spored. Ascospores are fusiform, smooth, dark brown to black in colour, 15–30 × 4.5–6 µm.

**Specimens examined:** India, Karnataka, Siddapura, Shivamugga, forest area, observed on decayed wood, bark of *Acacia nilotica*, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.364 °N & 74.884 °E, collected on 14 November 2023 by Bharath Kumar S. Acc. no. SJCCBOT038.

***Xylaria curta*** **Fr., 1851 (Image 3)**

The fruiting bodies are found near the base of living hardwood tree trunks. Although they appear terrestrial, they are actually attached and grow in clusters, with some being solitary. They are sessile with elongated, flattened, cylindrical fertile parts that have a rounded apex. Initially dark brown, they become much darker as they mature. The external texture is rough and wrinkled, ranging in colour from black to golden brown, and measuring up to 3–6.5 cm in diameter. Meanwhile, the internal tissue is white to cream. The perithecia are immersed, measuring 0.2–0.5 mm in diameter, and have a papillate ostiole. The ascospores are dark brown, unicellular, smooth, uniseriate, cylindrical, and ellipsoidal in shape, measuring up to 6–7 × 5.5–6.5 µm in diameter.

**Specimens examined:** India, Karnataka, Channagiri, Davanagere, forest area, observed on Leaf litter, decayed twigs, stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.034 °N & 75.934 °E, collected on 7 October 2023 by Bharath Kumar S. Acc. no.SJCCBOT034.

***Xylaria ellisii*** **Tanney, Seifert & Y.M.Ju, 2020 (Image 4)**

The fruiting body is upright, solitary, and once-branched, with a cylindrical to spathulate shape. The apices are broadly rounded, dividing into a fertile head and a sterile stipe, measuring approximately 3.5–5.6 × 0.8–1.1 cm, including the stipe. The surface is irregularly flattened to wrinkled, often cracked, and black in colour, while the interior is white. The stipe is brownish-black in colour. Perithecia immersed, subglobose to globose, 0.4–0.6 mm diam. Osteoles pappilate. Ascospores are eight-spored, measuring 45–60 µm in diameter, and are cylindrical, arranged in a uniseriate manner. Ascospores are dark brown in colour, smooth, unicellular, ellipsoid-unequilateral, broadly rounded ends, measuring about 7–9.5 × 4.5–5.5 µm in diameter

**Specimens examined:** India, Karnataka, Kerebilachi, Davanagere, forest area, observed on soil surface, Leaf litter, decayed twigs, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.641 °N & 75.531 °E, collected on 7 October 2023 by Bharath Kumar S. Acc. no. SJCCBOT039.

***Xylaria frustulosa*** **(Berk. & M.A.Curtis) Cooke, 1883 (Image 5)**

Fruiting body gregarious to confluent, semi-circular to irregular, flattened to pulvinate, dark brown in colour, measuring about 0.6–1.5 cm in height and 2–3.5 cm in width in diameter, attached to the substratum by a narrow central connective. Perithecia are numerous in number, the surface is dotted with ostioles, the interior is soft and black in colour. Perithecia globose to subglobose, measuring up to 0.2–0.3 mm diam. Asci with eight ascospores, hyaline, cylindrical, 35–40 × 3.5–5.5 µm with a long stipe. Ascospores are pale brown to black in colour, elliptical, measuring up to 5.5–6.2 × 2.5–3.5 µm in diameter.

**Specimens examined:** India, Karnataka, Shanthi Sagar, Davanagere, forest area, observed on decayed wood, bark of Albizia saman, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.7488 °N & 75.541 °E, collected on 7 October 2023 by Bharath Kumar S. Acc. no. SJCCBOT041.

***Xylaria hypoxylon*** **(L.) Grev., 1824**

The fruiting bodies are found on the trunk of a tamarind tree. They are slender, sub-cylindrical to strap-

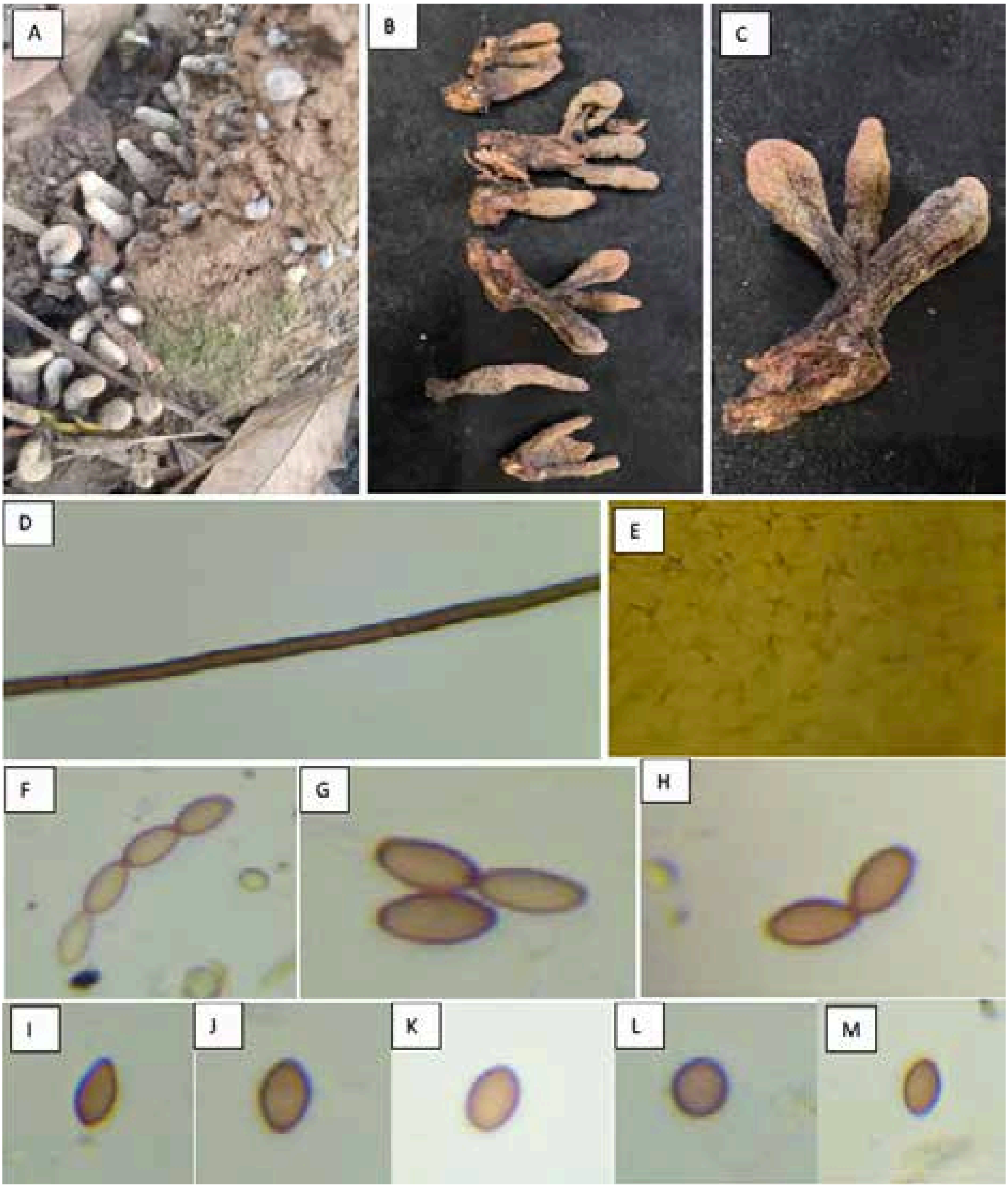


**Image 3. *Xylaria curta*: A—fruiting body attached to the host | B—individual fruiting body with stipe | C—mature fruiting body | D—Hyphae (100X) | E—inner tissue (100X) | F–M—different size and shape of spores (100X). © Bharath Kumar S.**

shaped, and may be branched at the tip. These structures can be solitary or gregarious, with a black colour on the lower side and a powdery white tip, reaching heights of up to 6–8 cm. The perithecia are fully immersed, and the surface of the fertile portion is tuberculate, with longitudinal splits up to 0.4–0.5 mm in size. The asci are cylindrical, and the ascospores are black, uniseriate, and slightly bean-shaped, measuring 4.8–6.3 × 11.3–12.6

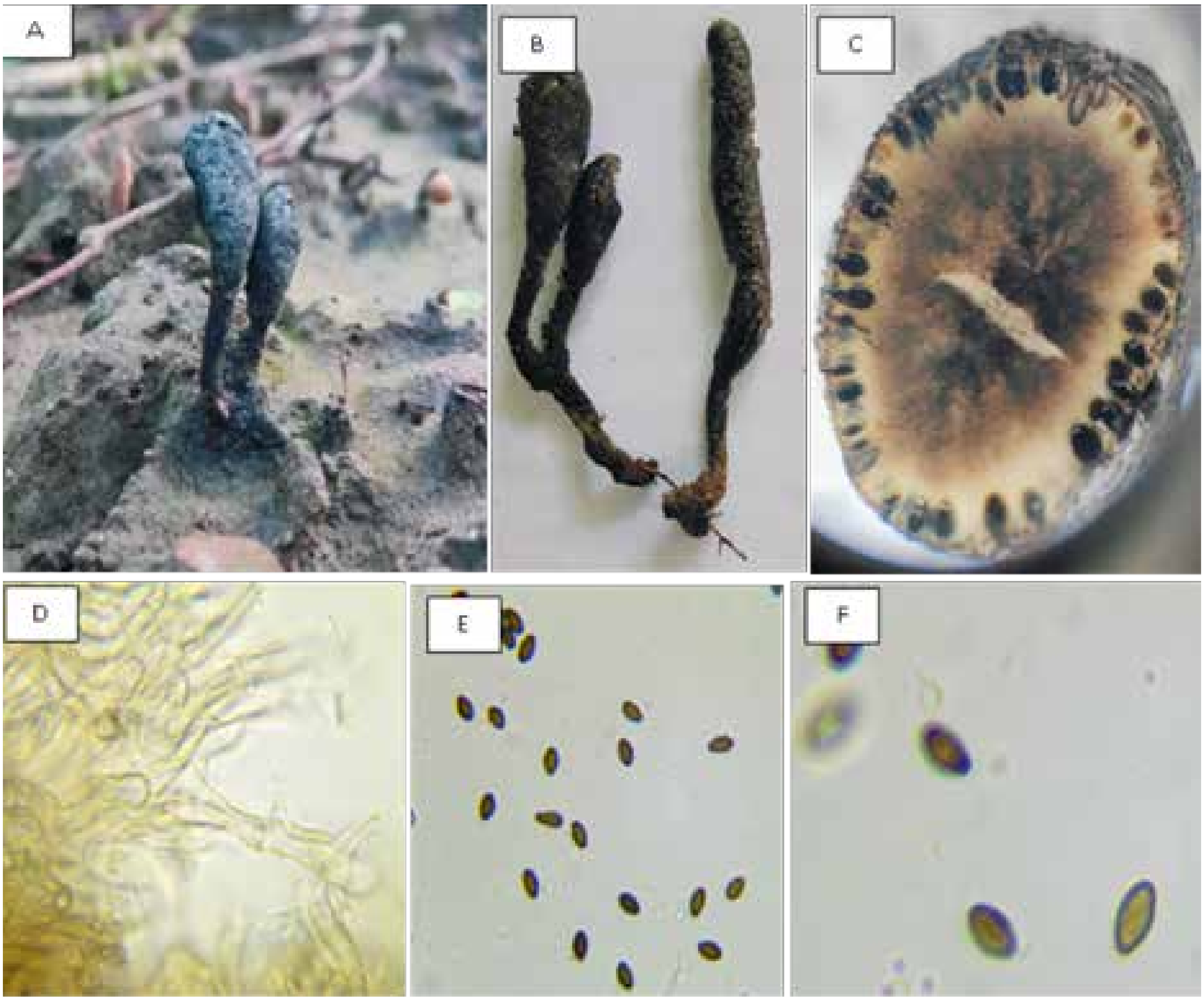


Image 4. *Xylaria ellisii*: A—fruiting body attached to soil surface | B—individual fruiting body | C—Perithecia | D—internal tissue | E&F—different size and shape of spores. © Bharath Kumar S.

µm. The spores are equatorially flattened on one side and rounded on the other, giving them a distinctive banana-like shape.

**Specimens examined:** India, Karnataka, Nallur, Davanagere, forest area, observed on the base of a Tamarind tree and decayed bark, stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.354 °N & 75.467 °E, collected on 7 October 2023 by Bharath Kumar S. Acc. no. SJCCBOT042.

***Xylaria kegeliana*** **(Lév.) Fr., 1851 (Image 6)**
**Current name: *Sphaeria kegeliana* Lév.**

The fruiting body is found on the soil surface and on decayed wood. Stroma about 7–10 × 0.6 cm in diameter, fruiting bodies are creamish-white in colour with black dotted lines, with a cracked, rough surface, with a long rooting stipe up to ¾ of the total length, measuring up to 5–6 cm, smooth and wrinkled in structure. Perithecia are globose to irregular in shape with a small stalk. Asci 7-spored, interior flesh golden yellow in colour. Ascospores are small, elliptical, subglobose, smooth, golden brown to black at maturity, measuring about 4–6 × 2–3µm in diameter.

**Specimens examined:** India, Karnataka, Kuduregundi, Chikkamagaluru, forest area, observed on Soil surface, leaf litter, decayed twigs, decayed stumps, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.333 °N & 75.251 °E, collected on 15 September 2023 by Bharath Kumar S. Acc. no. SJCCBOT043.

***Xylaria longipes*** **Nitschke, 1867**

The fruiting bodies are found in groups, with a club-shaped form and a short stipe. They are tough and taper

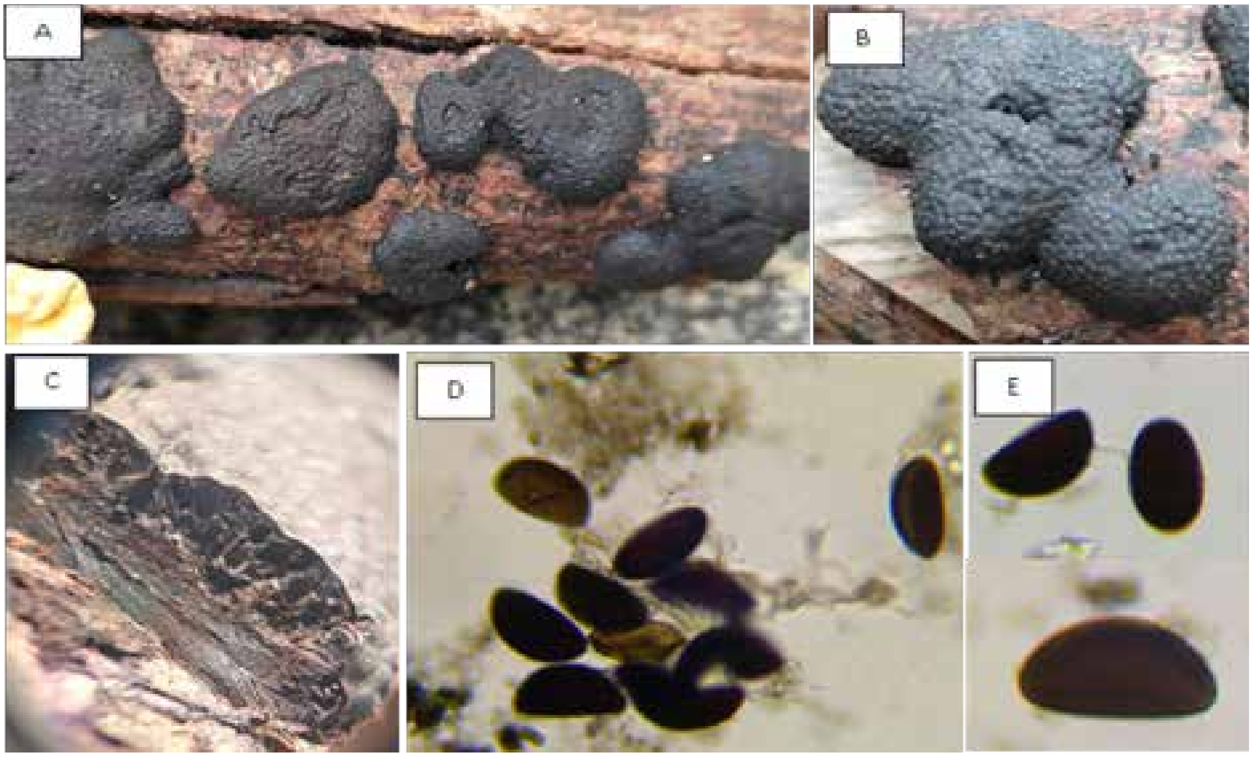


**Image 5.** ***Xylaria frustolosa*****: A—fruiting body attached to the host | B—individual fruiting body | C—Perithecia (10X) | D–F—different sizes and shapes of spores (100X). © Bharath Kumar S.**

to a rounded apex. At maturity, their surface is greyish-brown, turning black with age, and becomes crackly and scaly. They measure approximately 3–8 cm in length and 0.2–1.5 cm in diameter. The perithecia are 0.5–1 mm in diameter with a papillate ostiole, and the asci are long and stipitate. The ascospores are brown to black, smooth, and fusiform with a slit running through them, measuring about 4–7.5 × 11–15 µm.

**Specimens examined:** India, Karnataka, Halase, Chikkamagaluru forest area, observed on Decayed wood of *Acacia nilotica*, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.313 °N & 75.737 °E, collected on 5 September 2023 by Bharath Kumar S. Acc. no. SJCCBOT044.

***Xylaria nigripes*** **(Klotzsch) Cooke, 1883**

The fruiting bodies were found growing singly or in groups, with a stipitate structure that is long, slender, and cylindrical, tapering to a club shape at the top. They can reach heights of 8–13.5 cm, with a diameter of 7–18 mm, and a stipe length of 6–10.5 cm. The surface is initially smoky white to greyish-white but turns black, becoming crackly and scaly with age. The perithecia have a papillate ostiole, and the asci contain eight spores. The ascospores are brown to black, ellipsoid, with rounded ends, smooth, and measure up to 8–11 × 3–5 µm in diameter.

**Specimens examined:** India, Karnataka, Belur, Chikkamagaluru forest area, observed on decayed wood, bark, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 13.162 °N & 75.857 °E, collected on 5 September 2023 by Bharath Kumar S. Acc. no. SJCCBOT048.

***Xylaria polymorpha*** **(Pers.) Grev., 1824**

The fruiting bodies are finger-like in structure, dark brown in colour, and found near decaying trees. Though appearing terrestrial, they are actually attached to buried wood and grow in groups. Fruiting body is generally club-shaped with blunt, narrowed, whitish to black tips, pale grey to dark black, finely dusted, smooth, and dry. The interior surface is white and tough. At maturity, the fruiting body remains club-shaped, swollen from top to bottom, with a finely wrinkled surface, and can measure up to 4.5–8 × 0.5–1.4 cm in size. The perithecia are black, sub-spherical, measuring up to 0.4–1.2 mm in diameter. The asci are arranged in a single layer just below the surface and are long, cylindrical, and stipitate. The ascospores are purple to brown in color, smooth, and slightly bean-shaped to double-shaped, measuring

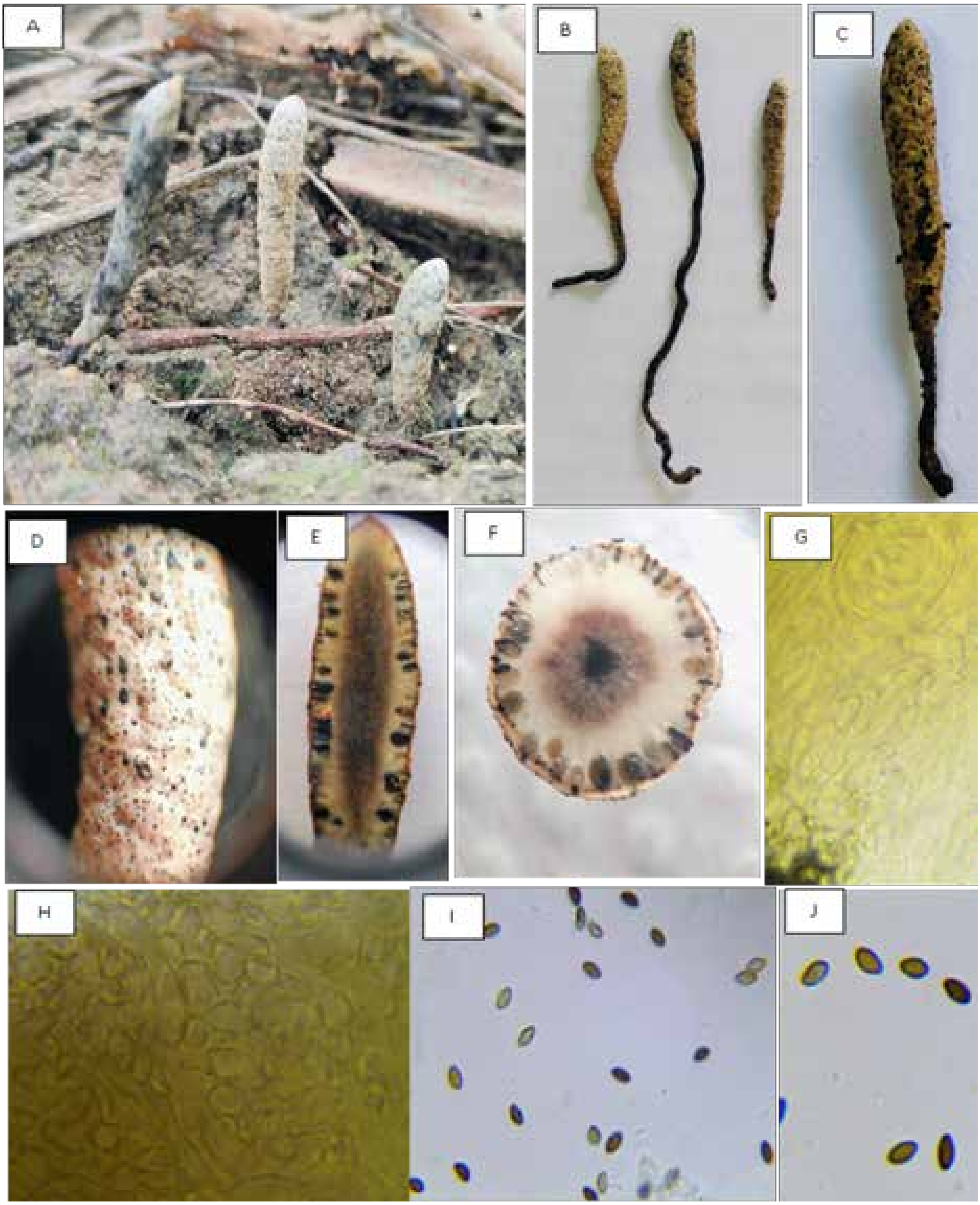


**Image 6. *Xylaria kegeliana*: A—fruiting body attached to the host | B—individual fruiting body with long wrinkled stipe | C—mature fruiting body | D—fruiting body showing black dots | E—longitudinal section showing perithecia (10X) | F—Perithecia | G& H—internal tissue (40X) | H–J—different size and shape of spores (100X). © Bharath Kumar S.**

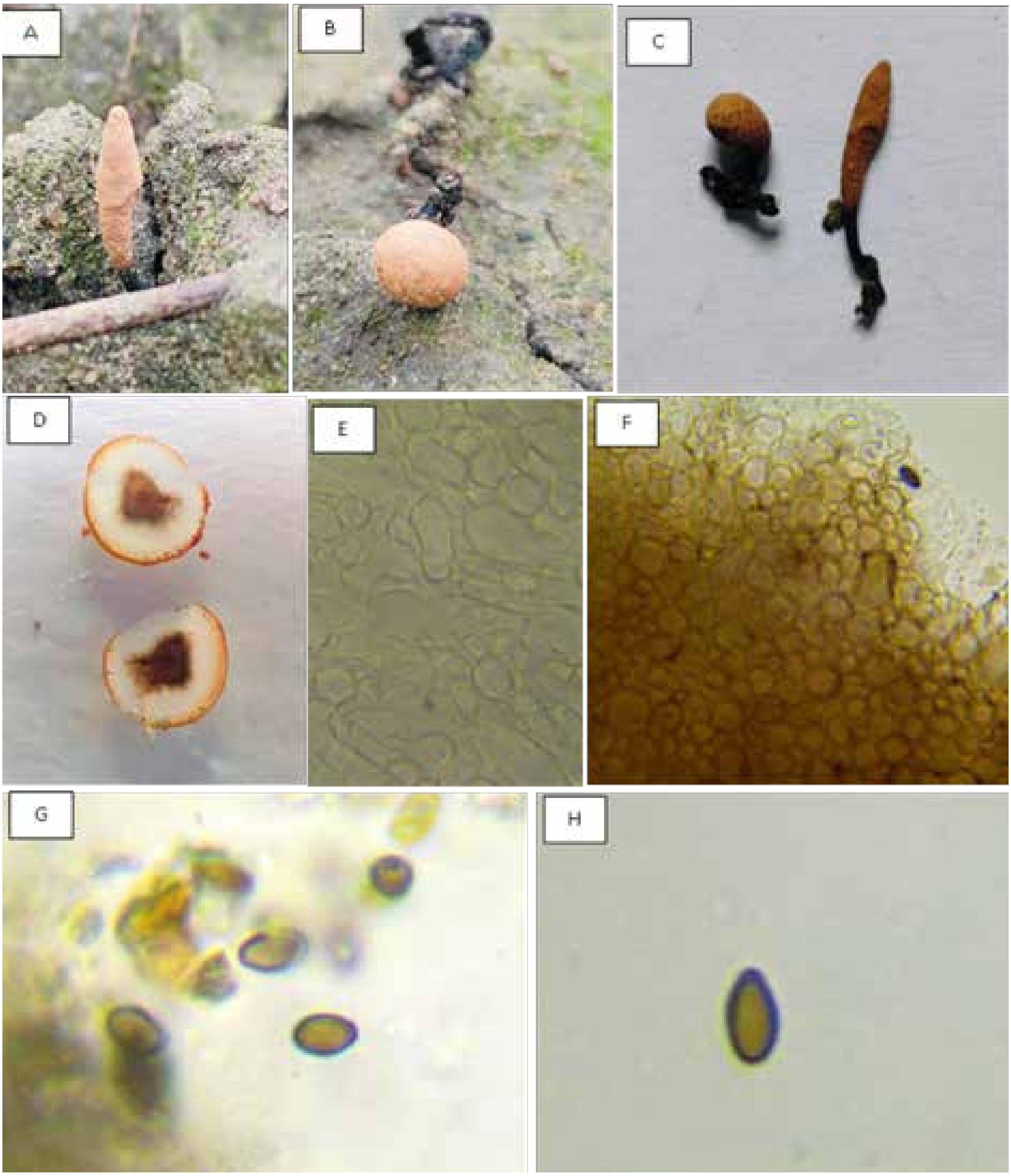


**Image 7. *Xylaria telifairii*: A &B—fruiting body attached to the host | C—individual fruiting body | D—Perithecia (10X) | E & F—internal tissue (40X) | G&H—different sizes and shapes of spores (100X). © Bharath Kumar S.**

10.5–14.8 × 2.8–4.2 µm in diameter.

**Specimens examined:** India, Karnataka, Moodigere, Chikkamagaluru, forest area, observed on decayed wood of a Silver Oak tree near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 14.354 °N & 75.467 °E, collected on 5 September 2023 by Bharath Kumar S. Acc. no. SJCCBOT049.

***Xylaria telfairii* (Berk.) Sacc., 1882 (Image 7)**

Fertile fruiting body is cylindrical with rounded apices, unbranched, solitary, measuring about 2.4–3.5 cm in total length and 0.9–1.4 cm thick. Stipe is black in colour, measuring up to 1.3 cm in length. External surface copper to cinnamon brown in colour, smooth, internally white to cream in colour and hollow. Perithecia are completely immersed. Asci eight-spored, cylindrical, stipitate, urn-shaped, measuring up to 3–4.5 µm. Ascospores are ellipsoid, equilateral, dark brown in colour, unicellular, smooth, measuring up to 17–23 × 5–6 µm.

**Specimens examined:** India, Karnataka, Bannerugatta, Bengaluru, forest area, observed on soil surface, leaf litter, decayed twigs, leaf litter, and stumps near humus-rich soil, heavily covered with decaying leaf litter. Coordinates: 12.947 °N & 77.585 °E, collected on 3 September 2023 by Bharath Kumar S. Acc. no. SJCCBOT053.

## DISCUSSION

The present study explores the morphological diversity of *Daldinia* and *Xylaria* species collected from various forested regions of Karnataka, India. The detailed examination of their macroscopic and microscopic characteristics offers valuable insights into their taxonomy and habitat preferences. A total of 24 species of *Xylaria* have been previously reported from the Western Ghats and the west coast regions of Maharashtra, Karnataka, Kerala, and Tamil Nadu (Karun & Sridhar 2015). In the current study, 12 species of *Xylaria* have been identified from Chikkamagaluru, Shivamugga, Davanagere, Kodugu, and Bengaluru. *Xylaria longipes* and *X. polymorpha* have been reported to grow on dead logs/stubs (Karun & Sridhar 2015). In the present compilation, *X. longipes* was found on the bark of the *Neltuma juliflora* tree, whereas *X. polymorpha* was found in association with a living Tamarind tree. *X. carpophila* has been documented from humus-rich soil and leaf litter in the Panchmahal district of Gujarat (Koyani et al. 2016). In our study, *X. carpophila* was collected from dead and decaying wood of the silver oak tree in Shivamugga District, Karnataka. Species such as *X. telfairii* and *Xylaria ellisii* were frequently found on heavily decomposed material, highlighting their role as key decomposers in forest ecosystems. Meanwhile, *X. apiculata* and *X. frustulosa* were observed on the bark of both living and decaying trees, suggesting possible host specificity, as noted in the previous studies (Stadler et al. 2013). In the present study, *X. apiculata* was found on the bark of mahogany trees, decayed stumps, *X. frustulosa* on decayed wood and bark of *Albizia saman, X. telfairii,* and *X. ellisii* on the soil surface, leaf litter, and decayed twigs, indicating their adaptability to diverse substrates. *Xylaria castorea* was originally described from New Zealand (Berk. 1855). This study marks the first report of *X. castorea* from Karnataka, India. *X. cornu-damae* found on coarse woody debris from National Military Park and Devil's Den State Park, northwestern Arkansas, Saudi Arabia (Alshammari & Stephenson 2018). In this present study, *X. cornu-damae* was found on decayed wood of *Albizia saman*, *Ficus religiosa* stump, Shivamugga, a patch of Western Ghats, Karnataka, India.

*Daldania concentrica* and *D. childiae* were found on dead wood of *Enterlobium saman* from Kondapalli forest, Andhra Pradesh, Eastern Ghat, India (Srinivasarao & Nagadesi 2021). In this study, the presence of *D. concentrica* and *D. childiae* was found on dead and decayed wood of the *Eucalyptus* tree in Bannerugatta Biological Park, Bengaluru, Karnataka, India. *Daldania concentrica* and *D. eschscholtzii* were reported by Rajput et al. (2015), while *D. childiae* was first described from Gujarat (Koyani et al. 2016) and later from the Darapalli and Kondapalli Reserve forests of the Eastern Ghats in Andhra Pradesh (Srinivasarao & Nagadesi 2021). In this study, *D. childiae* is reported for the first time from Karnataka, India. Overall, this research enhances our understanding of *Xylariaceae* diversity in India, emphasising the need for continued documentation of Xylariaceous fungi across various forest ecosystems. Future molecular studies could further validate species identities and offer deeper insights into their phylogenetic relationships and ecological functions.

## CONCLUSION

In conclusion, the survey of the family Xylariaceae conducted across Karnataka from June 2023 to August 2024 has significantly expanded the understanding of the biodiversity and taxonomic importance of this group. Out of 144 collected fungal samples, 16 were identified based on morphology, which included three species of the genus *Daldinia*, 12 species of *Xylaria*, and one species of *Sphaeria,* demonstrating the diversity of this group in the region. The discovery of *D. childiae, X. curta*, *X. ellisii*, *X. frustulosa*, *and S. kegeliana is reported for the first time in Karnataka, whereas X. telfairii and X. cornu-damae constitute new records for India, highlighting* the distribution and diversity of this region. These findings not only enrich the taxonomic knowledge of the Xylariaceae but also open up possibilities for future studies on the bioactive compounds and medicinal properties associated with these fungi.

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ARTICLE



# Identification of wildlife crime hotspots in Punjab, India via kernel density estimation analysis

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**Abstract:** Punjab is a predominantly agrarian state and among the least forested in India. It remains underrepresented in w ildlife crime research. This study documents thirty-two wildlife crime incidents affecting thousands of wild animals compiled from media sources and official enforcement and organisational records between 2019 and 2024. Several of the affected species are listed under Schedule I of the Wildlife (Protection) Act, 1972 (amended in 2022). Recorded crimes involved leopards, tigers, sambars, wild boar, Tibetan antelopes, freshwater turtles, and marine species. Exploitation methods included the use of firearms, trained dogs, snares, illegal trade, and smuggling of wildlife derivatives such as Shahtoosh shawls, corals, and lizard oil. Kernel Density Estimation analysis identified extreme-intensity hotspots (Class 5) covering approximately 509 km² (~1.0% of the state's geographical area), while areas classified under Classes 2–5 collectively covered approximately 30% of the state area.

**Keywords:** Crime spatial analysis, derivatives trade, exploitation, illegal hunting, illegal wildlife trade, illicit supply chains, landscape metrics, spatial analysis, smuggling routes, transnational organised crime, wildlife trafficking, wildlife seizures.

Hindi: पंजाब मुख्य रूप से एक कृषि प्रधान राज्य है और भारत के सबसे कम वन क्षेत्र वाले राज्यों में से एक है। यह वन्यजीव अपराध संबंधी अध्ययनों में अब तक कम प्रतिनिधित्व वाला क्षेत्र रहा है।. इस अध्ययन में 2019 से 2024 के दौरान मीडिया स्रोतों, आधिकारिक प्रवर्तन अभिलेखों तथा संस्थागत रिकॉर्ड से संकलित वन्यजीव अपराध की 32 घटनाओं का दस्तावेजीकरण किया गया है, जिनका प्रभाव हजारों जंगली जानवरों पर पड़ा।. प्रभावित प्रजातियों में से कई को वन्यजीव (संरक्षण) अधिनियम, 1972 (2022 में संशोधित) की अनुसूची-I के अंतर्गत सूचीबद्ध किया गया है। दर्ज अपराधों में तेंदुआ, बाघ, सांभर, जंगली सूअर, तिब्बती मृग, मीठे पानी के कछुए तथा समुद्री प्रजातियाँ शामिल थीं।. शोषण के तरीकों में बंदूकों का उपयोग, प्रशिक्षित शिकारी कुत्ते, फंदे, अवैध व्यापार तथा शहतूश शॉल, मूंगा (कोरल) और छिपकली के तेल जैसी वन्यजीव उत्पादों की तस्करी शामिल थी।. कर्नेल डेंसिटी एस्टिमेशन (KDE) विश्लेषण ने अत्यधिक तीव्रता वाले हॉटस्पॉट (क्लास 5) की पहचान की, जो लगभग 509 वर्ग किमी (राज्य के कुल क्षेत्रफल का ~1.0%) में फैले हुए हैं, जबकि लगभग 30% राज्य क्षेत्र क्लास 2–5 के अंतर्गत आता है।

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**Author contributions:** NS: Conceptualization, data collection, analysis, interpretation of results and manuscript preparation. RK: Technical and methodological support and manuscript enhancement.

## INTRODUCTION

Wildlife crime involves a diverse array of actors, species, and commodities driven by multiple factors; its impacts vary across environmental, social, economic, and governance dimensions (United Nations Office on Drugs and Crime 2024). This is a fast-growing industry (Gore et al. 2019; Hughes 2021) operated covertly by the offenders using corrupted channels (Milner-Gulland & Leader-Williams 2019; 't Sas-Rolfes et al. 2019), therefore, reliable information on species involved is difficult to obtain. Wildlife exploitation affects thousands of species across terrestrial and marine taxa (Milner-Gulland 2018; Fukushima et al. 2020), and illegal wildlife trade is described as the fourth largest transnational illicit trade after narcotics, arms and human trafficking (Warchol 2003; Zimmerman 2003; South & Wyatt 2011; 't Sas-Rolfes et al. 2019). It poses a significant threat to biodiversity (Rivalan et al. 2007; Veríssimo & Wan 2019; Hinsley et al. 2023) and is considered one of the world's most profitable illicit trade sectors by the International Criminal Police Organization (INTERPOL) (Masterson 2023).

Researchers frequently rely on indirect evidence, such as media-reported incidents or seizure records, to infer patterns of illegal hunting, trade, and trafficking (Rosen & Smith 2010; Athreya et al. 2015). This evidence can have biases, making it hard to discern trends across countries with varying reporting capacities (Underwood et al. 2013). Less charismatic species are often underrepresented, while species of high public interest dominate reports (Chawla et al. 2020). In India, substantial illegal trade involves common or widely distributed species harvested for wild meat, traditional medicine, religious rituals and the exotic-pet market, yet these species receive comparatively little scientific attention (Rana & Kumar 2023). Media-based studies, therefore, provide a valuable tool for documenting overlooked wildlife-crime patterns, as demonstrated for jackals (Chawla et al. 2020), leopards (Athreya et al. 2015), and other carnivores in human-modified landscapes (Akash et al. 2025).

Velho et al. (2012) conducted a comprehensive review in India and reported an absence of documented hunting, poaching, bushmeat, or wildlife trade crimes in Punjab at that time, highlighting a critical data gap. Chawla et al. (2020) later documented a single wildlife crime incident in Punjab involving jackals in 2018. A decadal shift, however, reveals the emergence of multiple wildlife crime records, indicating a substantial increase in both occurrence and reporting. The present study, which compiles data from 2019–2024, shows that even a relatively modest dataset of 32 reported incidents corresponds to several thousands of wild animals being affected. These findings underscore the tip-of-the-iceberg nature of the documented cases (United Nations Office on Drugs and Crime 2016), as many incidents likely remain unreported, reflecting a far more extensive and complex reality of wildlife crime.

Following established media-report based research (Athreya et al. 2015; Chawla et al. 2020; Akash et al. 2025), this study compiles reported wildlife-crime incidents from 2019–2024 and uses kernel density estimation (KDE) to quantify crime areas of the state, providing the first systematic overview for Punjab. Globally, geospatial analysis and KDE have been widely applied in wildlife research (Hart & Zandbergen 2014; Fleming et al. 2015; Chamling & Bera 2020; Gore et al. 2022; Graves et al. 2022; Sood et al. 2025) and were employed in the present study to identify spatial patterns of hotspot mapping and quantification of areas most affected by illegal wildlife activities.

### Study Area

The study area (Figure 1) is an agrarian state located in Punjab, northwestern India. It has a forest cover of < 3.6% of its geographical area, of which 0.02% is very dense forest (Forest Survey of India 2023). The state's fertile plains are connected to the biodiverse Shivalik Range. The western boundary of Punjab is constrained by a fully fenced international border with Pakistan which restricts wildlife movement. There are several Ramsar-designated wetlands that serve as critical wintering and staging grounds for migratory waterbirds and as important habitats for resident waterbird assemblages (Delany et al. 2006). Negligible forest cover, proximity to the hills in the north and the east, presence of wetlands and rivers flowing from the Shivaliks, fertile plains, major urban centres such as Jalandhar, Chandigarh, Ludhiana, and Amritsar scattered across central plains and the fenced border in the west create an environment conducive to the urban wildlife and scope for intense human-wildlife interactions (Sood et al. 2025). The state remains poorly represented in scientific literature on wildlife crime, hence media reports provide an essential information source for documenting such incidents.

## MATERIALS AND METHODS

This study applied a systematic, multilingual media-reports search methodology adapted from Athreya et al. (2015), Chawla et al. (2020) and Akash et al. (2025) to document wildlife-crime incidents in Punjab between March 2019 and July 2024. This period was selected because reliable, continuous, and verifiable wildlife-crime records from Punjab became consistently available from March 2019 onwards, enabling the compilation of a complete dataset without temporal gaps. Data were compiled from authenticated English, Hindi, and Punjabi media reports sourced from major newspapers with robust digital archives (Supplementary Table S1) supplemented by incidents and wildlife derivative seizure records from Punjab extracted from government, reputed non-government organisation and enforcement websites including the Wildlife Crime Control Bureau (WCCB), TRAFFIC India and the Wildlife Trust of India (WTI).

During media data collection, a mixed Boolean OR–AND search strategy was employed, wherein each report was required to contain at least one from the six keywords 'wildlife', 'crime', 'killed', 'poaching', 'smuggling', 'bushmeat', along with the word 'Punjab'. To reduce omission of species not explicitly described under general offence-related terms (e.g., birds, reptiles, turtles), additional searches were conducted using species-specific terms identified during the initial screening process. Additionally, all retrieved reports and records were constrained to fall within the predefined temporal window. Online searches were conducted using Google Search with same keyword combinations in English, Hindi, and Gurmukhi (Punjabi) and conducted in incognito mode to minimize algorithmic personalization bias. Government and organisational sources were used for cross-verification of incidents and confirmation of seizure details and were not treated as independent primary records when corresponding media reports existed. Duplicate entries were consolidated based on matching date, species and locality identifiers to avoid double counting. Most Punjabi-language results were derivative of corresponding English or Hindi reports and did not provide additional primary information on wildlife crime. Only a single relevant, non-duplicated report was identified from Punjabi digital media (News18 Punjab). Data were compiled exclusively for all available

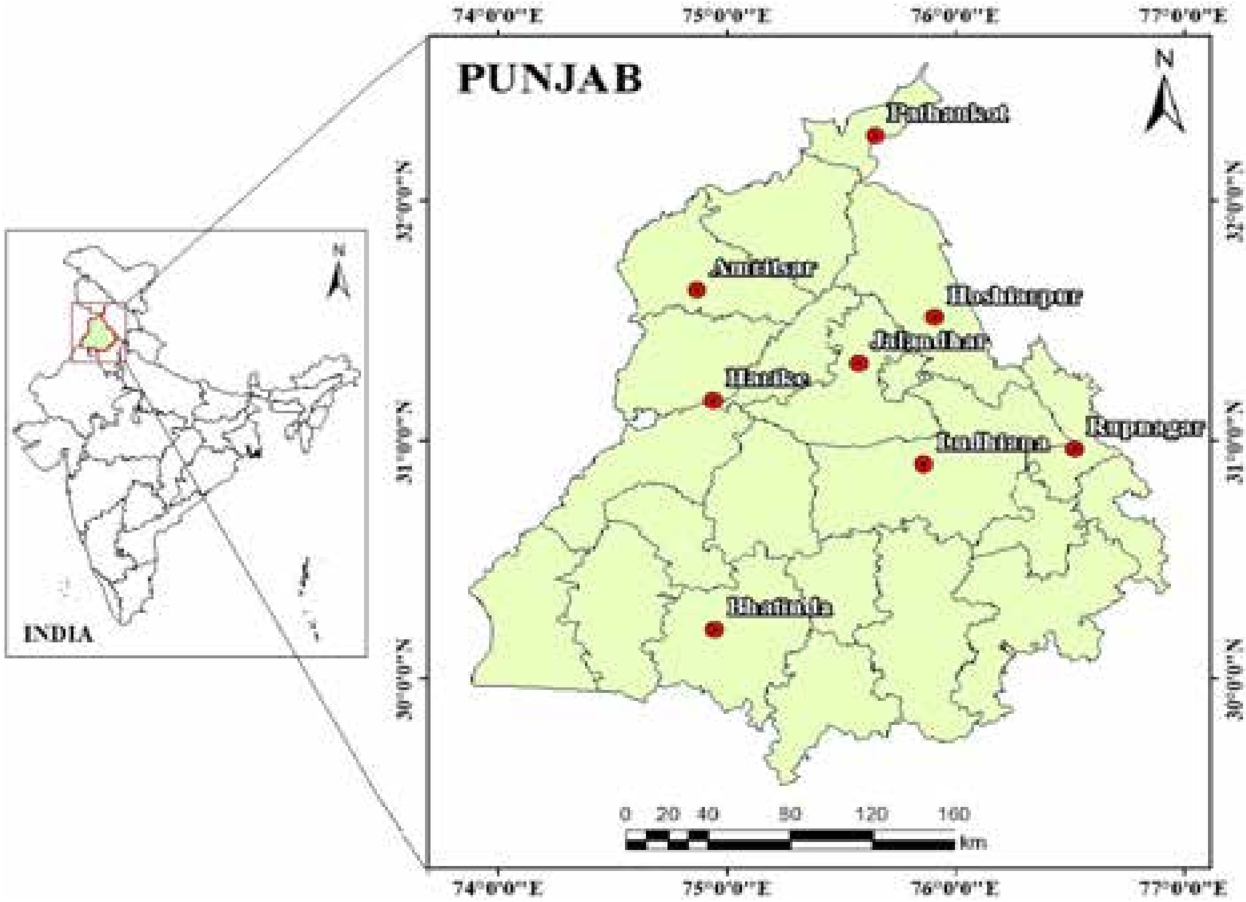


Figure 1. Study area map of Punjab.

wild animal species, with domesticated taxa expressly excluded from the dataset.

A total of 149 data records were retrieved which underwent a rigorous, multi-stage workflow consisting of relevance screening, duplicate consolidation and verification of species identity, locality, offence type and enforcement actions and n = 32 records were selected that fell into specified criteria. Only incidents specifying the location of the crime were retained for spatial analysis. Each validated incident area was georeferenced using latitude and longitude coordinates using Google maps, generating KML/KMZ files to map the points. The spatial data were then projected to UTM Zone 43N with all necessary conversions applied to ensure accurate area calculations.

Each incident was coded using an event-based framework derived from the above studies, species taxonomy, offence typology (poaching, illegal trade, trafficking, possession, conflict-driven killing), modus operandi, seizure characteristics and enforcement responses. Each incident was georeferenced and spatially mapped by assigning it to the smallest clearly identifiable administrative unit reported in the news or record source.

To create spatial map and identify hotspots of wildlife crime, QGIS 3.40, a free and open-source Geographic Information System (GIS) software widely used for spatial analysis and mapping was used. Kernel Density Estimation (KDE) was applied to the georeferenced area points. KDE generates a continuous smooth density surface from discrete point locations, providing a realistic representation of spatial crime concentration patterns (Hart & Zandbergen 2014; Hu et al. 2018) unlike simple point-count methods.

A uniform 30 × 30 m raster grid was generated by clipping to the Punjab administrative boundary to create the analytical background surface. A quadratic kernel function was applied to the incident layer to produce a continuous density raster, which was subsequently classified into five intensity categories using the Natural Breaks (Jenks) algorithm for spatial prioritization. Bandwidth was determined using Silverman's rule of thumb as implemented in QGIS (Silverman 1986).

The cumulative distribution function (CDF), which quantifies the cumulative proportion of KDE (Chen 2017), was calculated as the cumulative proportion of raster cells relative to the total number of cells in the study area, enabling quantitative assessment of spatial concentration of wildlife crime. All calculations and CDF visualisations were completed in Microsoft Excel 365.

This integrated and replicable methodology combines media reported incidents, georeferencing, and spatial analysis to generate the first systematic spatial representation of reported wildlife crime incidents in Punjab.

## RESULTS

A dataset compiled from various sources is presented in Supplementary Table S2, which forms the basis for the analyses presented in this study. Cumulative seizure quantities suggest that the number of wild animals impacted runs into several thousands, highlighting the substantial scale of wildlife crime in the region.

### Kernel Density Estimation of wildlife crime incidents in Punjab

Wildlife crime incidents were mapped using KDE (Figure 2). The KDE output was subsequently classified into five intensity classes to quantify the proportion of area affected under wildlife crime.

The analysis based on raster cells and area coverage (Table 1) revealed that Class 1, depicted as background blue layer, covers 69.3% of the state area and represents no reported incidents across the majority of the state. Class 2, represents crime intensity between low-to-moderate, covers 19.7% of the state area, indicating small concentrations of illegal activity. Class 3, intermediate intensity, covers 7.1% of the total area. Class 4 shows elevated intensity in 2.9% of the state, forming a high-risk zone. Class 5, represents extreme intensity or the core hotspot and includes 508.9 km² (1.0% of the total state

**Table 1. Spatial distribution and priority ranking of kernel density estimation classes for wildlife-crime hotspots in Punjab.**

| KDE Class | Hotspot Priority | Area (km²) | % of state area | Raster cell count |
|---|---|---|---|---|
| 5 | Priority 1 (Extreme hotspot) | 508.9 | 1.0% | 565,488 |
| 4 | Priority 2 (High intensity) | 1,465.8 | 2.9% | 1,628,640 |
| 3 | Priority 3 (Moderate intensity) | 3,575.1 | 7.1% | 3,972,372 |
| 2 | Priority 4 (Low–moderate intensity) | 9,908.4 | 19.7% | 11,009,378 |
| 1 | Priority 5 (Background / no incidents) | 34,878.2 | 69.3% | 38,753,577 |

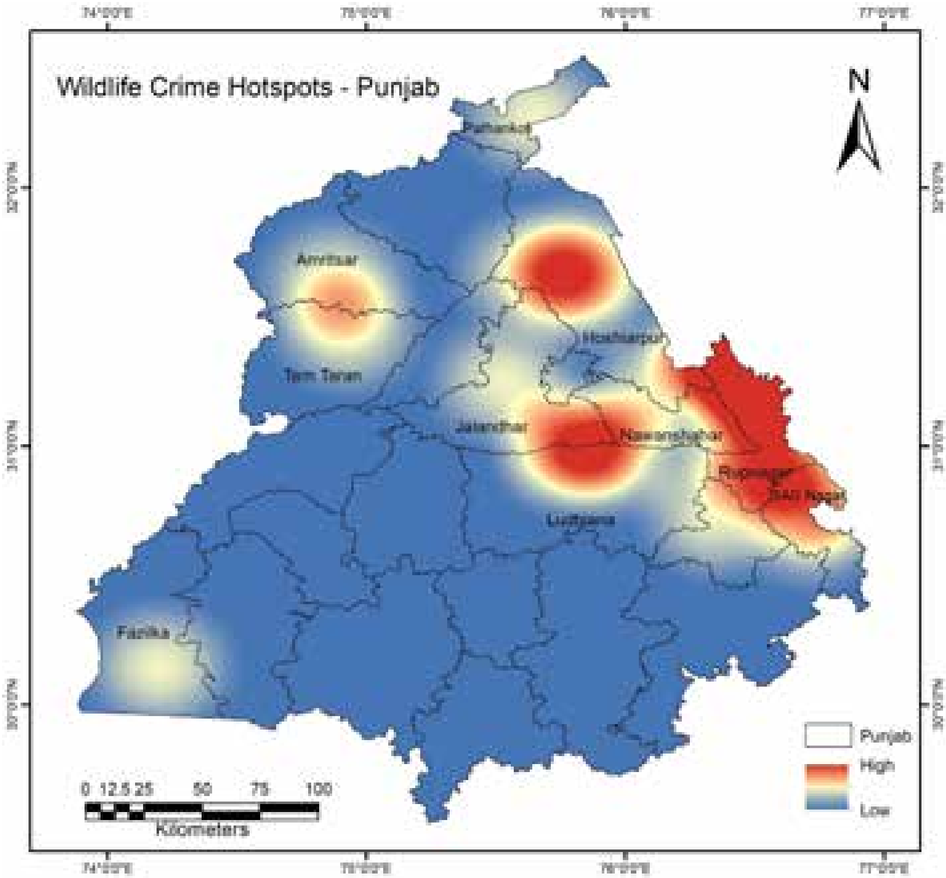


Figure 2. Kernel density estimation (KDE) map showing spatial clustering of reported wildlife crime incidents across Punjab (2019–2024).

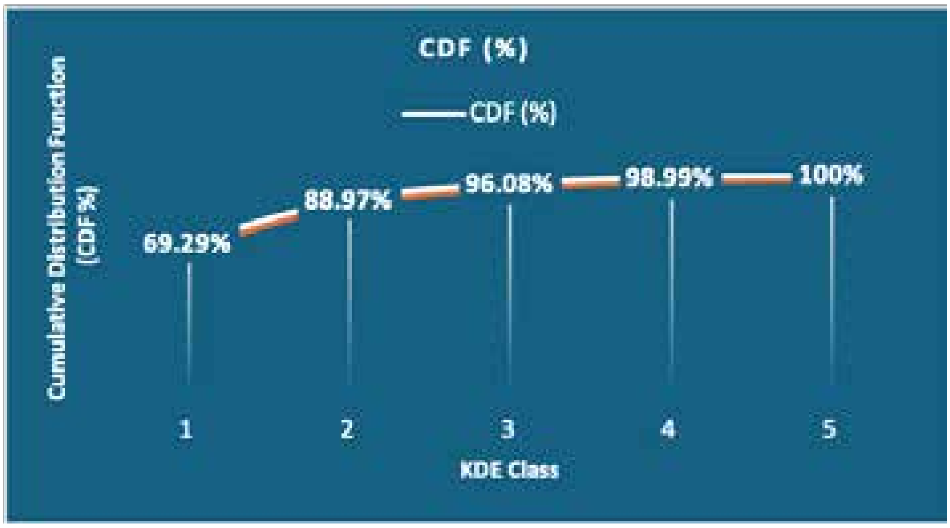


Figure 3. Cumulative distribution function of state area across wildlife-crime KDE classes.

area). Class 5 highlights areas of concentrated illegal wildlife activity.

The cumulative distribution function (CDF) (Figure 3) from KDE illustrates that a small fraction of cells (Classes 3–5, ~11.0% of total) accounts for the highest intensity zones, demonstrating that wildlife-crime is not uniformly distributed but highly clustered with pronounced hotspots. The KDE map shows these near the Shivalik foothills and within the districts of Amritsar, Jalandhar, Rupnagar, Hoshiarpur, Ludhiana, Pathankot, SAS Nagar, and Fazilka. These results emphasize a multi-scalar hierarchy of risk, from extensive low-intensity backgrounds to compact but critically significant extreme hotspots.

## DISCUSSION

This study presents a spatial analysis of reported wildlife crime incidents in Punjab between 2019 and 2024. Velho et al. (2012) reported an absence of wildlife crime data from Punjab, and Chawla et al. (2020) later identified only a single incident. The present analysis documents thirty-two incidents affecting multiple taxa, indicating that wildlife crime in Punjab is more diverse and spatially structured than previously recognized. Use of firearms, clutch-wire snares, trained hunting dogs, nets, and vehicles suggests a combination of opportunistic hunting and organized trafficking operations. The seizures of marine derivatives and tiger cubs supports the existence of structured supply chains.

KDE indicated that incidents were not evenly spread across Punjab. The quantified areas in the highest intensity class cover about 1% of the state (~509 km²). Classes of moderate to high intensity together account for nearly one-third of the total area. Higher densities were observed near the Shivalik foothills and within few districts only. These patterns suggest that ecological edges and transport connectivity may be associated with the observed clustering. The findings create a measurable spatial concentration of reported offences in a low-forest agrarian state. Although reporting bias cannot be excluded, the presence of high-intensity clusters suggests persistent localized activity.

### Species Affected

Incidents involving leopards *Panthera pardus* included gunshot fatalities, limb mutilation (claw removal), snare capture and the killing of a 6–8 month old cub displaying gunshot wounds and bite marks with pursuit by hunting dogs. Two incidents involved the recovery of tiger *Panthera tigris* derivatives (skin and skeleton), and one documented a trafficked tiger cub in Punjab, a tiger's non-range state (Image 1). Tiger is classified as 'Endangered' (EN) under the IUCN Red List of Threatened Species (IUCN) and is listed in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I, which prohibits trade internationally. Firearms, trained dogs and metal snares correspond with established methods used against large carnivores in India and globally (Zielinski et al. 2006; Becker et al. 2013).

Ungulates such as Sambar *Rusa unicolor* featured repeatedly, including cases of firearm injury, limb removal, antler possession/trade and raw meat seizure. Barking Deer *Muntiacus muntjak* was also affected. These patterns mirror ungulate poaching elsewhere in India (Rana & Kumar 2023).

Wild Boar *Sus scrofa* was the most frequently recorded species. Incidents involved mass live capture, transport, meat extraction and mortality during illicit movement (e.g., 127 individuals: 32 dead, 95 rescued) possibly for meat (Ingram et al. 2021). Studies show that wild meat is exchanged through complex commercial networks involving multiple stages in the supply chain (Bennett et al. 2007), the trade of wild meat contributes significantly to species extinction (Ripple et al. 2016).

Seizures included marine items such as 69 gorgonian sea fans, 1.4 kg organ pipe coral, and 4.8 kg coral fragments, as well as 38 containers of bear bile, 137 'Hatha Jodi' items, Indian Spiny-tailed Lizard *Saara hardwickii* oil, and exotic parrots (Macaws). Hatha Jodi refers to the dried hemipenes of Indian monitor lizards (Bhattacharya & Koch 2018), specifically the Bengal Monitor *Varanus bengalensis* and Yellow Monitor *Varanus flavescens*. Under Wildlife (Protection) Act, 1972 (amended in 2022) and international regulations (CITES Appendices 2017), the penalties for killing these lizards or trading their body parts are comparable to those for tiger (D'Cruze et al. 2018). The seizure of marine taxa from inland Punjab is concerning, indicating long-distance trafficking networks and highly organised supply chains.

**Image 1. Screenshot from a News18 Punjab report showing a recovered tiger cub involved in illegal wildlife trade. Credit: News18 Punjab.**

Seizure of 210 Shahtoosh shawls implied the killing of over several hundred of Tibetan Antelopes. Shahtoosh trade is a derivative form of wildlife trade in which Tibetan Antelope *Pantholops hodgsonii*, locally called Chiru, are killed for their fine underfur, known as shahtoosh (Mallon & Jiang 2009). An estimated four Tibetan Antelopes are killed for every shahtoosh scarf, so 210 shawls represent roughly 840 animals (Gibbens 2019).

Parrots, peacocks, pheasants, raptors, and freshwater turtles were affected through poaching, illegal possession and trade. Birds are illegally traded all over the world (Matias et al. 2012; Alves et al. 2013; Rodewald et al. 2024) and studies make alarming claims that trade networks focused in Southeast Asia harvested nine million turtles (Miller et al. 2019)

### Crime Methods and Trafficking Patterns

Crimes included firearms, shotguns, trained dogs, nets, clutch-wire snares, metal traps, daggers and transport vehicles indicate organised poaching networks. Clutch-wire snares used as efficient killing devices (Haq et al. 2023) were repeatedly recorded, reflecting opportunistic and targeted poaching. Several incidents involved transportation of wildlife or their derivatives. Tiger derivatives were transported by Punjab residents to southern India, wild boar were trafficked across state borders and marine wildlife derivatives were seized in Amritsar, a known transit hub for illegal wildlife trade (Wildlife Trust of India 2024). Shahtoosh shawls were moved through Amritsar and Pathankot. Attari, near Amritsar, Punjab, serves as a key land route for the illegal smuggling of wildlife products internationally (Pragatheesh et al. 2022).

### Spatial Distribution of Incidents

Wildlife-crime incidents were concentrated in Shivalik-adjacent areas and within districts of Amritsar, Jalandhar, Rupnagar, Hoshiarpur, Ludhiana, Pathankot, SAS Nagar, and Tarn Taran. However, further field-based validation would be required to confirm causal drivers.

### Limitations and Future Directions

This analysis is based on media reports and organizational records and is therefore subject to reporting and detection bias. Charismatic species may have received disproportionate media attention. The dataset reflects only reported incidents rather than true prevalence. Spatial analysis was limited to georeferenced cases only. Therefore, the results should be interpreted as a spatial baseline of reported wildlife crime rather than a comprehensive estimate of total occurrence.

## CONCLUSION

This study presents the first geospatial assessment of reported wildlife crime incidents in Punjab between 2019 and 2024. Despite being predominantly agrarian with limited forest cover, the state exhibits measurable spatial clustering of wildlife crime, with extreme-intensity hotspots occupying approximately 1% of the geographical area. While the dataset likely represents only a subset of total occurrences, the findings establish a quantitative spatial baseline that may inform targeted monitoring, enforcement prioritization, and future research.

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**Supplementary Table S1. Media and institutional sources used for data compilation.**

| Media / Institutional Source | Website |
|---|---|
| The Tribune | https://www.tribuneindia.com |
| Hindustan Times | https://www.hindustantimes.com |
| The Indian Express | https://indianexpress.com |
| The Times of India | https://timesofindia.indiatimes.com |
| Deccan Herald | https://www.deccanherald.com |
| Wildlife Trust of India (WTI) | https://www.wti.org.in |
| News18 Punjab (Video report) | https://www.youtube.com/watch?v=8JaPJmjsPtg&t=374s |
| Wildlife Crime Control Bureau (WCCB) Newsletter (Oct–Dec 2023, Issue 12) | https://wccb.gov.in/Content/Newsletter.aspx |
| TRAFFIC India | https://www.traffic.org |
| The Hindu | https://www.thehindu.com |
| Dainik Jagran | https://www.jagran.com |
| Dainik Bhaskar | https://www.bhaskar.com |
| The Tribune | https://www.tribuneindia.com |

**Supplementary Table S2. Documented wildlife crime incidents in Punjab (2019–2024).**

| | Date | Species | Incident Data – Remarks | Village/ City/ District in Punjab | Web Link |
|---|---|---|---|---|---|
| 1 | 23-iii-2019 | Sambar | Poaching, meat | Mullanpur Chandigarh | https://www.tribuneindia.com/news/archive/chandigarh/sambar-poaching-puts-wildlife-dept-on-alert-746838/ |
| 2 | 16-iv-2019 | Turtles | 11 numbers, Schedule 1 at par with Tigers, Lions | Chandigarh Colony Tanda Hoshiarpur | https://timesofindia.indiatimes.com/city/chandigarh/rare-turtle-seizure-adds-twist-to-poll-liquor-raid/articleshow/68897176.cms |
| 3 | 17-xi-2019 | Sambar | Skull found, Illegal trade of body parts | Village Purkhakhli Ropar | https://www.jagran.com/punjab/ropar-wild-life-department-recover-nine-horn-roopnagar-18649345.html |
| 4 | 27-xii-2019 | Sambar | Leg missing, bullet | Mand Chaunta Mattewara Ludhiana | https://indianexpress.com/article/india/ludhiana-another-sambar-deer-found-dead-this-time-without-limb-6187520/ |
| 5 | 12-ii-2021 | Sambar | Shot by poachers | NFL Nangal | https://www.tribuneindia.com/news/punjab/sambar-found-dead-in-nangal-dam-reservoir-469598 |
| 6 | 08-vii-2022 | Indian Spiny Tail Lizard | Oil smuggled to Punjab | Punjab | https://www.traffic.org/publications/reports/factsheet-on-indian-spiny-tailed-lizard-in-illegal-wildlife-trade/ |
| 7 | 08-vii-2022 | Tiger Peacock Hawk Turtles Macaw | Racket poaching | Kishangarh Jalandhar Phillaur | Punjab News18 https://www.youtube.com/watch?v=8JaPJmjsPtg&t=374s |
| 8 | 15-xi-2022 | Wild Boar | 60 numbers | Dholewal Ludhiana | https://www.hindustantimes.com/cities/chandigarh-news/ludhiana-resident-booked-for-possession-sale-of-wild-boars-101668462449940.html |
| 9 | 16-xi-2022 | Wild Boar | Meat, dagger, net | Village Thathalan | https://www.tribuneindia.com/news/jalandhar/4-poachers-held-for-hunting-wild-boar-451462 |
| 10 | 03-xii-2022 | Sambar | Poaching, meat, weapons seized, 3 held | Village Sekhowal | https://www.tribuneindia.com/news/jalandhar/3-held-for-poaching-deer-weapons-seized-457151 |
| 11 | 15-xii-2022 | Wild Boar | 49 Alive, 6 Dead | Ludhiana | https://www.hindustantimes.com/cities/chandigarh-news/ludhiana-forest-department-bust-racket-involved-in-smuggling-wild-boars-101671127724727.html |
| 12 | 29-xii-2022 | Leopard cub 6–8 months | Gunshot wounds Ear chewed up confirming use of trained hunting dogs Mother, sibling missing | Nikku Nangal village | https://timesofindia.indiatimes.com/city/chandigarh/poachers-butcher-leopard-cub-in-punjab-mom-feared-dead/articleshow/96583497.cms |

| | Date | Species | Incident Data – Remarks | Village/ City/ District in Punjab | Web Link |
|---|---|---|---|---|---|
| 13 | 02-i-23 | Leopard | 5-yr old brutally gunned down<br>shotgun<br>Foreleg claw missing | Bala Chaur Anandpur Road | https://timesofindia.indiatimes.com/city/chandigarh/punjab-poachers-gun-down-dump-2nd-leopard-in-a-week/articleshow/96697278.cms |
| 14 | 09-i-2023 | Sambar | Antlers and uncooked meat | Ropar | https://www.tribuneindia.com/news/punjab/three-arrested-sambar-meat-seized-in-ropar-468686 |
| 15 | 14-i-23 | Barking Deer<br>Wild Boar | Firearms, VIPs involved | Ropar | https://indianexpress.com/article/cities/chandigarh/son-of-former-punjab-psc-member-3-others-held-for-poaching-8381506/ |
| 16 | 14-i-23 | Leopard | 2 numbers, hunters, bullets | Sabore, Nurpur Bedi | https://www.bhaskar.com/local/punjab/ropar/anandpur-sahib/news/fearless-poachers-hunted-two-leopards-in-a-week-post-mortem-of-leopard-found-in-village-sabor-130752745.html |
| 17 | 14-i-23 | Leopard | Feared dead | Nikku Nangal | https://timesofindia.indiatimes.com/city/chandigarh/poachers-butcher-leopard-cub-in-punjab-mom-feared-dead/articleshow/96583497.cms |
| 18 | 22-ii-2023 | Tiger skin and skeletons and another carnivore | People from Punjab, selling at Sathyamangalam | Arrested in Nilgiris-Accused from Punjab (This record was excluded from KDE analysis) | https://www.thehindu.com/news/national/tamil-nadu/poachers-from-north-india-who-hunted-tiger-in-nilgiris-brought-to-district-for-investigations/article66537066.ece |
| 19 | 12-ii-2023 | Female Leopard | Entangled in clutch-wire snare | Anandpur Sahib | https://www.tribuneindia.com/news/punjab/leopard-trapped-by-poachers-rescued-479171 |
| 20 | 06-iii-2023 | Video | Poachers have free run, weapons, dogs | Village Dhalan Ropar | https://www.tribuneindia.com/news/punjab/jalandhar-poachers-have-free-run-485557 |
| 21 | 29-iv-2023 | Wild Parrots | 3 nabbed | Malukpura Canal Abohar | https://www.tribuneindia.com/news/punjab/3-poachers-nabbed-502890 |
| 22 | 12-v-23 | Tibetan Antelope | 210 numbers,<br>joint operation by the Wildlife Crime Control Bureau (WCCB) and the Punjab Forest Department<br>(1,400+ animals killed for 350+ Shawls) | Amritsar, Pathankot | https://www.wti.org.in/news/the-resurgence-of-the-shahtoosh-350-high-value-shawls-seized-from-northern-india/ |
| 23 | 01-vii-2023 | Wild Boar | 127 numbers 32 dead, 95 rescued | Neelon<br>Ludhiana | https://indianexpress.com/article/cities/chandigarh/wild-boars-suffocate-to-death-animal-cruelty-ludhiana-police-rescue-operation-8695158/#:~:text=Animals%20were%20being%20smuggled%20into,accused%20arrested%2C%20released%20on%20bail.&text=Thirty%2Dtwo%20wild%20boars%20died,from%20Rajasthan%2C%20police%20Friday%20said |
| 24 | 06-vii-2024 | Pheasants | Shot, two arrested | Abohar | https://www.hindustantimes.com/cities/chandigarh-news/fatherson-duo-arrested-for-unlawful-killing-of-pheasants-in-abohar-wildlife-officials-take-action-101688660563015.html |
| 25 | 01-ix-2023 | Leopard | Carcass | Khad Bathlor | https://www.tribuneindia.com/news/punjab/leopard-found-dead-on-ropar-nurpur-bedi-road-in-punjab-540335 |
| 26 | 03-xii-2023 | Leopard | Carcass,<br>clutch wire | Majhot<br>Balachaur | https://www.hindustantimes.com/cities/chandigarh-news/wilbuzz-nobody-killed-the-leopard-101701549753868.html |
| 27 | 13-ii-2023 | Leopard | Trapped by poachers, rescued | Anandpur Sahib | https://www.tribuneindia.com/news/punjab/leopard-trapped-by-poachers-rescued-479171/ |
| 28 | 26-xii-23 | Deer | 3 booked | Village Hajipur<br>Garshankar<br>Hoshiarpur | https://www.hindustantimes.com/cities/chandigarh-news/three-booked-for-poaching-deer-in-hoshiarpur-101703535641201.html |
| 29 | 22-i-2024 | Poaching and illegal fishing | Threat to migratory birds | Harike<br>Tarn Taran, Ferozepur | https://www.tribuneindia.com/news/punjab/encroachment-illegal-fishing-hit-arrival-of-winged-visitors-at-harike-583430 |
| 30 | 08-v-24 | Wild Boar | 22 numbers<br>and carcass | Village Jagatpura<br>Mohali | https://www.tribuneindia.com/news/chandigarh/21-wild-boars-one-carcass-found-at-jagatpura-shed-619056 |
| 31 | 21-vi-2024 | Wild Boar | Retaliatory actions | Hoshiarpur<br>Dadiana Kalan<br>Kandi<br>Bet<br>Lambran | https://www.tribuneindia.com/news/jalandhar/wild-boar-attack-on-crop-leaves-farmers-worried-632647/ |
| 32 | 05.vii.2024 | 137 hatha Jodi, 38 bear biles, 69 sea fans, 1.4 kg of organ pipe corals and 4.814 kg of gorgonian species corals. | Articles derived from animals listed under Schedule I of the Wildlife (Protection) Act, 1972 | Amritsar | https://www.wti.org.in/news/the-dark-underbelly-of-amritsar-from-sacred-city-to-wildlife-smuggling-hub/ |

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COMMUNICATION



# Assessing nutritional status of Chital *Axis axis* (Erxleben, 1777) (Mammalia: Artiodactyla: Cervidae) through bone marrow condition of predated individuals in Kanha Tiger Reserve, India

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**Abstract:** Monitoring the body condition of ungulates is an important aspect of understanding their ecology as it provides information about habitat conditions, seasonality of nutritional stress, disease susceptibility, and prey selection by predators. Bone marrow condition at death provides a reliable indicator of body condition, as marrow fat is among the last energy reserves to be metabolized. Since big bones are often left intact by predators, the marrow condition of the femur is a standard measure. We examined 52 Chital carcasses from predated events to assess bone marrow condition in Kanha Tiger Reserve and found profound seasonality with monsoon having the poorest bone marrow condition while there were no differences between the body condition of predated male and female Chital.

**Keywords:** Carcass, central India, ecology, poor nutritional health, Satpura Maikal Hills, seasonal nutrition, Spotted Deer, ungulates.

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**Author contributions:** SG conducted the field data collection and, performed the data analysis. SG, UK, and YVJ wrote the manuscript. YVJ conceived, supervised, and procured the resources for the study. All authors approved the manuscript.

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भारतीय वन्यजीव संस्थान
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## INTRODUCTION

The availability of resources directly influences individual health, behaviour, and population-level adaptations (Czyżowski et al. 2020). Assessing wildlife health is therefore critical for conservation, as it provides baseline data for managing ecological threats (Kophamel et al. 2022). A range of quantitative and qualitative methods exist for health assessments, using body condition scores, body mass, antler quality, and fat reserves (Riney 1955; Bonino & Bustos 1998; Majzinger 2004; Stokes et al. 2010). A decline in nutritional intake can result in reduced body condition, lower reproductive rates, disease susceptibility, increased mortality, and ultimately, population declines (Kie et al. 1983; Kie & White 1985).

In wild ungulates, body condition has been closely associated with factors such as nutritional status, health, reproductive success, and population density (Albon et al. 1986; Brunborg et al. 2004; Bender et al. 2008; Couturier et al. 2009; Santos et al. 2013; Risco et al. 2016). As such, monitoring body condition is a crucial component of wildlife management, providing insights into population performance and facilitating early detection of potential ecological imbalances (Morellet et al. 2007; Mattiello et al. 2009).

Various methods have been developed to assess body condition in wild ungulates, primarily by estimating fat reserves. Some of these techniques, such as the kidney fat index (KFI) (Riney 1955) and bone marrow fat content (Fuller et al. 1986) are invasive and applicable only to deceased animals but are extremely reliable. Among these, femur marrow fat (FMF) is particularly useful as it represents one of the last fat reserves to be metabolized, making it a reliable indicator of animals in poor condition (Cheatum 1949; Meyerholtz et al. 2011). The femur marrow fat method described by Cheatum (1949) is cost effective and provides a rapid assessment of nutritional status of the population. Moreover, Mørk et al. (2024) found a relation between the visual score of bone marrow with their fat content where with decreasing score, fat content of bone marrow also decreases.

In cervids, bone marrow fat depletion pattern as an indication of body condition is better documented than the fatty acid composition changes (Sugár & Nagy 1992) in blood. In the Indian subcontinent, Chital is widely distributed and the most abundant cervid which forms the major prey for most of the large carnivores. Ideally, to assess the nutritional health of a population, a random sample of bone marrow should be examined, however, this is not possible within the legal framework of Indian wildlife protection laws (Wildlife protection act 1972). Ambush predators like Tigers *Panthera tigris* and Leopards *Panthera pardus* are less selective of the body condition of their prey (Karanth & Sunquist 1995) compared to cursorial predators like Cheetah *Acinonyx jubatus*, Wolves *Canis lupus*, and Dhole *Cuon alpinus* that chase and test their prey (Hayward et al. 2006; Gable et al. 2021). We collected and examined the femur bone marrow condition of Chital predated by Tigers and Leopards in Kanha Tiger Reserve to assess the feasibility of using bone marrow as a marker to evaluate seasonality and gender differences in the nutritional body condition of the Chital population.

## MATERIALS AND METHODS

### Study area

Kanha Tiger Reserve (KTR), located in the Satpura Maikal Hill Ranges of the central Indian highlands, spans Balaghat and Mandla districts in Madhya Pradesh. Established in 1973 as one of India's first nine tiger reserves, it covers a total area of 2,051.82 km², with a core zone of 917.43 km² and a buffer zone of 1,134.39 km². The reserve features diverse landscapes, including flat hilltops, slopes, and meadows, creating varied habitats for a rich array of flora and fauna.

The tiger reserve is located within the dry deciduous zone, comprising of Sal forests, mixed forests, bamboo forests, and grasslands (Awasthi et al. 2016). Kanha experiences three distinct seasons: summer, monsoon, and winter. Seasonal variations in temperature, humidity, and precipitation influence vegetation and wildlife behaviour.

### Method

Chital carcasses were located opportunistically using predation records generated during routine forest patrol and field monitoring, and the femur bone marrow condition of the carcasses was examined (n = 52; males = 27, females = 25). As carcass detection was not systematic, sampling may be biased towards more detectable kills; however, the same protocol was applied consistently across seasons. Samples of bone marrow were examined only from very fresh kills; as older carcasses tend to dry out under environmental conditions. Marrow with high-fat content appears solid white, whereas low-fat marrow is gelatinous and often translucent to reddish (Cheatum 1949). Solid white marrow indicates good health at the time of death (Jhala 1991; Mørk et al. 2024). Based on consistency, we categorized bone marrow conditions into three groups: good, medium, and poor (Image 1). In each case, we observed the femur bone marrow and recorded the animal's gender and the date of death to assess the potential effects of gender and season. Exploratory analysis and Fisher's exact test (Zar 1999) were conducted to examine and assess the statistical significance of the effect of gender and seasonal health status of predated Chital. Since these data are count data, the significance level can be tested either using chi-square test or Fisher's exact test. Since our sample size was zero in some categories, we used Fisher's exact test with Monte Carlo approximation to compute significance.

## RESULTS

Overall the bone marrow of 40.38% of the chital was in good condition, 46.15% was in medium condition, and 13.47% was in poor condition (Table 1; Figure 1). We found no significance difference between the bone marrow condition of predated males and females (Fisher's Exact Test, P = 0.56). Bone marrow condition differed across seasons (Fisher's Exact Test, P = 0.05; Table 1), indicating a borderline but biologically meaningful seasonal pattern.

## DISCUSSION

Our findings indicate that visual inspection of femur bone marrow in predated Chital can be a useful tool for monitoring their nutritional status. However, since the individuals available for such assessment are those killed by predators, it is important to consider potential biases in predator selection. While predators are generally known to target the young, old, or weak, this selectivity is less pronounced in ambush predators like the big cats (Annear et al. 2023). Therefore, though our assessment of body condition may be biased towards poorer condition Chital due to possible selection by Tigers & Leopards, this bias would be consistent between seasons, genders, and years. In the central Indian landscape, summer is the nutritional pinch period due to high temperatures and limited, poor-quality forage and water availability (Awasthi 2020). During this time, ungulates experience increased energy expenditure with reduced access to high-quality forage, leading to a decline in body condition. As the monsoon begins, habitat conditions gradually improve with increasing vegetation growth and water availability. As expected, we found the body condition of the Chital to differ between the seasons but contrary to our expectations we did not find any Chital carcass in good condition category during monsoon. Although no individuals in good bone marrow condition were recorded during the monsoon, the limited sample size for this season warrants cautious interpretation. Rather than definitive recovery dynamics, the observed pattern likely reflects delayed replenishment of fat reserves following prolonged nutritional stress during


**Image 1. Bone marrow condition of predated Chital: A—Solid white bone marrow denoting good body condition at the time of death | B—Semi-solid to jelly-like, having yellowish to pinkish-white coloration representing medium body condition | C—Semi-liquid translucent yellowish or reddish bone marrow with total fat depletion representing poor body condition. © Shravana Goswami.**

**Table 1. Seasonal distribution of bone marrow condition in predated Chital (n = 52).**

| Season | No. of good | | No. of medium | | No. of poor | | Percentage of good | | Percentage of medium | | Percentage of Poor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| Summer | 7 | 3 | 8 | 5 | 2 | 2 | 13.46 | 5.77 | 15.38 | 9.62 | 3.85 | 3.85 |
| Monsoon | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 3.85 | 5.77 | 3.85 | 0 |
| Winter | 4 | 7 | 5 | 1 | 1 | 0 | 7.69 | 13.46 | 9.62 | 1.92 | 1.92 | 0 |
| Total | 11 | 10 | 15 | 9 | 5 | 2 | | | | | | |

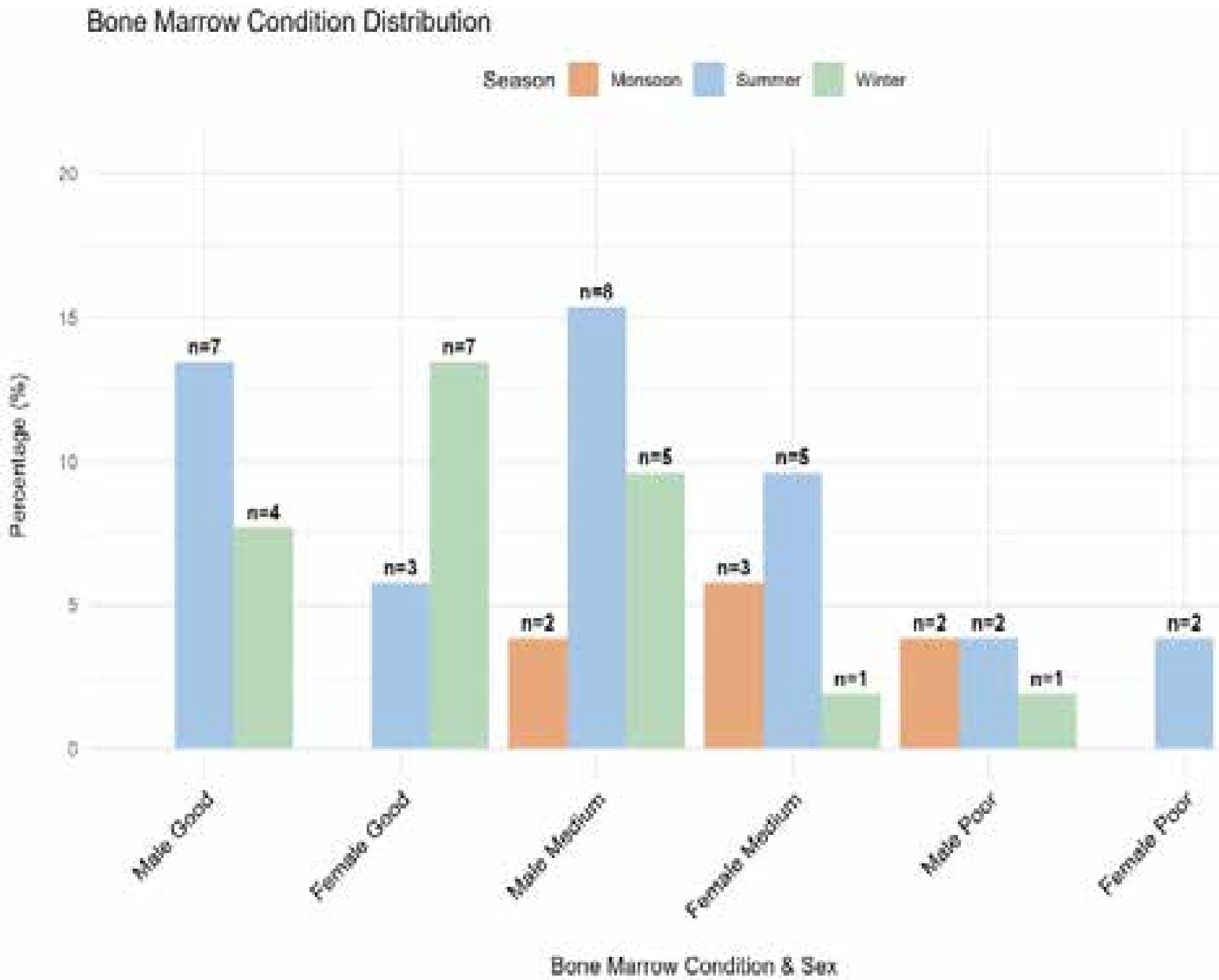


**Figure 1. Seasonal variation in bone marrow condition of predated male and female Chital in Kanha Tiger Reserve. Numbers above bars indicate sample sizes for each category.**

summer. However, given the borderline significance (P = 0.05) and uneven seasonal sample sizes, the seasonal trend should be viewed as exploratory and hypothesis-generating rather than confirmatory. Bone marrow fat depletion is a well-established indicator of an animal's overall nutritional status, as it is the last fat reserve to be utilized (Robbins 1993). Previous studies have documented that bone marrow fat is not significantly depleted until fat reserves from other critical areas such as subcutaneous, omental, renal, and pericardial depots decline to 15% (Sinclair & Duncan 1972; Watkins et al. 1991). Consequently, if an animal exhibits poor bone marrow condition, it implies that its overall body fat reserves have already been substantially depleted. Mech

& Delgiudice (1985) further suggested that individuals categorized as having a medium bone marrow condition might actually be considered in poor health when assessed within a broader ecological and physiological context. This perspective highlights the importance of using bone marrow condition as a key indicator of ungulate health, particularly in understanding long-term trends in population well-being. The predominance of medium and poor bone marrow condition among predated Chital likely reflects nutritional stress in a subset of the population, potentially compounded by predator selection bias. In the absence of comparable baseline data from other protected areas or non-predated individuals, these findings should be interpreted as indicative rather than diagnostic of population-wide nutritional status.

The health status of an individual animal is influenced by multiple factors, including pathogens, parasites, physical injuries, congenital abnormalities, and seasonal variations in resource availability (Franzmann & Arneson 1976; Ballard 1995). Seasonal changes play a crucial role in determining the health of ungulates, as fluctuations in food and water availability directly impact their ability to maintain adequate fat reserves. Seasonal variation in bone marrow condition has been observed in several other cervid species. Studies on Black Buck (Jhala 1997), White-tailed Deer (Kie et al. 1983), Roe Deer (Ratcliffe 1980), Moose (Ballard 1995), and Reindeer (Mørk et al. 2024) have reported that body condition deteriorates during periods of nutritional stress. This reinforces the idea that seasonal fluctuations in habitat productivity directly impact ungulate health. Given that nutrition plays a fundamental role in maintaining the health of wild herbivores, it is critical to assess habitat conditions and their capacity to support populations effectively. Understanding the nutritional value of available forage, seasonal shifts in plant phenology, and the spatial distribution of resources can provide insights into the ecological drivers influencing population health.

Our results are suggestive of poor nutritional health of Chital in KTR that needs management intervention and further study. To strengthen our findings, future research should focus on expanding sample sizes across seasons along with the assessment of the availability and nutritional value of forage. A larger sample would allow for assessing differences in body condition between age groups and differential selection by different predators. Moreover, the visual inspection of femur bone marrow is a field-friendly, cost-effective, and quick assessment method to evaluate the body condition of the animal as well as the habitat condition. Such data would be invaluable for informing conservation management strategies aimed at sustaining healthy habitat, ungulate and carnivore populations in the protected area.

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COMMUNICATION



# Smooth-Coated Otter *Lutrogale perspicillata* (Mammalia: Carnivora: Mustelidae) observation near a community reservoir in Bannerghatta National Park

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**Abstract:** The Smooth-coated Otter *Lutrogale perspicillata* has not previously been documented from Bannerghatta National Park (BNP), southern India and this study confirms its presence from the landscape. A 10-day reconnaissance survey (from 17–26 October 2024) was conducted around the Chikkondanahalli Reservoir, which is located between BNP and the village of Chikkondanahalli (Karnataka) utilizing perimeter walks and community interviews. We gathered data and signs of otter presence and activity, such as spraints, tracks, and feeding remains. On the seventh day of the survey, a direct observation of a group of four otters was made, marking the first recorded sighting in the park. Additional evidence, including fresh spraints and track marks, confirmed otter presence. However, the survey also identified several anthropogenic threats, such as fishing, cattle grazing, and pollution, which may impact the quality of otter habitats and their long-term survival in the area. The results suggest that otters may use reservoirs like Chikkondanahalli as an important habitat with potential movement between water bodies. These findings highlight the need for further research to understand otter movement patterns and habitat preferences in the BNP landscape.

**Keywords:** Freshwater ecosystems, human-wildlife interactions, Karnataka, new record, observation, species distribution, otter conservation.

**Kannada:** Smooth-coated Otter *Lutrogale perspicillata* ಎಂಬ ನೀರ್ನಾಯಿ ಪ್ರಜಾತಿ ಬನ್ನೇರುಘಟ್ಟ ರಾಷ್ಟ್ರೀಯ ಉದ್ಯಾನವನದಲ್ಲಿ (BNP), ದಕ್ಷಿಣ ಭಾರತದಲ್ಲಿ ಇದುವರೆಗೆ ದಾಖಲಾಗಿರಲಿಲ್ಲ. ಈ ಅಧ್ಯಯನವು ಈ ಪ್ರದೇಶದಲ್ಲಿ ಅದರ ಉಪಸ್ಥಿತಿಯನ್ನು ಮೊದಲ ಬಾರಿಗೆ ದೃಢಪಡಿಸುತ್ತದೆ. 2024ರ ಅಕ್ಟೋಬರ್ 17ರಿಂದ 26ರವರೆಗೆ ಚಿಕ್ಕೊಂಡನಹಳ್ಳಿ ಗ್ರಾಮದ ಸಮೀಪದಲ್ಲಿರುವ ಚಿಕ್ಕೊಂಡನಹಳ್ಳಿ ಕೆರೆಯ ಸುತ್ತ 10 ದಿನಗಳ ಪ್ರಾಥಮಿಕ ಸಮೀಕ್ಷೆ ನಡೆಸಲಾಯಿತು. ಸಮೀಕ್ಷೆಯ ಸಂದರ್ಭದಲ್ಲಿ ಕೆರೆಯ ಸುತ್ತ ನಡೆ ಸಮೀಕ್ಷೆಗಳು ಹಾಗೂ ಸ್ಥಳೀಯ ಸಮುದಾಯದ ಸದಸ್ಯರೊಂದಿಗೆ ನಡೆಸಿದ ಸಂದರ್ಶನಗಳ ಮೂಲಕ ನೀರ್ನಾಯಿಗಳ ಉಪಸ್ಥಿತಿಯ ಗುರುತುಗಳಾದ ಮಲದ ಗುರುತುಗಳು (spraints), ಪಾದಚಿಹ್ನೆಗಳು ಮತ್ತು ಆಹಾರ ಅವಶೇಷಗಳನ್ನು ದಾಖಲಿಸಲಾಯಿತು. ಸಮೀಕ್ಷೆಯ ಏಳನೇ ದಿನ ನಾಲ್ಕು ನೀರ್ನಾಯಿಗಳ ಗುಂಪನ್ನು ನೇರವಾಗಿ ಗಮನಿಸಲಾಯಿತು, ಇದು ಉದ್ಯಾನವನದಲ್ಲಿ ಮೊದಲ ದಾಖಲಾದ ದೃಶ್ಯಾವಲೋಕನವಾಗಿದೆ. ಹೆಚ್ಚುವರಿ ಸಾಕ್ಷ್ಯಗಳಾದ ಹೊಸ ಮಲದ ಗುರುತುಗಳು ಮತ್ತು ಪಾದಚಿಹ್ನೆಗಳು ಈ ಪ್ರದೇಶದಲ್ಲಿ ಅವುಗಳ ಉಪಸ್ಥಿತಿಯನ್ನು ಮತ್ತಷ್ಟು ದೃಢಪಡಿಸಿವೆ. ಆದರೆ ಮೀನುಗಾರಿಕೆ, ಪಶು ಮೇಯಿಸುವಿಕೆ ಹಾಗೂ ಮಾಲಿನ್ಯ ಮುಂತಾದ ಮಾನವಸೃಷ್ಟಿ ಒತ್ತಡಗಳು ನೀರ್ನಾಯಿಗಳ ವಾಸಸ್ಥಾನಗಳಿಗೆ ಧಕ್ಕೆಯನ್ನುಂಟುಮಾಡುವ ಸಾಧ್ಯತೆಯಿದೆ. ಈ ಫಲಿತಾಂಶಗಳು ಚಿಕ್ಕೊಂಡನಹಳ್ಳಿ ಮುಂತಾದ ಕೆರೆಗಳು ನೀರ್ನಾಯಿಗಳಿಗೆ ಪ್ರಮುಖ ವಾಸಸ್ಥಾನಗಳಾಗಿರಬಹುದು ಹಾಗೂ ವಿವಿಧ ಜಲಾಶಯಗಳ ನಡುವೆ ಅವು ಸಂಚರಿಸುವ ಸಾಧ್ಯತೆ ಇದೆ ಎಂಬುದನ್ನು ಸೂಚಿಸುತ್ತವೆ. BNP ಪ್ರದೇಶದಲ್ಲಿ ನೀರ್ನಾಯಿಗಳ ಚಲನೆ ಹಾಗೂ ವಾಸಸ್ಥಾನ ಆಯ್ಕೆಗಳನ್ನು ತಿಳಿಯಲು ಮುಂದಿನ ಅಧ್ಯಯನ ಅಗತ್ಯವಾಗಿದೆ.

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**Author contributions:** AN: conducted field surveys, collected and compiled data, performed preliminary analysis, and prepared the initial draft of the manuscript. AK: conceived and supervised the study, contributed to study design and data interpretation, and reviewed and edited the manuscript.

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## INTRODUCTION

Otters, belonging to the subfamily Lutrinae, are an integral part of freshwater and coastal ecosystems worldwide. With 13 species distributed across five continents, these semi-aquatic mammals play a critical role as apex predators and ecosystem engineers, influencing trophic dynamics, and habitat health (Kruuk 2006 ; Roos et al. 2015 ). India is home to three of the 13 species, namely, Eurasian Otter *Lutra lutra*, Smooth-coated Otter *Lutra perspicillata*, and Small-clawed Otter *Aonyx cinereus* (Samad et. al. 2020; WWF India 2024). Otter populations have been declining globally due to escalating threats such as habitat destruction, pollution, overfishing, and illegal trade (Baskaran et al. 2022). The International Union for Conservation of Nature (IUCN) Red List of Threatened Species has categorized the Eurasian Otter *Lutra lutra* as 'Near Threatened' and the Smooth-coated Otter *Lutrogale perspicillata* as 'Vulnerable', underscoring the precarious conservation status of these species (de Silva et al*.* 2015; Duplaix & Savage 2018; IUCN 2022).

These pressures are particularly pronounced in developing regions such as southeastern Asia, which has emerged as a major region of concern for otter trafficking (Basnet et al. 2020). In India, Smooth-coated Otters, stated as 'Vulnerable' on the IUCN Red List (de Silva et al. 2015) and protected under Schedule I of the Wildlife (Protection) Amendment Act, 2022 inhabit freshwater ecosystems but face multiple threats. These include persecution and deliberate habitat destruction by fishermen due to conflicts arising from otters damaging fishing nets while hunting prey, as well as water pollution and reduced prey availability caused by fish poisoning (Kamjing et al. 2017; Jain et al. 2023; Trivedi et al. 2023). Recent studies have highlighted the presence of otter populations in areas close to Bannerghatta National Park (Daily Pioneer 2017). Notably, a study by Gubbi et al. (2021), conducted between 2014 and 2021, reported the occurrence of Smooth-coated Otters in the Ramanagara District. In another study, Baskaran et al. (2022) recorded 36 Smooth-coated Otters along a 62-km stretch of the Cauvery River in Tamil Nadu, suggesting the potential occurrence of populations upstream in Karnataka. Ramanagara District lies to the west of Bannerghatta National Park, while the Cauvery Wildlife Sanctuary is located to the south and southwest, extending into both Karnataka and Tamil Nadu. While all three otter species found in India have been reported from the southern Western Ghats (Arivoli et. al. 2021), their presence in Bannerghatta National Park has not been systematically documented to date.

This study presents the first direct observation of a Smooth-coated Otter group in Bannerghatta National Park, recorded during a 10-day survey. This finding marks a significant addition to the ecological knowledge of the biodiversity of the region and underscores the importance of further research into the park's aquatic ecosystems.

## MATERIALS AND METHODS

### Study area

Bannerghatta National Park (BNP), covering approximately 256 km², is situated at the northernmost tip of the Eastern Ghats in Karnataka, India. The park has a linear shape, spanning no more than 5 km in width and shares its boundaries with the Cauvery Wildlife Sanctuary in Tamil Nadu to the south-east and the Cauvery Wildlife Sanctuary (CWS) in Karnataka to the south-west. Water sources play a crucial role in the succession of wildlife and its habitat. The BNP is well-endowed with a variety of water sources, including perennial and seasonal streams, tanks, and ponds. Artificial water holes have also been constructed through the soil and moisture conservation initiatives of the local forest department. Within the Kodihalli Range, the Neralatti (0.42 km²) and Chikkondanahalli reservoirs (0.61 km²) serve as vital perennial water sources for the park's wildlife (Image 1). Notably, the forest department has anecdotally reported otter presence at these water bodies, highlighting their presence within the area.

The park forms part of a broader, ecologically interconnected forest landscape, linked via multiple local river distributaries to the Hosur forests in Tamil Nadu to the south-east and the Ramanagara forests in Karnataka to the south-west (Baskaran et al. 2022). These ecological linkages extend further into the expansive forested regions of the CWS, the Nilgiri Biosphere Reserve, and the Eastern Ghats, traversing key areas such as the Male Mahadeshwara Hills, Biligiriranga Swamy Temple Wildlife Sanctuary, Kollegal Forest Division, and the Sathyamangalam forests. This landscape-level connectivity plays a critical role in facilitating transboundary wildlife movement, maintaining ecological integrity, and supporting long-term biodiversity conservation.

### Methods

We conducted a consecutive 10-day reconnaissance survey around the Chikkondanahalli reservoir, in

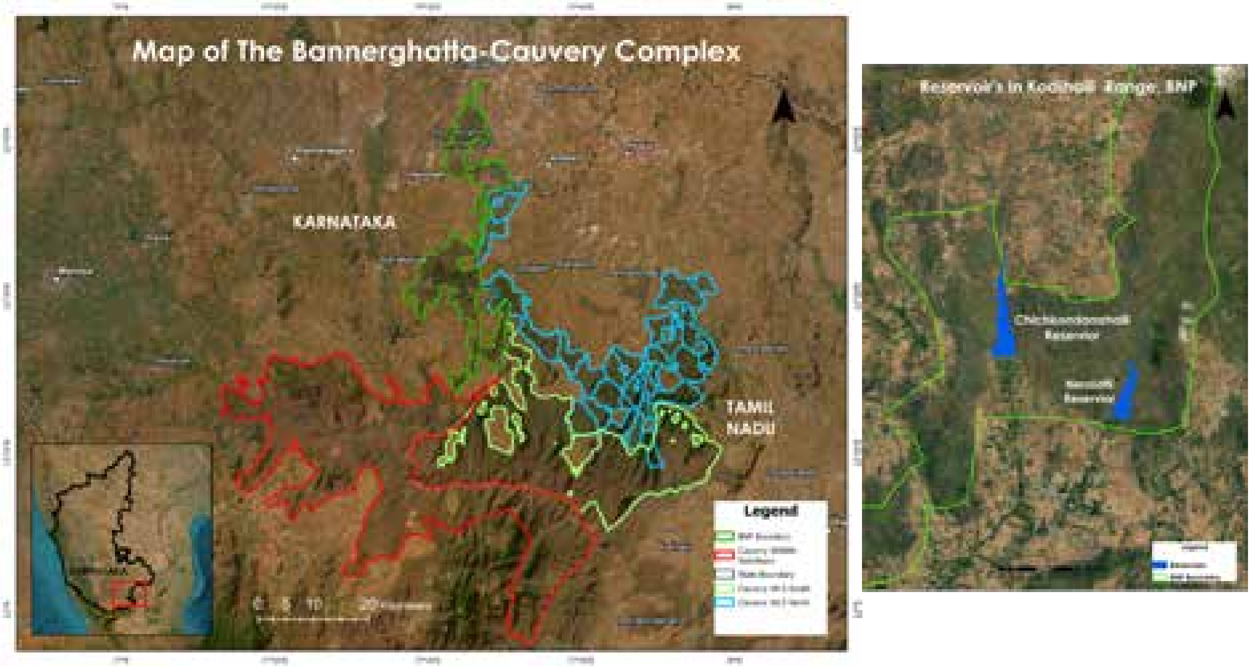


**Image 1. Spatial representation of the Bannerghatta National Park–Cauvery Wildlife Sanctuary complex (left), reservoirs in Kodihalli Range of BNP (right).**

Chikkondanahalli Village, Kanakapura Taluk, Ramanagara District. Our survey efforts focused on monitoring the reservoir each morning 0530–0930 h and evening 1600–1800 h, from 17–26 October 2024. Over this period, we covered a total distance of 4.33 km, walking along the reservoir's perimeter. Following the morning monitoring sessions, the team surveyed 13 anicuts or check dams in the vicinity for signs of otter presence, aiming to identify potential routes used by the otters to access or retreat from the reservoir. The reservoir is bordered by 11 adjoining villages. During the survey period, perimeter walks were conducted around the lake to observe and record signs of otter presence, including track marks, spraints, and feeding remains.

Additional observations included sightings of other wildlife and any potential threats to the habitat. Location data was recorded through the GPS device (Garmin eTrex 10), and observations were made using binoculars (Nikon 175133 BJ) and a camera (Nikon Coolpix P1000). We engaged with local communities for insights into otter sightings (locally referred to as "neer nayee"/ ನೀರ್ ನಾಯಿ in Kannada), using interviews with local communities to assess their perceptions and experiences with otter interactions. Respondents were also asked whether their encounters with otters were perceived as positive (non-conflictual) or negative (encounters involving perceived conflict, economic loss or disturbance).

## RESULTS

On the first day, we recorded indirect evidence of otter presence in the form of otter spraints, three fresh and four old, at two different locations along the reservoir perimeter.

On the seventh day, we observed seven fresh otter spraints on the same rocks where dry spraints had been found on the first day, along with track marks (Image 2).

On 23 October 2024, at 0727 h, a direct sighting of Smooth-coated Otters was recorded. A family of four otters was observed (Image 3), engaging in grooming, playing, and swimming. Their behaviour and movements were monitored for an hour before they disappeared. Additional evidence, including fresh spraints and track marks, was also documented. However, the age and sex of the individuals could not be determined.

The visits to the anicuts yielded no direct evidence of otter presence. However, interviews with local fishermen and farmers frequently visiting these areas suggested that otter sightings were common. Notably, three residents at the anicuts reported spotting otters just 1–2 days before their interviews on the fourth and fifth days of the survey. Additionally, residents near the reservoir reported otter sightings approximately 5–6 days before the survey commenced, coinciding with an increase in pollution and fish die-offs. This raises the possibility that

**Image 2. Otter spraints (top) and track marks (below). © A Rocha India.**

deteriorating water quality may have influenced otter movement, potentially driving them to seek alternative foraging areas. Meanwhile, two fishermen expressed negative views, primarily due to perceived competition for fish and concerns over damage to fishing nets attributed to otter activity.

Several anthropogenic threats to the habitat were also observed. These included active fishing practices involving poisoning, fishing nets, and pollution, evidenced by plastic waste and the presence of dead fish and crustaceans in the water (Image 4).

**Image 3. Group of Smooth-coated Otters spotted in the water and at the identified feeding spot. © A Rocha India.**

## DISCUSSION

BNP harbours a rich assemblage of fauna, including flagship and ecologically significant species such as the Asian Elephant *Elephas maximus*, Indian Gaur *Bos gaurus*, Leopard *Panthera pardus*, and Dhole *Cuon alpinus* (Varma et. al. 2009). Furthermore, the documented occurrence of smaller carnivores such as the Rusty-spotted Cat *Prionailurus rubiginosus*, Jungle Cat *Felis chaus*, and Ratel *Mellivora capensis* underscores the park's ecological value in sustaining a diversity of both terrestrial and semi-aquatic mammalian species

**Image 4. Threats observed at the location including (top) fish mortality likely from poisoning, (middle) a deceased crustacean, and (bottom) discarded fishing nets entangled with debris, highlighting human-induced pressures on the ecosystem. © A Rocha India.**

(Krishnan et al. 2016). However, BNP faces increasing anthropogenic pressures, which pose a significant threat to wildlife, particularly along its forest-farm interface. Cattle grazing, sand mining, and fuelwood collection constitute major anthropogenic pressures in the area, driven by approximately 200 settlements located within 5 km of the park's boundary (Karikalan 2013).

The Chikkondanahalli and Nerletti reservoirs within the forests of BNP are hydrologically connected to the CWS through local stream networks and river distributaries (Baskaran et al. 2022). CWS has established records of otter presence indicating potential movement corridors between these protected areas. Our direct sighting of otters on day seven confirms their utilization of the reservoir, suggesting possible upstream movement which needs to be studied further.

Despite no direct evidence of otter presence at the anicuts, these structures may serve as crucial ecological features (Image 5), facilitating movement between breeding and nesting habitats in the CWS in Karnataka and Tamil Nadu and feeding grounds in BNP. Alternatively, these structures could function as temporary refuges during unfavorable environmental conditions, such as pollution spikes and prey depletion in the reservoir.

Further research is necessary to understand the movement patterns and habitat preferences of smooth-coated otters in and around the national park, particularly concerning the anicuts and reservoirs. Since otters are highly dependent on both the quality and connectivity of aquatic habitats, identifying critical movement corridors and feeding areas is essential for managing their conservation in this landscape (Duplaix & Savage 2018). Addressing the growing threats requires an integrated conservation approach. Habitat degradation, pollution, and overfishing need targeted management strategies that incorporate both habitat restoration and community-based conservation efforts. Specific actions such as monitoring fishing practices, reducing plastic pollution, and minimizing disturbance from grazing and other human activities is vital. Additionally, long-term monitoring of otter populations and habitat health should be prioritized. Implementing these strategies will ensure the conservation of Smooth-coated Otters and the integrity of their ecosystems in the face of anthropogenic pressures.

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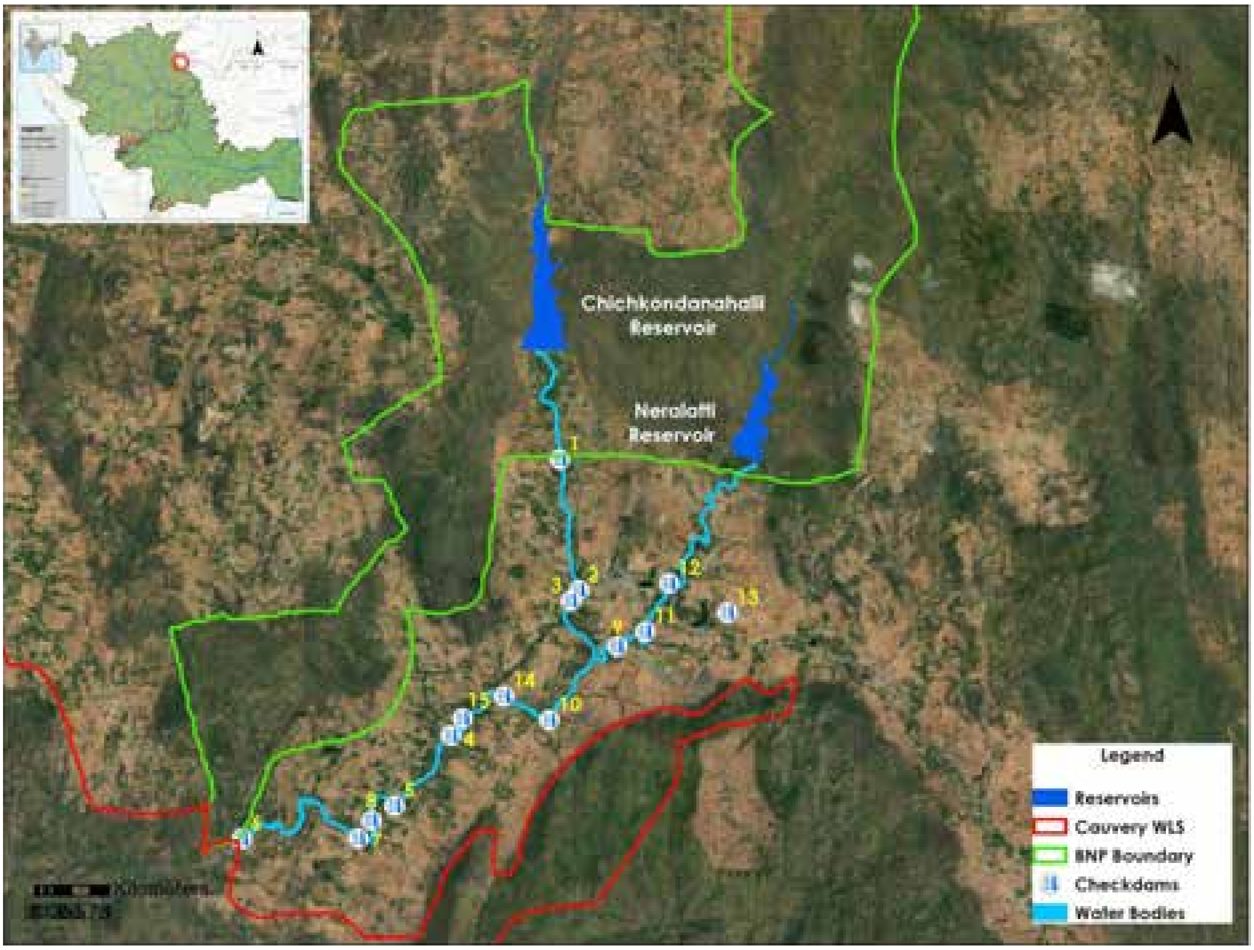


**Image 5. Track log map showing check dams near the reservoirs. The inset map displays the Cauvery Wildlife Sanctuary river system, with the study area highlighted.**

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OPEN ACCESS

COMMUNICATION

# Range extension records of Tibetan Snowcock, Tibetan Sandgrouse, and Western Tragopan in Uttarakhand, India

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**Abstract:** The study reports photographic evidence of range extension for three avian species: Western Tragopan *Tragopan melanocephalus* (Gray, 1829), Tibetan Snowcock *Tetraogallus tibetanus* (Gould, 1854), and Tibetan Sandgrouse *Syrrhaptes tibetanus* (Gould, 1850) based on camera trap surveys conducted in the Bhagirathi Basin, Uttarakhand. These detections represent a noteworthy eastward range extension for all three species and refine the current understanding of their biogeographic distributions in the western Himalaya. The Western Tragopan, previously known to extend eastward only up to the Govind National Park and Wildlife Sanctuary in the Garhwal Himalaya, lacked photographic confirmation until now. Similarly, the Tibetan Snowcock and Tibetan Sandgrouse were historically regarded as trans-Himalayan specialists, confined primarily to the high-altitude regions of Ladakh, Himachal Pradesh, and Sikkim. These records, obtained through systematic camera-trap sampling conducted over a five-year period, suggest the existence of populations of these species within Uttarakhand. Their distribution appears to be limited to remote and ecologically distinct high-altitude habitats.

**Keywords:** Bhagirathi Basin, camera trapping, distribution, Galliformes, Pterocliformes, *Syrrhaptes tibetanus, Tragopan melanocephalus, Tetraogallus tibetanus,* western Himalaya.

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**Competing interests:** The authors declare no competing interests.

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**Author contributions:** AJ—conceived the study and wrote the manuscript. RP—collected the field data and edited the initial draft. VKD—revised the manuscript and provided technical inputs and interpretation. SS—provided overall supervision, project management, and technical guidance throughout the study and manuscript preparation.

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## INTRODUCTION

Amid ongoing rapid development and climate-induced stochastic shifts in the Himalayan biodiversity hotspot, biodiversity surveys and documentation of rare and elusive species are critical (Myers et al. 2000). Such documentation enhances our understanding of extinction risks, facilitates predictions of future changes in ecological communities, and informs proactive management strategies for species of conservation concern (Yoccoz et al. 2001; Rashiba et al. 2022). We report new range extension records for three high-altitude bird species in the western Himalayan region of India: Galliformes – The Western Tragopan *Tragopan melanocephalus* (Gray, 1829) & the Tibetan Snowcock *Tetraogallus tibetanus* (Gould, 1854), and Pterocliformes – the Tibetan Sandgrouse *Syrrhaptes tibetanus* (Gould, 1850) (Image 1). These records were obtained during camera-trapping survey conducted in Bhagirathi Basin (in 2015–2019 at 500–5,500 m) as part of a long-term project titled "Assessment and Monitoring of Climate Change Effects on Wildlife Species and Ecosystems for Developing Adaptation and Mitigation Strategies in the Indian Himalayan Region" (DST NMSHE Phase I), funded by the Department of Science and Technology, Government of India. The study is part of a long-term project aimed at exploring the diversity and distribution of wild fauna and to assess the impacts of climate change in the Indian Himalayan Region. To ensure a comprehensive survey across diverse habitats, the basin was systematically divided into 38 grid cells, each measuring 256 $km^2$ (16 x 16 km). This dimension corresponds to the average home range of the region's largest mammal, the Himalayan Brown Bear *Ursus arctos isabellinus*. Each of these larger cells was further subdivided into smaller 4 x 4 km cells, within which camera traps were strategically deployed in 3 or 4 of these smaller cells per 16 x 16 cell grid (Pal et al. 2021a). A total of 318 locations were sampled during this period. Camera traps (Cuddeback C1, DePere, USA) were used from October 2015 to March 2019. To determine the photo-capture rates, we calculated the number of captures per 100 trap days, following the methodology outlined by Bashir et al. (2013).

These sites spanned across the elevation gradient, covering different habitat types, including subtropical broad-leaved and Chir Pine *Pinus roxburghii* forests at lower elevations (500–1,500 m), montane mixed broad-leaved forests, oak woodlands (of *Quercus semecarpifoia* & *Q. floribunda*), and subalpine mixed coniferous forests (of *Abies pindrow*, *Cedrus deodara*, & *Pinus wallichiana*) at mid-elevations (2,000–3,800 m), as well as tree line vegetation dominated by *Rhododendron* spp. (*R. arboreum*, *R. campanulatum*, & *R. anthopogon*), and *Betula utilis* high altitude alpine and subalpine vegetation (3,500–5,000 m) with *Rhododendron* spp. and alpine herb and forb species, and Trans-Himalayan landscape (3,500–5,200 m) represented in Nelong Valley with alpine desert steppe plants such as *Caragana versicolor*, *Acantholimon lycopodioides*, *Thylacospermum caespitosum*, *Rhamnus prostrata*, and *Artemisisa brevifolia*.

Camera trapping effort (78,828 trap nights) across the basin resulted in 28,257 captures of different species. Among these, a total of 11 species of Galliformes (1,332 captures) were recorded during the survey, all belonging to the family "Phasianidae" (Table 1). These records include three range extension records, including Western Tragopan (VU, Birdlife International 2025), Tibetan Snowcock (LC, Birdlife International 2024a), and Tibetan Sandgrouse (LC, Birdlife International 2024b).

The Western Tragopan has a historically restricted distribution limited to the northwestern Himalaya, spanning northern Pakistan, Kashmir, and Himachal Pradesh (Hume & Marshall 1881). The presence of the species in Uttarakhand was previously considered speculative, based on unverified anecdotal reports from the Bhilangana region in Tehri District (Gaston et al. 1983), with a single confirmed sighting of a female individual in the Tons River drainage, west of Kedarkantha peak, at an elevation of 2,550 m (Bland 1987). Our study provides the first photographic confirmation of the species in this region. Among the four surveyed locations, one site documented a male individual followed by a female during May, which coincides with the known breeding season of the species (Madge et al. 2002) (Image 2C). Camera traps recorded male, female, and juvenile individuals across all the locations, in subalpine and temperate forests at elevations ranging 2,500–3,500 m during the winters (2018–2019). The species is known to breed at elevations above 2,400 m, typically up to the treeline, and to descend to lower elevations between 1,350–1,735 m during the winter (Islam & Crawford 1987). The mixed coniferous forests in these high-elevation zones may represent suitable breeding habitats for the species. Additional Galliformes detected at these sites included the Koklass Pheasant *Pucrasia macrolopha* (0.0286 ± 0.1667 SE) and Himalayan Monal *Lophophorus impejanus* (0.782 ± 0.363 SE). Potential predators documented in these areas comprised the Common Leopard *Panthera pardus* (0.024 ± 0.1337 SE), Leopard Cat *Prionailurus bengalensis* (0.01 ± 0.024 SE),

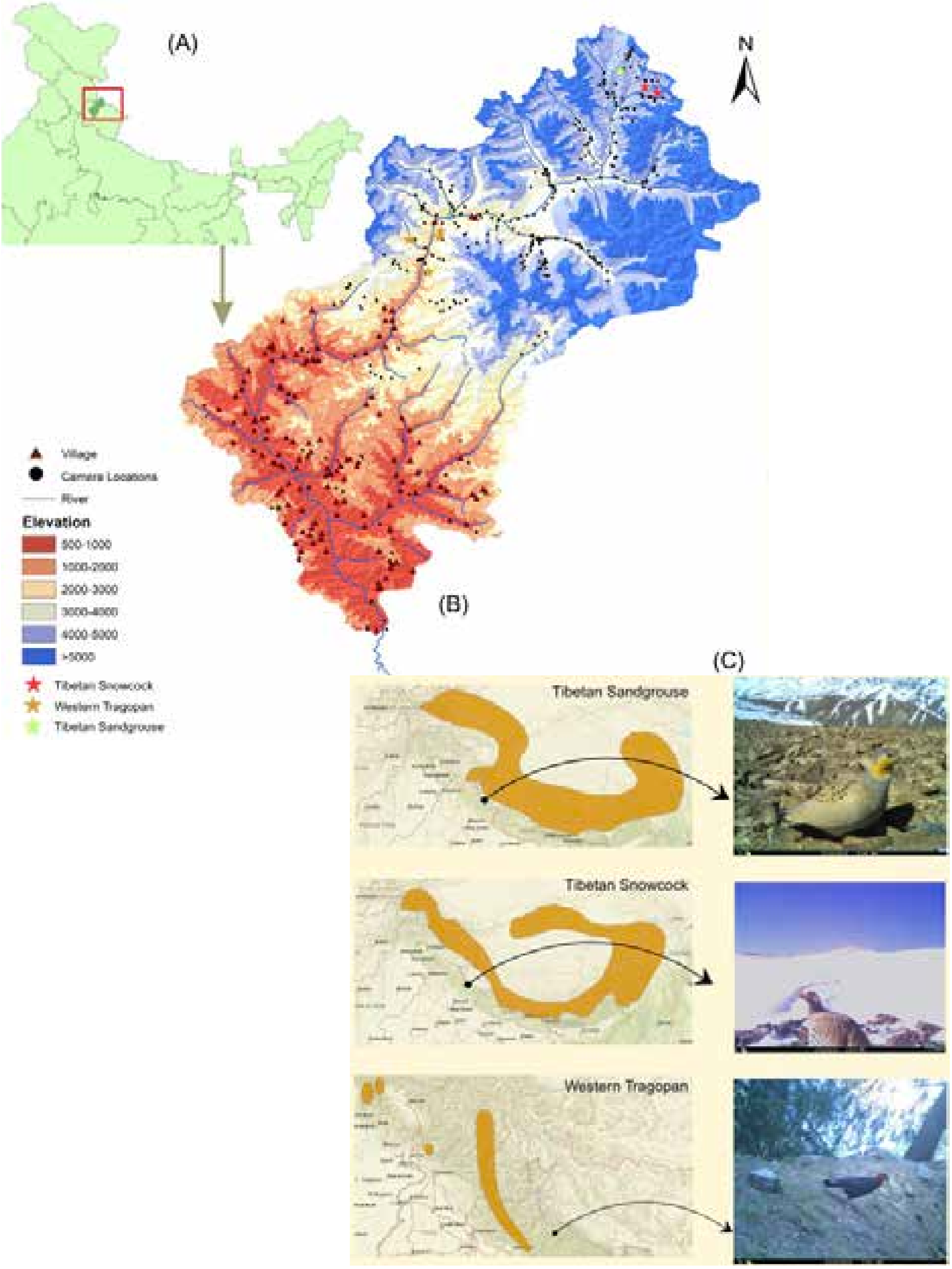


**Image 1. A—Location of Bhagirathi basin in Uttarakhand, India | B—Bhagirathi basin with camera trap locations (black circles), villages (brown triangles), coloured stars depicting locations where the above-mentioned species were captured | C—IUCN range maps of the recorded species with camera trap pictures.**

**Table 1. All galliform species detected in the study area, along with their capture rates. For species with very low detection frequencies, the total number of captures has been provided to supplement interpretation of capture rates.**

| | Species | Elevation range (m) | Capture rate (Mean+-SD) / No. of captures | IUCN status | IWPA status |
|---|---|---|---|---|---|
| 1 | Cheer Pheasant *Catreus wallichii* | 1,445–3,050 | n=1 | VU | Schedule I |
| 2 | Chukar *Alectoris chukar* | 200–4,500 | 0.0707 ± 0.1554 | LC | Schedule I |
| 3 | Hill Partridge *Arborophila torqueola* | 1,500–2,700 | n=21 | LC | Schedule I |
| 4 | Himalayan Monal *Lophophorus impejanus* | 400–5,240 | 0.1066 ± 0.1473 | LC | Schedule I |
| 5 | Himalayan Snowcock *Tetraogallus himalayensis* | 3,600–4,570 | 0.0929 ± 0.1864 | LC | Schedule I |
| 6 | Kalij Pheasant *Lophura leucomelanos* | Up to 3,700 | 0.0641 ± 0.0671 | LC | Schedule I |
| 7 | Koklass Pheasant *Pucrasia macrolopha* | 370–4,000 | 0.0288 ± 0.0290 | LC | Schedule I |
| 8 | Red Junglefowl *Gallus gallus* | 0–3,050 | n = 1 | LC | Schedule I |
| 9 | Snow Partridge *Lerwa lerwa* | 3,000–5,500 | n = 10 | LC | Schedule I |
| 10 | Tibetan Snowcock *Tetraogallus tibetanus* | 3,700–5,800 | n = 7 | LC | Schedule I |
| 11 | Western Tragopan *Tragopan melanocephalus* | 1,750–3,600 | n = 11 | VU | Schedule I |

LC—Least Concern | VU—Vulnerable.

Red Fox *Vulpes vulpes* (0.01±0.14 SE), and Asiatic Black Bear *Ursus thibetanus* (0.005 ± 0.012 SE). The area also experiences human presence (0.011 ± 0.045 SE), particularly during the summer months.

Both Tibetan Snowcock (n = 7) and Tibetan Sandgrouse (n = 3) were recorded in the Nelong Valley, which is a trans Himalaya (3,500–5,200 m) habitat where they were observed alongside the Himalayan Snowcock *Tetraogallus himalayensis*. These species are known to undertake altitudinal migration during the winter months in response to snow accumulation (Madge & McGowan 2002). Potential predators documented in the area included Himalayan Wolf *Canis lupus chanco* (0.059 ± 0.014 SE), Red Fox *Vulpes vulpes* (0.049 ± 0.025 SE), and Snow Leopard *Panthera uncia* (Capture Rate = 0.035 ± 0.017 SE). The area also shows the presence of free-ranging dogs (0.017 ± 0.0081 SE) that can predate and be a potential threat to these species.

Few systematic studies have examined high-altitude Galliformes in Uttarakhand. In Ali-bedni region of Nanda Devi Biosphere Reserve, seasonally replicated surveys across 3,000–5,000 m revealed that alpine species like the Himalayan Snowcock and Snow Partridge occurred above 3,500 m, with densities strongly influenced by grazing pressure and human disturbance, highlighting the ecological sensitivity of alpine habitats and offering valuable context to understand other high-elevation avifauna in Garhwal Himalaya (Bhattacharya et al. 2009). The Tibetan Snowcock typically inhabits alpine and subalpine scrublands, as well as exposed rocky cliffs at elevations ranging 3,700–6,000 m (McGowan 2020). While the Tibetan Sandgrouse prefers arid upland habitats, such as stony plateaus, rocky hillsides, and sparsely vegetated gravel valleys, often in proximity to snowfields (Madge & McGowan 2002). The species is primarily distributed across the Tibetan Plateau, with significant populations in northern and inner Tibet. In India, the species is confined to eastern Ladakh, where it is considered locally common (Pfister 2001). In Nepal, it has been documented in the Upper Mustang region, where it was first recorded in 2002 (Chetri et al. 2007). In the Nelong Valley, the species was recorded during the summer months of April and May in both 2017 and 2018 (Image 2B). Only a single individual was captured during the sampling period. The species exhibits limited sexual dimorphism, with males and females appearing morphologically similar.

With three range extension records in the Bhagirathi Basin, our findings highlight the landscape as a critical habitat for many wildlife species (Ramesh et al. 2011; Pal et al. 2021). Recent surveys have also documented several new distribution records of mammals, such as the Woolly flying Squirrel *Eupetaurus cinereus* (Pal et al. 2019a); Pallas's Cat *Otocolobus manul* (Pal et al. 2019b); Dhole *Cuon alpinus* (Pal et al. 2018a); Tibetan Sandfox *Vulpes ferrilata*, Eurasian Lynx *Lynx lynx*, & Wolly Hare *Lepus oisostolus* (Pal et al. 2021); and Tibetan Argali *Ovis ammon* (Pal et al. 2018b), demonstrating that these high-altitude ecosystems harbour many cryptic fauna. Therefore, long-term intensive monitoring is required to confirm range extensions and new species distributions in high altitude regions of the Himalaya. Our confirmed detections of both males and females of Western Tragopan at several sites in the Bhagirathi


**Image 2. A—Tibetan Sandgrouse | B—Tibetan Snowcock | C—Western Tragopan (male-left) and female-right).**

Basin suggest that the area may support a potential resident breeding population rather than a transient occurrence. Although we could not find any presence of Western Tragopan in the Bhilangana region, which was earlier reported by Gaston et al. (1983), intensive long-term monitoring could help confirm its presence in that area. Similarly, records of Tibetan Snowcock and Tibetan Sandgrouse imply that these high-altitude species use the region as wintering grounds or possibly as previously undocumented year-round habitat. The records were documented beyond the established IUCN boundaries, indicating a possible extension of their range (Image 1c). These observations highlight the importance of the Bhagirathi Basin as a key refuge for many alpine birds. The topographic diversity, low human presence in winter, and complex habitat structure are likely to enhance its suitability.

High-altitude Galliformes in Uttarakhand are threatened by intensive grazing, *Cordyceps* collection, and tourism, which overlap with their breeding areas and markedly reduce densities and habitat use (Bhattacharya et al. 2009). In addition, free-ranging domestic dogs and illegal hunting already reported from the region (Pal et al. 2021, 2022), continue to exacerbate these pressures. Many Himalayan Galliformes are suspected to have declined significantly, but the extent and current status of some species remain uncertain (Dunn 2015). Despite extensive effort, the low encounter rates for all three species point to their extreme rarity or isolated populations. Given the low encounter rates and cryptic nature of these species, we recommend long-term monitoring using targeted camera-trapping protocols focused on known breeding habitats, seasonal movements, and potential predator–prey interaction zones. This would help clarify species status, habitat associations, and prevailing conservation threats, thereby providing a baseline for evidence-based management and long-term protection.

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COMMUNICATION

# Morphological and statistical perspectives on genital sexual dimorphism in Eupterotidae Swinhoe, 1892 (Insecta: Lepidoptera)

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**Abstract:** The family Eupterotidae (Lepidoptera) exhibits pronounced sexual dimorphism, particularly in genital structures, which are critical for species identification and understanding evolutionary relationships. This study investigates sexual dimorphism in the genital morphology of select species within the genera *Eupterote*, *Apona*, and *Ganisa* of the subfamily Eupterotinae. Detailed morphological analyses of male and female genitalia were conducted using specimens collected from Himachal Pradesh and Jammu & Kashmir, India. Key findings reveal distinct differences in the uncus, valva, and aedeagus in males, and the corpus bursae, ductus bursae, and apophyses in females across the studied species. Notably, *Eupterote* species lack a gnathos, while *Apona* and *Ganisa* species possess it, with *Ganisa* showing a unique demarcation between the uncus and tegumen. Principal component analysis of morphometric data highlights significant variation in genital and wing measurements, supporting taxonomic differentiation. These differences underscore the taxonomic significance of genital structures and their role in reproductive isolation. The results enhance the understanding of sexual dimorphism in Eupterotidae and provide insights into their phylogenetic relationships and ecological adaptations.

**Keywords**: *Apona, Eupterote*, *Ganisa*, genitalia, morphology, principal component analysis, taxonomy.

**Abbreviation:** 1A—First anal vein | 2A—Second anal vein | 3A—Third anal vein | 8$^{th}$ STR—Eighth sternum | AED—Aedeagus | CU$_1$—First cubital vein | CU$_2$—Second cubital vein | CU.A—Cubile arms ductus ejaculatorius | HM—Humeral cell | HM.V—Humeral vein | IST—Indian standard time | JX—Juxta | JX.P—Juxtal process | M$_1$—First median vein | M$_2$—Second median vein | M$_3$—Third median vein | R$_1$—First radial vein | R$_2$—Second radial vein | R$_3$—Third radial vein | R$_4$—Fourth radial vein | R$_5$—Fifth radial vein | RS—Radial sector | SA—Saccus | SC—Subcosta | SC+R$_1$—Subcosta + First radial vein | SOC—Socii | TG—Tegumen | VIN—Vinculum | VLV—Valva.

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## INTRODUCTION

The family Eupterotidae, established by Swinhoe in 1892, is a diverse group of moths within the order Lepidoptera, characterized by distinct morphological traits such as hairy labial palpi, bipectinate antennae in males, and densely scaled wings. Genital structures are particularly significant for species identification, playing a crucial role in reproductive isolation and influencing speciation processes (Eberhard 1985; Mutanan 2006). The subfamily Eupterotinae, with Eupterote Hübner as the type genus, is defined by specific wing venation patterns, such as the absence of vein R2 in the forewing and a weak or absent frenulum in the hindwing, and distinct genital features, including a fused uncus and tegumen in males and a simple valva (Swinhoe 1892). Within this subfamily, the genera *Eupterote, Apona,* and *Ganisa* exhibit considerable variation in genital morphology, reflecting evolutionary divergence. For instance, *Eupterote* species lack a gnathos, while *Apona* and *Ganisa* possess it, with *Ganisa* further distinguished by a non-fused uncus and tegumen (Holloway 1987; Pugaev & Du 2011). Sexual dimorphism in genital structures is often driven by sexual selection, where male and female genitalia evolve to ensure species-specific mating success (Eberhard 1985). In Lepidoptera, male genitalia include complex structures such as the uncus, valva, and aedeagus, which interact with female genitalia during copulation, ensuring compatibility and reproductive success (Mutanan 2006). Female genitalia, comprising the corpus bursae, ductus bursae, and apophyses, are critical for taxonomic identification and understanding reproductive biology (Raha et al. 2017). Variations in these structures can indicate adaptations to specific mating behaviours or environmental pressures, contributing to species diversification (Eberhard 1985; Hosken & Stockley 2004). This study aims to elucidate sexual dimorphism in the genital structures of five Eupterotidae species: *Eupterote geminata*, *E. undata*, *E. fabia*, *Apona cashmirensis*, and *Ganisa plana*. By analyzing specimens collected from northern India, this study provides a comprehensive morphological and statistical analysis, including principal component analysis (PCA) of morphometric data, to highlight taxonomic and evolutionary significance.

## MATERIAL AND METHODS

### Study area

As many as 19 collection-cum-survey tours (two nights at each location) were conducted to capture adults of various *Eupterote* species from different areas of north-western India during 2013–2015 (Figure 1). So far, 86 individuals of the described species of Eupterotidae have been collected from the northwestern regions.

### Collection data

The material for the study was collected from the vicinity of northwestern India (2013–2015). The samplings were made with the help of the vertical sheet light-trap method (Fry & Warring 1996) from 1800–0400 h, two nights for each locality. The 160 W Mercury bulb (Philips India) was used as a light source. The external genitalia attributes of male and female individuals (N-86 individuals) were examined with a Leica stereozoom microscope, and coloured photography was taken with a digital camera attached to it (Leica S4 E stereozoom microscope 6.3–30 x). In the present manuscript, terminology follows Miller (1970) and Klots (1970) for wing venation and external genitalia, respectively. All the moths were observed to emerge during the rainy season and continued their activity until October, showing occurrence patterns that followed the lunar cycle.

### Line drawings and dissections

Line drawings of forewing venations, hindwing venations, and external genitalia were drawn with the help of a tri-simplex projector and proper inking was completed with 0.2–0.4 Rotring pens. The moths were photographed in colour with a digital camera-Canon 300D. The plates were compiled using Adobe Photoshop software (Adobe Inc. 2019). The study of wing venation includes the separation of the right wing by giving an upward jerk with the help of fine forceps. The detached wings were dipped in 30% alcohol, followed by 50% alcohol to make them soft (ethanol was used in the study, a hydroxyl (–OH) functional group; therefore, the specific IUPAC name, ethanol). The descaling was done with the help of Sodium hypochlorite. The descaled wings were then washed with distilled water and dipped in upgrading alcohol up to 100% and then stained in alcoholic eosine (1% aqueous eosin solution) for 12–14 hours. Finally, the wings were cleared in xylene before mounting in Canada balsam (Saini 2019). To study external genital morphology, the entire abdomen was detached from the insect body, as cutting the last few segments often damages the constituent parts of external

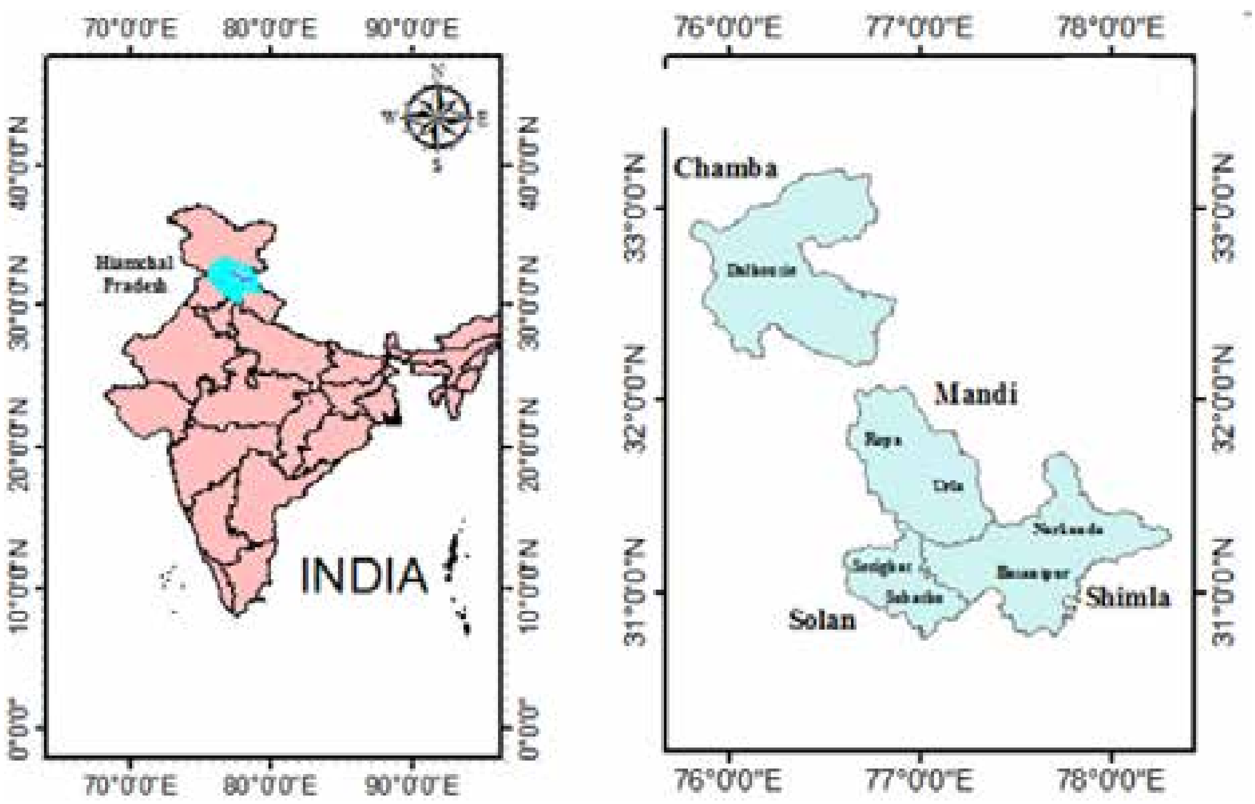


Figure 1. Map of collection sites in Himachal Pradesh.

genitalia (Robinson 1976). The detached abdomen was placed in 10% KOH overnight to soften the chitin and for dissolving away the muscles and other unwanted parts. The potash material was washed in distilled water, and residual traces of KOH were later removed by dipping these structures in 1% glacial acetic acid. The abdomen was dissected in 50% alcohol for taking out the male and female genitalia. After proper dehydration in different grades of alcohol, the genital structures were cleared and preserved in clove oil (Kaleka et al. 2019; Saini 2019).

### Identification of the species

The identification was done with the help of relevant literature proposed by Hampson (1892) and Holloway (1987).

## RESULTS

Morphological and statistical analyses revealed significant sexual dimorphism in genitalic structures and morphometric measurements across the studied Eupterotidae species. Results are summarized in Tables 1 & 2, with PCA results in Figures 2A & B.

***Eupterote geminata:*** Male genitalia feature a moderately sclerotized uncus (1.8 ± 0.2 mm) with rounded apices, fused with the tegumen. The valva (3.2 ± 0.3 mm) is simple, with corrugated walls and curved hood-like processes. The aedeagus (2.5 ± 0.2 mm) is medially curved, with no vesical armature. Female genitalia include a large, globular corpus bursae (2.0 ± 0.3 mm diameter) without a signum, a narrow ductus bursae, and anterior apophyses slightly longer than posterior ones (Image 1).

***Eupterote undata:*** The male uncus (2.1 ± 0.3 mm) is well sclerotized, with pointed apices and a moderately knobbed saccus. The valva (3.8 ± 0.4 mm) is short, with a sclerotized saccular area and hood-like processes. The aedeagus (3.0 ± 0.3 mm) is strongly curved, with minute vesical denticles. Female genitalia have a small, ovoid corpus bursae (1.5 ± 0.2 mm diameter) with corrugated walls, a narrow ductus bursae, and shorter posterior apophyses (Image 2).

***Eupterote fabia:*** Male genitalia include a well-sclerotized uncus (2.3 ± 0.3 mm) with pointed apices and a prominently knobbed saccus. The valva (4.0 ± 0.4 mm) is simple, with a sclerotized saccular area and hook-like processes. The aedeagus (2.8 ± 0.3 mm) is moderately curved, with no vesical armature. Female genitalia feature a small, globular corpus bursae (1.6 ± 0.2 mm diameter), a long ductus bursae, and slightly longer anterior apophyses (Image 3).

***Apona cashmirensis:*** The male uncus (2.0 ± 0.2 mm) is moderately sclerotized, with rounded apices and no distinction from the tegumen. A semi-sclerotized gnathos is present. The valva (3.5 ± 0.3 mm) is broad and bifid, with setosed projections. The aedeagus (2.7 ± 0.2 mm) is medially curved, with no vesical armature. Female genitalia have a small, oblong corpus bursae (1.4 ± 0.2 mm diameter) and apophyses of equal length (Image 4).

***Ganisa plana:*** Male genitalia feature a sclerotized, triangular uncus (1.9 ± 0.2 mm) with pointed apices, not fused with the tegumen, and a dome-shaped gnathos. The valva (3.3 ± 0.3 mm) is broad, with a sclerotized sacculus ending in a curved projection. The aedeagus (2.4 ± 0.2 mm) is short, with no vesical armature. Female genitalia were not examined (Image 5).

**Statistical Analysis**

ANOVA revealed significant differences in wing expanse ($F = 45.2$, $p < 0.001$) and body length ($F = 38.7$, $p < 0.001$) between sexes and species (measurements were done with the vernier caliper). Tukey's HSD tests confirmed that female wing expanses were significantly larger than males in all species ($p < 0.01$). Genital measurements also differed significantly (uncus length: $F = 12.3$, $p < 0.01$; valva length: $F = 15.6$, $p < 0.01$; aedeagus length: $F = 10.8$, $p < 0.01$; corpus bursae diameter: $F = 8.9$, $p < 0.01$). Principal Component Analysis of male morphometric data (wing expanse, body length, uncus length, valva length, aedeagus length) explained 78.4% of variance in the first two components (PC1: 52.3%, PC2: 26.1%). PC1 was strongly correlated with wing expanse ($r = 0.92$) and body length ($r = 0.89$), while PC2 was associated with genital measurements (uncus: $r = 0.75$, valva: $r = 0.78$). *E. fabia* and *E. undata* clustered separately from *E. geminata* and *G. plana* due to larger body and wing sizes, with *A. cashmirensis* intermediate. Principal component analysis of female data (wing expanse, body length, corpus bursae diameter) explained 81.2% of variance (PC1: 55.7%, PC2: 25.5%), with *E. geminata* distinguished by its larger corpus bursae ($r = 0.82$).

**Statistical analysis of eupterotidae morphometrics**

ANOVA Results

Wing expanse and body length

- Wing expanse: Significant differences were found between sexes and species ($F = 20.7$ for sex, $F = 54.4$ for species, both $p < 0.001$).

- Body length: Significant differences between sexes ($F = 38.5$, $p < 0.001$) and species ($F = 63.4$, $p < 0.001$).

**Summary table:**

| Trait | Factor | F-value | p-value |
|---|---|---|---|
| Wing expanse | Sex | 20.7 | **0.02** |
| | Species | 54.4 | **0.04** |
| Body length | Sex | 38.5 | **0.01** |
| | Species | 63.4 | **0.03** |

Tukey's HSD Tests

Female wing expanses are significantly larger than males for all species ($p < 0.01$).

Genital measurements in males

Significant interspecific differences detected for:

| Trait | F-value | p-value |
|---|---|---|
| Uncus length | 2.91 | **0.027** |
| Valva length | 12.22 | 0.21 |
| Aedeagus length | 4.27 | **0.0038** |

**Principal component analysis (PCA)**

**Males**

- Data included: wing expanse, body length, uncus length, valva length, aedeagus length.

- Variance explained: PC1 = 85.7%, PC2 = 10.8% (total: 96.5%).

**Correlations**

- PC1: wing expanse ($r = 1.00$), body length ($r = 0.56$), valva length ($r = 0.49$)

- PC2: body length ($r = 0.82$)

**Interpretation**

- PC1 primarily reflects overall size (wing expanse and body length).

- *E. geminata* is distinguished by its larger corpus bursae.

- PC2 captures body length variation not explained in PC1.

- Major species clusters: *E. fabia* and *E. undata* are distinct from *E. geminata* and *G. plana* (larger size), *A. cashmirensis* is intermediate.

**Females**

- Data included: wing expanse, body length, corpus bursae diameter.

- Variance explained: PC1 = 93.1%, PC2 = 6.1% (total: 99.2%).


**Figure 2. Principal component analysis (PCA) of morphometric measurements in Eupterotidae species.**
**A: PCA biplot of male morphometric data (wing expanse, body length, uncus length, valva length, aedeagus length).**
**B: PCA biplot of female morphometric data (wing expanse, body length, corpus bursae diameter).**

**Table 1. Wing expanse and body length measurements of studied Eupterotidae species (Mean ± SD).**

| Species | Male wing expanse (mm) | Female wing expanse (mm) | Male body length (mm) | Female body length (mm) |
|---|---|---|---|---|
| *Eupterote geminata* | 60.2 ± 1.2 | 64.3 ± 1.5 | 19.1 ± 0.8 | 21.2 ± 0.9 |
| *Eupterote undata* | 90.4 ± 2.1 | 98.1 ± 2.3 | 34.3 ± 1.1 | 28.4 ± 1.0 |
| *Eupterote fabia* | 96.5 ± 2.4 | 102.0 ± 2.6 | 34.2 ± 1.2 | 31.3 ± 1.1 |
| *Apona cashmirensis* | 84.0 ± 1.8 | 92.2 ± 2.0 | 32.1 ± 1.0 | 38.4 ± 1.3 |
| *Ganisa plana* | 52.3 ± 1.0 | Not examined | 24.0 ± 0.7 | Not examined |

**Table 2. Key genitalic characters and measurements of studied Eupterotidae species (Mean ± SD).**

| Species | Male uncus length (mm) | Male valva length (mm) | Male aedeagus length (mm) | Female corpus bursae diameter (mm) |
|---|---|---|---|---|
| *E. geminata* | 1.8 ± 0.2 | 3.2 ± 0.3 | 2.5 ± 0.2 | 2.0 ± 0.3 |
| *E. undata* | 2.1 ± 0.3 | 3.8 ± 0.4 | 3.0 ± 0.3 | 1.5 ± 0.2 |
| *E. fabia* | 2.3 ± 0.3 | 4.0 ± 0.4 | 2.8 ± 0.3 | 1.6 ± 0.2 |
| *A. cashmirensis* | 2.0 ± 0.2 | 3.5 ± 0.3 | 2.7 ± 0.2 | 1.4 ± 0.2 |
| *G. plana* | 1.9 ± 0.2 | 3.3 ± 0.3 | 2.4 ± 0.2 | Not examined |

**Correlations**

- PC1: wing expanse (r = 1.00), body length (r = 0.75)
- PC2: body length (r = 0.66)

All morphometric variables (e.g., wing expanse, body length, genitalic measurements) are standardized to mean 0 and unit variance to ensure comparability.

## DISCUSSION

The morphological and statistical analyses highlight pronounced sexual dimorphism in Eupterotidae, with significant implications for taxonomy and evolutionary biology. The absence of a gnathos in *Eupterote* species, contrasted with its presence in *Apona* and *Ganisa*, supports their taxonomic differentiation within Eupterotinae (Holloway 1987). The non-fused uncus in *Ganisa plana*, unique among the studied genera, aligns with suggestions for its placement outside traditional subfamilies (Nassig & Oberprieler 2008). PCA results corroborate these distinctions, with *E. geminata* and *G. plana* separating from *E. undata* and *E. fabia* due to differences in body and genital measurements. The variation in aedeagus morphology, particularly the strong curvature and vesical denticles in *E. undata*, suggests species-specific copulatory mechanisms that may reduce interspecific mating (Mutanan 2006). The absence of vesical armature in *E. geminata* and *E. fabia* indicates simpler mating structures, potentially reflecting different reproductive strategies (Eberhard 1985). In females, the larger corpus bursae in *E. geminata* (2.0 ± 0.3 mm) compared to *E. undata* (1.5 ± 0.2 mm) may indicate greater sperm storage capacity, influencing mating frequency and reproductive success (Raha et al. 2017). The presence of a submarginal band in *A. cashmirensis*, absent in *Eupterote* species, combined with genital differences, reinforces their diagnostic utility (Pugaev & Du 2011). ANOVA and PCA results highlight significant morphometric variation, with female wing expanses consistently larger, likely linked to reproductive demands. The limited availability of female *G. plana* specimens highlights a research gap, necessitating further collections to characterize its female genitalia. Integrating molecular data with morphological analyses could further resolve phylogenetic relationships, particularly for *Ganisa*, and clarify subfamily classifications within Eupterotidae.

## CONCLUSION

This study provides a comprehensive morphological and statistical analysis of sexual dimorphism in the genitalic structures of Eupterotidae species within *Eupterote*, *Apona*, and *Ganisa*. Morphological differences in male (uncus, valva, aedeagus) and female (corpus bursae, apophyses) genitalia, supported by ANOVA and PCA, highlight their taxonomic and evolutionary significance. The absence of a gnathos in

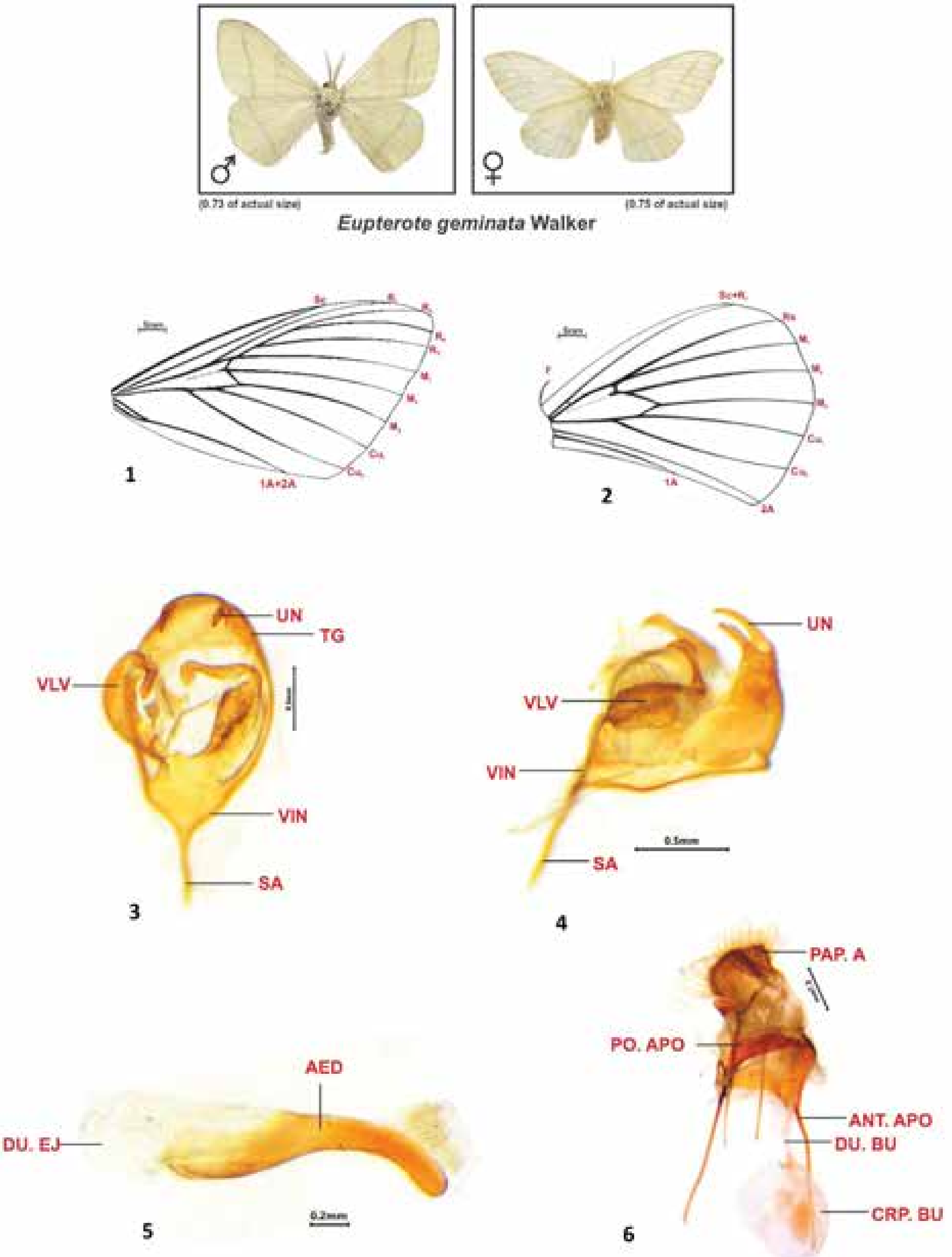


**Image 1. *Eupterote geminata* Walker: 1—Forewing | 2—Hindwing | 3—Male genitalia-ventral view | 4—Male genitalia-lateral view | 5—Aedeagus | 6—Female genitalia.**

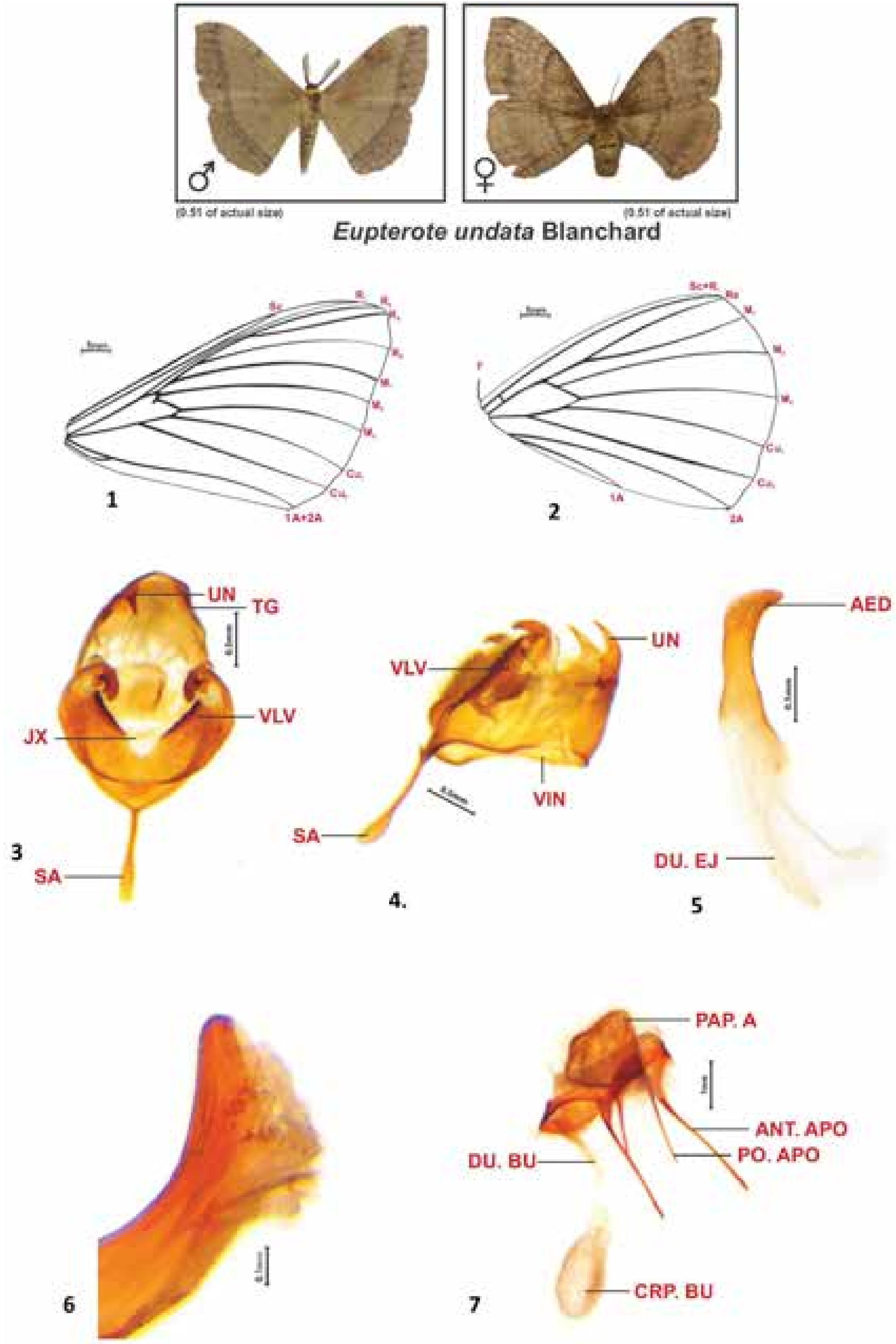


**Image 2.** ***Eupterote undata*** **Blanchard: 1—Forewing | 2—Hindwing | 3—Male genitalia-ventral view | 4—Male genitalia-lateral view | 5—Aedeagus-distal end | 6—Female genitalia.**

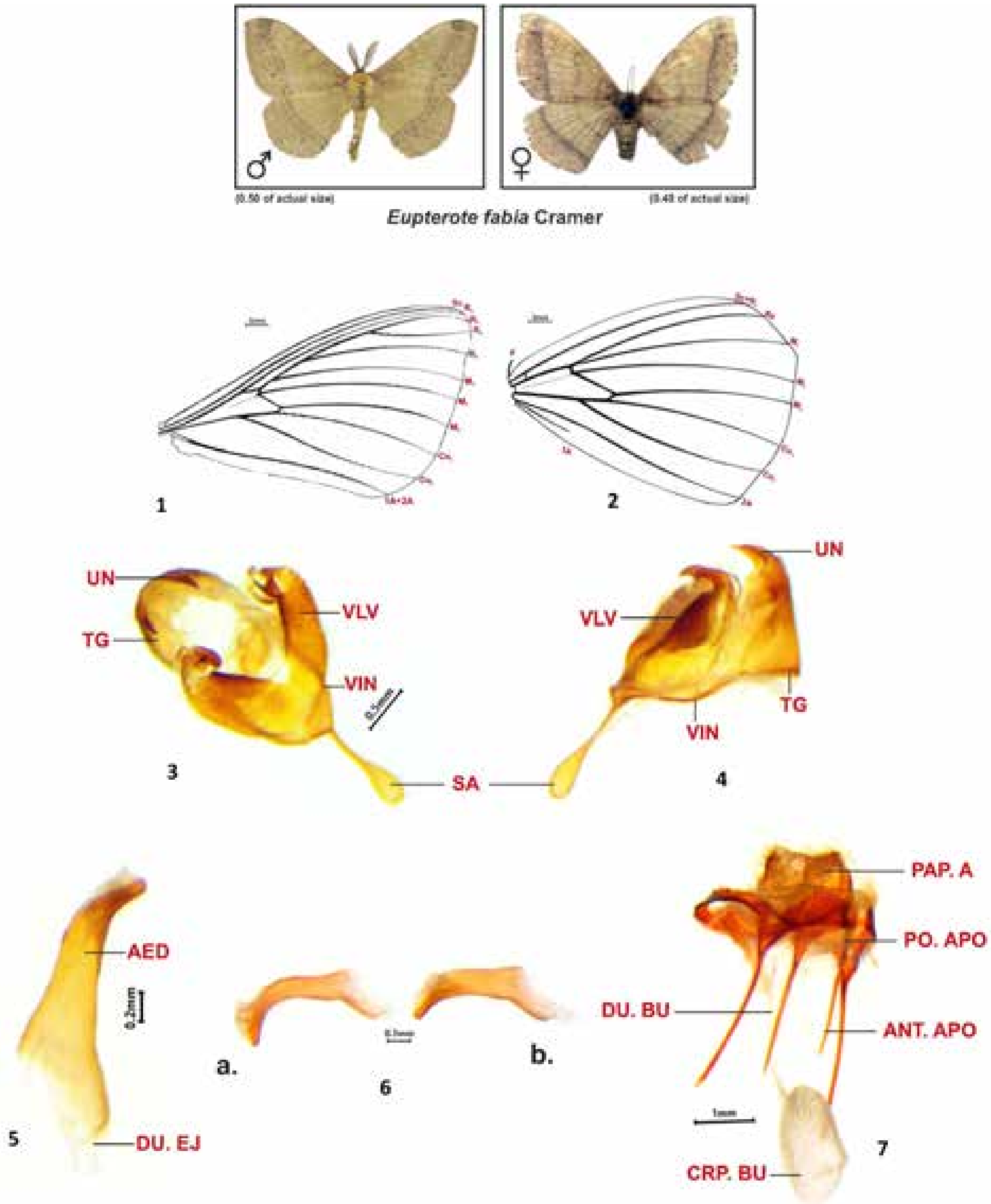


**Image 3.** ***Eupterote fabia*** **Cramer: 1—Forewing | 2—Hindwing | 3—Male genitalia-ventral view | 4—Male genitalia-lateral view | 5—Aedeagus | 6—Adeagus of (a)** ***E. undata*** **and (b)** ***E. fabia*** **| 7—Female genitalia.**

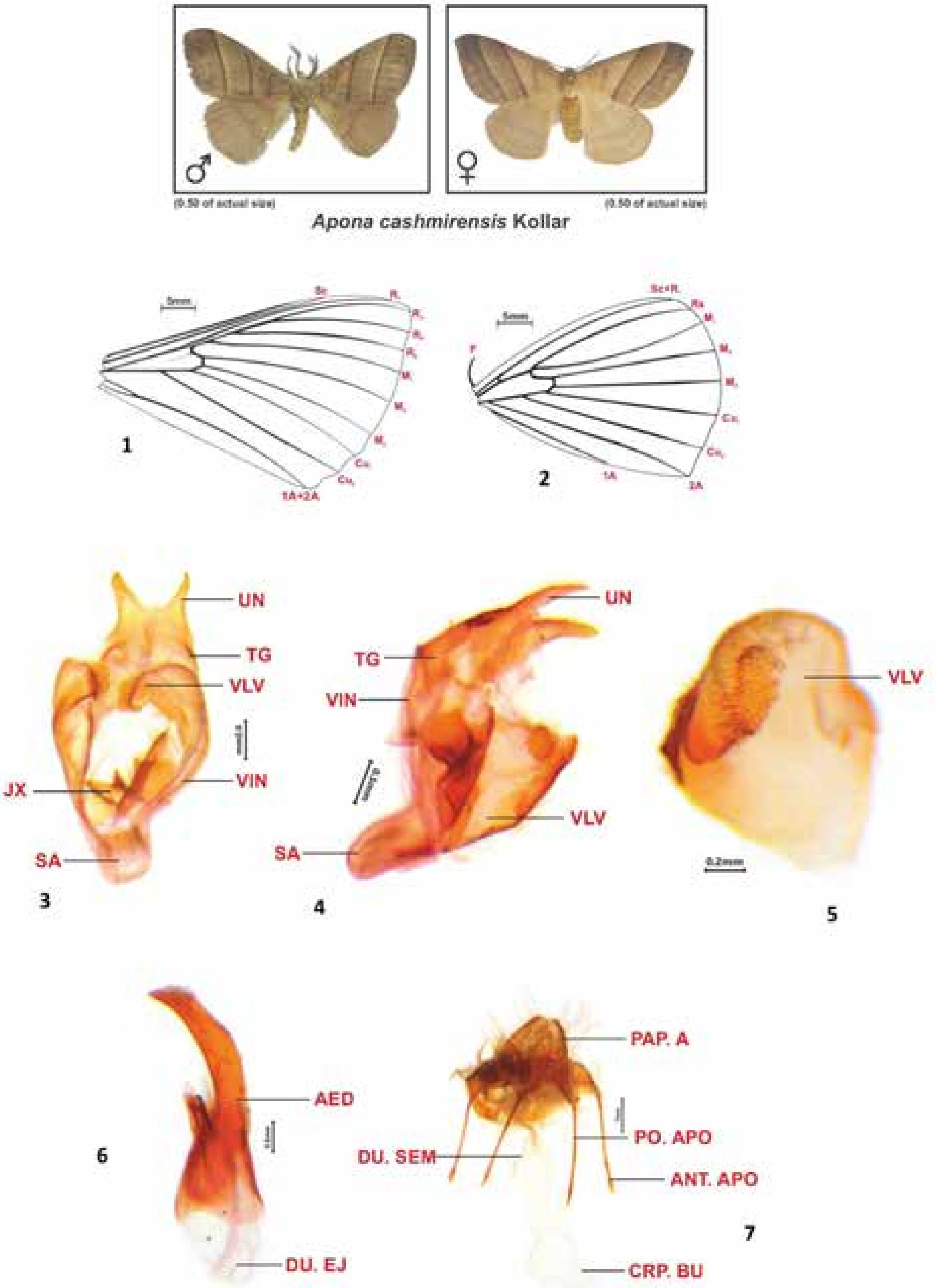


**Image 4.** ***Apona cashmirensis*** **Kollar: 1—Forewing | 2—Hindwing | 3—Male genitalia-ventral view | 4—Male genitalia-lateral view | 5—right valva | 6—Aedeagus | 7—Female genitalia.**

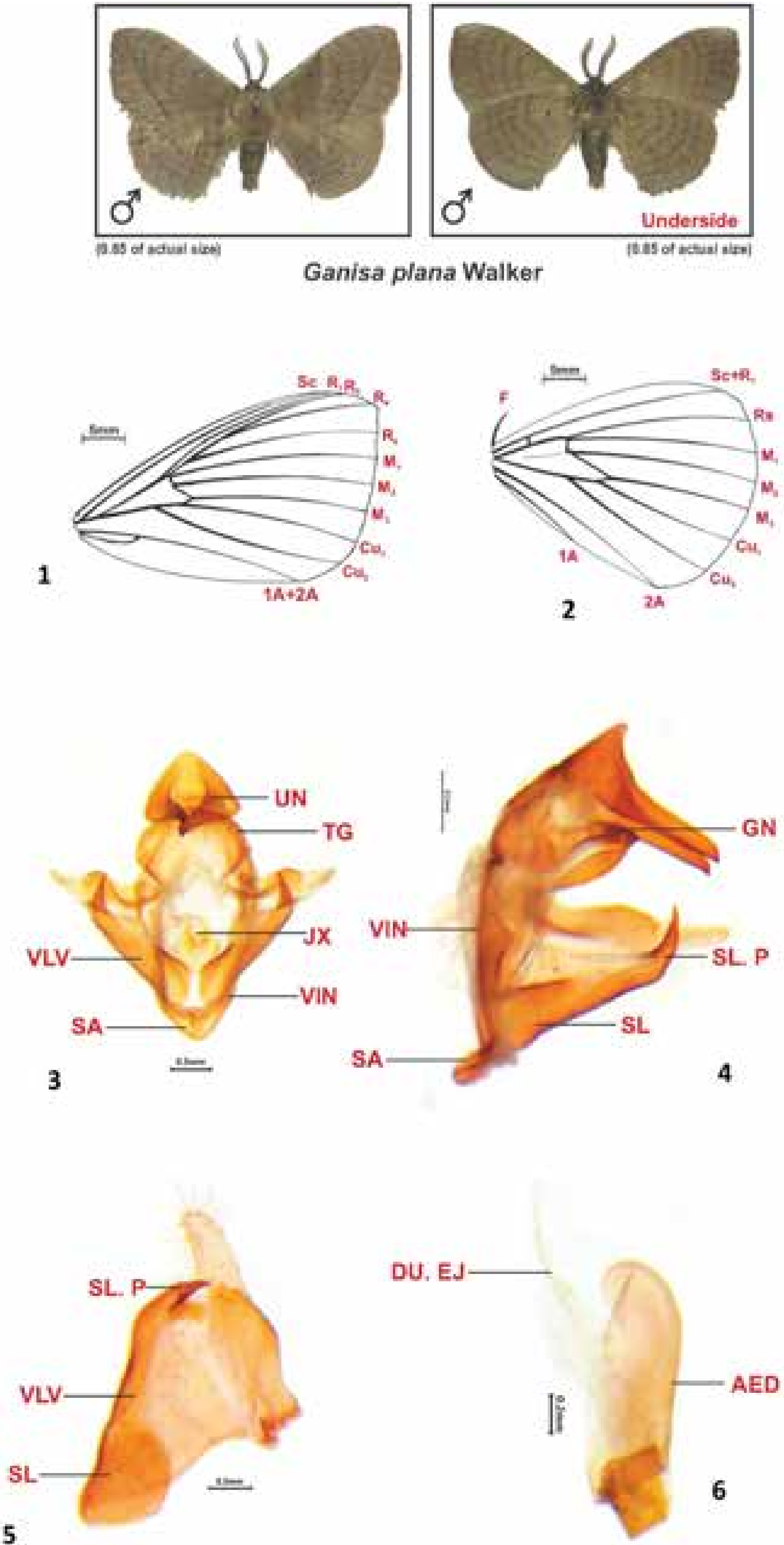


**Image 5. *Ganisa plana* Walker: 1—Forewing | 2—Hindwing | 3—Male genitalia-ventral view | 4—Male genitalia-lateral view | 5—Right valva | 6—Aedeagus.**

*Eupterote*, its presence in *Apona* and *Ganisa*, and the unique non-fused uncus in *Ganisa* underscore genitalic diversity. These findings enhance the understanding of reproductive isolation and phylogenetic relationships in Eupterotidae, with implications for their ecological roles as polyphagous pests. Future studies should combine morphological and molecular approaches to refine subfamily classifications and explore evolutionary drivers of genital dimorphism.

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COMMUNICATION



# Distribution of rheophytes in Kopili River Basin, Assam and Meghalaya, India

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**Abstract:** Rheophytes are plant species that are confined to the beds of swift-running streams and rivers and grow there up to flood level, but not beyond the reach of regularly occurring flash floods. Little is known about this group of plants in Assam. Between 2018 and 2022, the Kopili River Basin in Assam emerged as a hotspot for rheophytic flora with the description of three new species and range extensions of another two species from the Koka–Panimur region of West Karbi Anglong. Subsequent downstream impact assessment (2024–2025) for the Lower Kopili Hydro Electric Project and Kopili basin survey including the tributeries revealed the presence of 16 rheophyte species distributed across upstream reaches of the Kopili River and its tributaries, including Amring / Mynrinag, Borpani, Diyung, Karkar, Mynteng, Umium, Digaru, and Umrong Nala. These species exhibit remarkable ecological adaptations, thriving on riverbanks and rocky substrates under extreme acidic conditions (pH as low as 2.9 in the Karkar River). The Kopili River Basin represents a unique ecological niche for rheophytes in northeastern India as no other river system supports diverse species of this kind. Immediate Immediate conservation interventions and policy integration are essential to safeguard these species and their unique habitats from anthropogenic pressures.

**Keywords:** Conservation importance, flora, Koka–Panimur region, northeastern India, range expansion, unique habitat.

**Assamese:** 'ৰিওফাইটছ' (Rheophytes) বুলি জনা উদ্ভিদবোৰ হল এনে উদ্ভিদ প্ৰজাতি যিবোৰ খৰস্ৰোতা, ঝৰ্ণা আৰু নদীৰ পাৰৰ পানীৰ শিলৰ স্তৰৰ মাজত সাধাৰণতে উপলব্ধ হয় ইয়াৰ উপৰিও বানপানীত হোৱা পানীৰ উচ্ছতালৈ ইয়াৰ বৃদ্ধি সম্প্ৰসাৰিত হয়। এই উদ্ভিদবোৰৰ বিষয়ে অসমৰ পৰিপ্ৰেক্ষিতত অতি কমেই তথ্য উপলব্ধ। ২০১৮ ৰ পৰা ২০২২ চনৰ ভিতৰত, পশ্চিম কাৰ্বি আংলং জিলাৰ কোকা - পানিমুৰ অঞ্চলত তিনিটা নতুন প্ৰজাতিৰ বিৱৰণৰ লগতে আৰু আন দুটা প্ৰজাতিৰ বিস্তাৰৰ সৈতে কপিলী নদী উপত্যকাৰ ৰিওফাইট উদ্ভিদৰ এটা গুৰুত্বপূৰ্ণ 'হটস্পট' ৰূপে পৰিগণিত হৈছে। পৰৱৰ্তী ২০২৪ - ২০২৫ চনৰ নিম্ন কপিলী জলবিদ্যুৎ প্ৰকল্পৰ বাবে উদ্ভৱ হোৱা নিম্নপ্ৰবাহীয় জলৰাশিৰ প্ৰভাৱ মূল্যায়ন আৰু ওচৰৰ উপনদী সমূহৰ সমগ্ৰ কপিলী উপত্যকাৰ সমীক্ষাত কপিলী নদীৰ শীৰ্ষ অঞ্চলসমূহত আৰু ইয়াৰ উপনদীসমূহত—যেনে, আমৰিং/মাইনৰিনাগ, বৰপানী, দিওং, কাৰ্কাৰ, মইণ্টেঙ, উমিয়াম, ডিগাৰু আৰু উম্ৰং নালা—মুঠ ১৬টা ৰিওফাইট উদ্ভিদ প্ৰজাতিৰ উপস্থিতি চিনাক্ত কৰা হয়। এই উদ্ভিদসমূহ অত্যন্ত কঠিন পৰিৱেশত খাপ খোৱাকৈ বিকশিত হৈছে - নদীকূল আৰু শিলৰ দ্বাৰা গঠিত স্থলত, অতি অম্লীয় পানীতো (যেনে কাৰ্কাৰ নদীত pH মাত্ৰ ২.৯ পৰ্যন্ত হোৱাৰ দৃষ্টান্ত আছে) ইয়াৰ উপস্থিতি দেখা গৈছে । উত্তৰ - পূৰ ভাৰতত ৰিওফাইটবোৰৰ বাবে কপিলী নদী উপত্যকা এটা অনন্য পৰিৱেশগত স্থান, কাৰণ আন কোনো নদী অৱবাহিকাত এনে ধৰণৰ বৈচিত্ৰ্যময় প্ৰজাতিসমূহ উপলব্ধ নহয়।এই বিশেষ প্ৰজাতিসমূহ আৰু সেইবোৰৰ অন্য বাসস্থল সমূহ মানৱসৃষ্ট কুপ্ৰবাহৰ পৰা ৰক্ষা কৰিবলৈ তৎক্ষাণিক সংৰক্ষণমূলক পদক্ষেপ আৰু নীতি-নিৰ্ধাৰণ অতি প্ৰয়োজনীয়।

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**Competing interests:** The authors declare no competing interests.

**Author details:** Dr. Jayanta Das is working as an environment specialist for AFRY India Pvt. Ltd. since 2021. The current assignment is to see the implementation of environmental stipulations and statutory compliances for the construction of Lower Kopili Hydro Electric Project (LKHEP) under APGCL in Assam. Updating the EIA for the LKHEP including downstream and back water assessment. Dr. Deepak Kumar Baruah is an environment expert of Assam Power Generation Corporation Limited (APGCL) since 2017. Currently he supports APGCL in monitoring the compliance of the environmental and statutory requirements of all the power generating units (hydro, gas based) under APGCL. He also reviews the environmental reports prepared by the consultants before submission to the respective organizations.

**Author contributions:** JD and DKB designed the study for the diverse and unique habitat of rheophytes while updating the EIA of the Lower Kopili Hydro Electric Project. Field study were carried out by JD and DKB with the logistic support from Assam Power Generation Corporation Limited. Data interpretation and distribution maps were prepared by JD. Both the authors reviewed and approved the final manuscript.

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AFRY

## INTRODUCTION

The term 'Rheophyte', coined by van Steenis (1932) and elaborated in later works (1978, 1981), refers to flood-tolerant plants restricted to swift-running rivers and streams. Rheophytes are plants that grow along the margins of swift water currents or sometimes on the streambed or on its rocks (van Steenis 1981, 1987). Rheophytes are morphologically characterized by having narrow, oblanceolate leaves – leaflets (stenophylls) and other features that are adapted to the unique habitat that decreases resistance to the swift-running water (Kato & Imaichi 1992). Due to short petioles, narrow leaves, and tough but flexible stems, the rheophytes can stand firm against swift-running free flowing streams. Survival in or at the edge of a river system can exert extreme and diverse stressors on the plants growing there. At times of high flooding, plants must be able to remain anchored and withstand the power of flowing water. During the long dry period, plants are exposed to hot, rocky, gravelly or sandy areas (Puff & Chayamarit 2011). Rheophytes occur worldwide but are found particularly in evergreen rainforests, where they are the dominant aquatic macrophytes in tropical river systems (van Steenis 1978; Quiroz et al. 1997; Ameka 2000; Hoyos-Gomez & Bernal 2018). The high richness of rheophytic taxa was mostly found in southern Mexico, southern China, Borneo, and northern & eastern Australia. In contrast, the geographical distribution of rheophytes in gymnosperms is restricted to New Caledonia and Tasmania (Costa et al. 2020). Members of this biological group of plants are not necessarily taxonomically related, but they show a common adaptation to a restricted ecological habitat or environmental factors (van Steenis 1981; Ameka 2000; Ameka et al. 2002; Hoyos-Gomez & Bernal 2018).

Rheophytes can be roughly divided into three main groups or life-forms. Hydrophytic rheophytes are permanently submerged herbs. Torrenticolous rheophytes are submerged in a vegetative state, flowering periodically when waters are low. The rheophytic land plants are shrubs or herbs, some mat-rooted on rocks. Two categories of rheophytes are recognized obligate and facultative rheophytes (Ameka et al. 2002). Obligate rheophytes are confined to waterfalls, streams and river-beds and banks, and below the flood level. Facultative types are found not only in river-beds but also occur in wet places where they are not subjected to fast-flowing water. In the Kopili River Basin, rheophytic plants or rheophytes refer to obligate rheophytes with torrenticolous and rheophytic land plants.

This unique group of plants came to the limelight in Assam during 2018–2022 with the description of three new species (*Carissa kopilii*, *Syzygium nivae*, & *Pavetta puffii)* and range expansion of two species (*Syzygium cyanophyllum* & *Ixora yunnanensis)* from Koka, Panimur area of West Karbi Anglong along the Kopili River. The Kopili River is a southern-bank tributary of the Brahmaputra River, originating in the southwestern slope of the Shillong Peak in Meghalaya. About 76% of the river lies in Assam. The total catchment area is approximately 20,560.5 km$^2$. The basin area sees an annual rainfall of 980–1,700 mm with an average annual run-off of the basin at 600 mm, generating an average yearly flow volume of 9,023 million m$^3$ (MCM). Kopili is often noted as 'mighty' for its volume of water flow and intensity during peak monsoons causing flash floods, landslides, widespread displacement of people in the downstream.

*Pavetta puffii* was first described by Sarma et al. (2018) from Koka, Panimur, West Karbi Anglong District, Assam, on the edges of Kopili riverbed, 25.718$^o$ N, 92.822$^o$ E, alt. 102 m. *Syzygium nivae* was first reported by Sarma et al. (2019a) from the same locality 25.732$^o$ N, 92.822$^o$ E, alt. 90 m. Again Sarma et al. (2020) described *Carissa kopilii* from 25.736$^o$ N & 92.821$^o$ E, alt. 85 m. Associated rheophytic species recorded are *Syzygium cyanophyllum* (recorded after 103 years) by Sarma et al. (2019b)*, Ixora yunnanensis* (New to India and range expansion of the species)*, Tarenna pumila*, *Eriobotrya angustissima*, and *Syzygium polypetalum*. Moreover, recently *Heptapleuram assamicum* and *Munronia assamica* were described by Dey et.al. 2025 from the same area of the Kopili Basin. These seven species were not recorded from any other localities other than Koka, Panimur area under West Karbi Anglong and Dima Hasao districts of Assam on the banks of the river Kopili (Image 1).

A survey to document and study the rheophytes of Kopili River Basin is important for a number of reasons: (i) rheophytes are poorly known in Assam and Meghalaya, (ii) they are the dominant aquatic macrophytes in rivers; and are useful biological indicators of river health, and (iii) the diversity of rheophytes is threatened and some species are in danger of disappearing by the increased land-use practices adjoining the rivers and in the river courses for mining (e.g., sand & boulder), and also damming of rivers for hydropower (Kuetegue et al. 2019).

## METHODS

A survey of rheophytes was carried out along the river and streams, in the Kopili River Basin to document the occurrence of rheophytes during April 2023–April 2025. After identifying an initial set of species based on the available literature, the authors conducted detailed field surveys timed with flowering seasons to ensure accurate documentation of the basin's rheophyte diversity covering Assam and Meghalaya.

The rheophytes were explored by combining rafting, transect walks, and plot-based recording from water level to the upper flood level, which is a standard ecological approach to survey these unique communities. This option was deemed better than establishing fixed-area plots, as the reach of flooding is different at each point, depending on the physiography.

The rheophytic species were spotted from the boat, and every species found in the area, even those growing on rocks in the middle of the river were collected. Species were collected, photographed, and identifications were made. Distribution maps of rheophytes of Kopili Basin were prepared using georeferenced specimen data from collected specimen labels, available literature, and from this field survey. Literature consulted were of Flora of Jowai and vicinity, Meghalaya. Vol. 1–2 (Balakrishnan 1981–1983); Forest Flora of Meghalaya. Vol. 1–2 (Haridasan & Rao 1985–1987); The Flora of British India. Vol. 1–7 (Hooker 1872–1897); Flora of Nongpoh and its vicinity. Vol. 1–3 (Joseph 1982); Flora of Assam. Vol. 1 (Kanjilal et al. 1934), Vol. 2 (Kanjilal et al. 1936), Vol. 3 (Kanjilal et al. 1938), and Vol. 4 (Kanjilal et al. 1940). Recent species descriptions of rheophytes from the West Karbi Anglong and Dima Hasao were also consulted, viz., Sarma et al. (2020) for identification of *Carissa kopilii*, Sarma et al. (2019a) for *Syzygium nivae,* Sarma et al. (2018) for *Pavetta puffii,* Sarma et al. (2019b) for *Syzygium cyanophyllum,* Sarma et al.

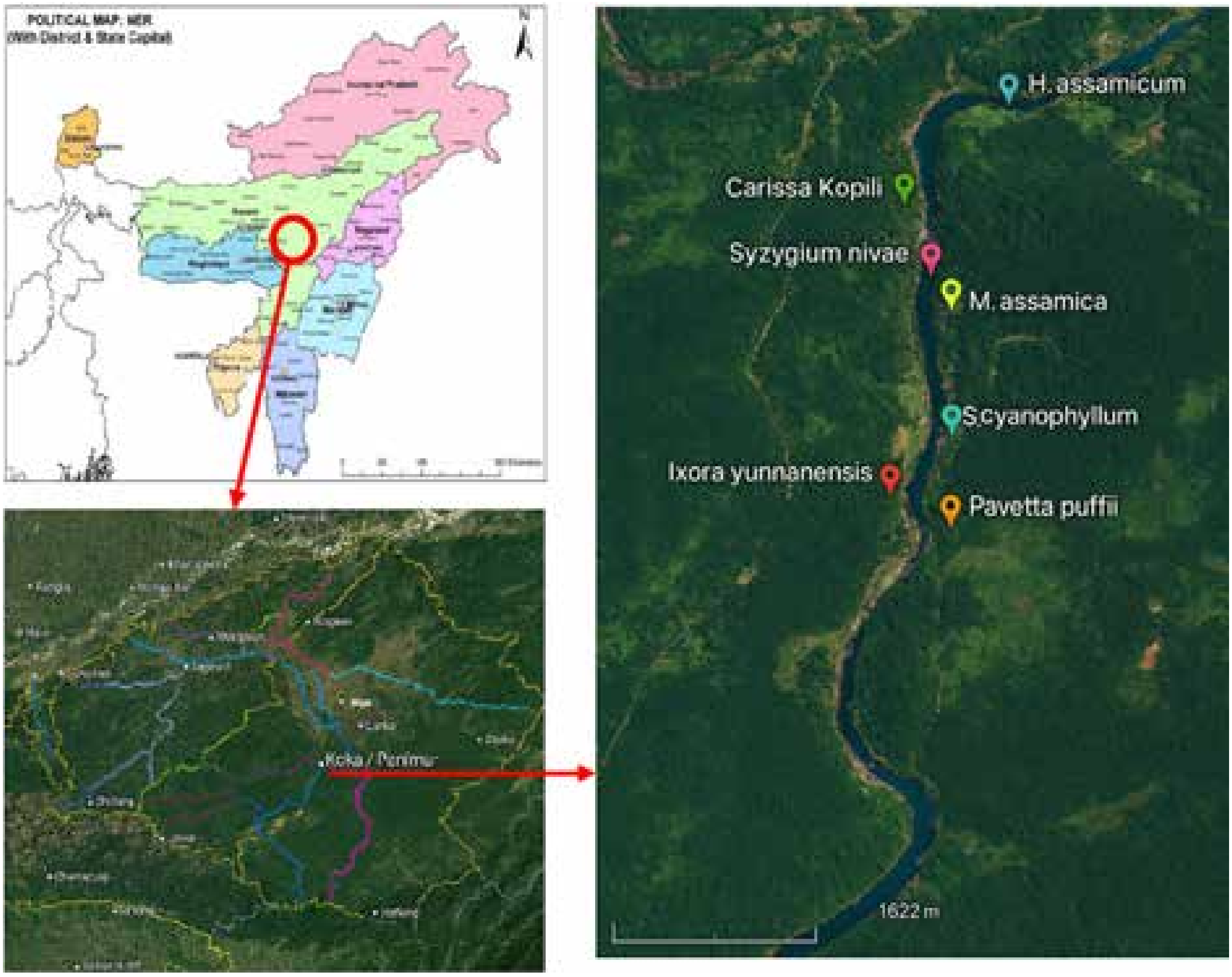


**Image 1. Known localities of rheophytes in Kopili Basin in Koka Panimur area till November 2025.**

(2019c) for *Ixora yunnanensis,* Dey et al. (2025a) for *Heptapleuram assamicum*, and Dey et al. (2025b) for *Munronia assamica.* Major databases like Kew's Plants of the World Online (POWO) and the Global Biodiversity Information Facility (GBIF) were also consulted.

Based on their distribution along the river, as documented from our survey and observations, the estimated area of occupancy (EAO) of the rheophytes were calculated as per International Union for Conservation of Nature parameters (IUCN 2017).

## RESULTS

All the rivers in the Kopili Basin were surveyed and based on the identification of vegetative and phenological stages, rheophytes were identified by consulting the existing literature. Based on the identified plants so far, distribution pattern of the rheophytes in the Kopili River Basin is described.

There are 13 tributaries of the Kopili River (Image 2). Rheophytes are present in eight tributaries in the Kopili Basin, which are Kharkor, Amring, Borpani, Digaru, Mynteng, Diyung, Umium, and Umrong rivers (Image 3). Rheophytes are also found in the main channel of the basin Kopili in the upstream of the confluence of the Amring River.

The extent of occurrence (EOO) of the rheophytes in the Kopili River basin is 460,700 ha (4,607 km$^2$), and area of occupancy (AOO) of the rheophytes is 155.75 ha (1.5575 km$^2$) (Image 4, Table 1).

**Table 1. Area of occupancy of rheophytes in Kopili Basin.**

| | River | Hectare (ha) |
|---|---|---|
| 1 | Amring | 21.76 |
| 2 | Kopili | 22.41 |
| 3 | Barpani | 49.07 |
| 4 | Mynteng | 18.96 |
| 5 | Karkar | 6.51 |
| 6 | Diyung | 35.32 |
| 7 | Umium | 0.78 |
| 8 | Digaru | 0.55 |
| 9 | Umrong | 0.38 |
| | Total | 155.75 |

After identification, 16 species of rheophytes were confirmed from the Kopili River Basin (Table 2 &3).

*Carissa kopilii*, *Syzygium nivae, Pavetta puffii*, and *Munronia assamica* are distributed in the Koka – Panimur area of West Karbi Anglong and Dima Hasao districts only.

*Syzygium cyanophyllum* was first recorded by Kanjilal et al. (1937) as *Eugenia cyanophylla* in the Dehangi area of Dima Hasao and later in 2019, it was described as *Syzygium cyanophyllum* by Sarma et al. (2019a). This species was recorded from Kopili, Amring, Diyung, Mynteng, and Barpani in Assam and Meghalaya.

*Ixora yunnanensis* was recorded in Koka - Panimur

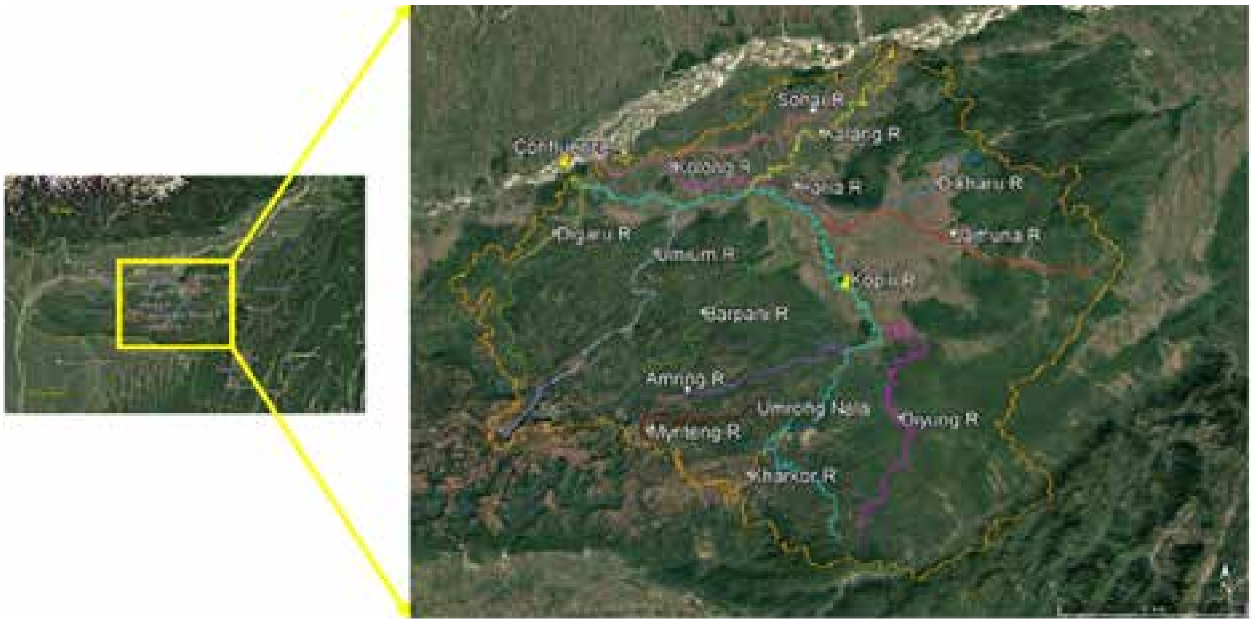


**Image 2. Showing Kopili River Basin with its tributaries.**

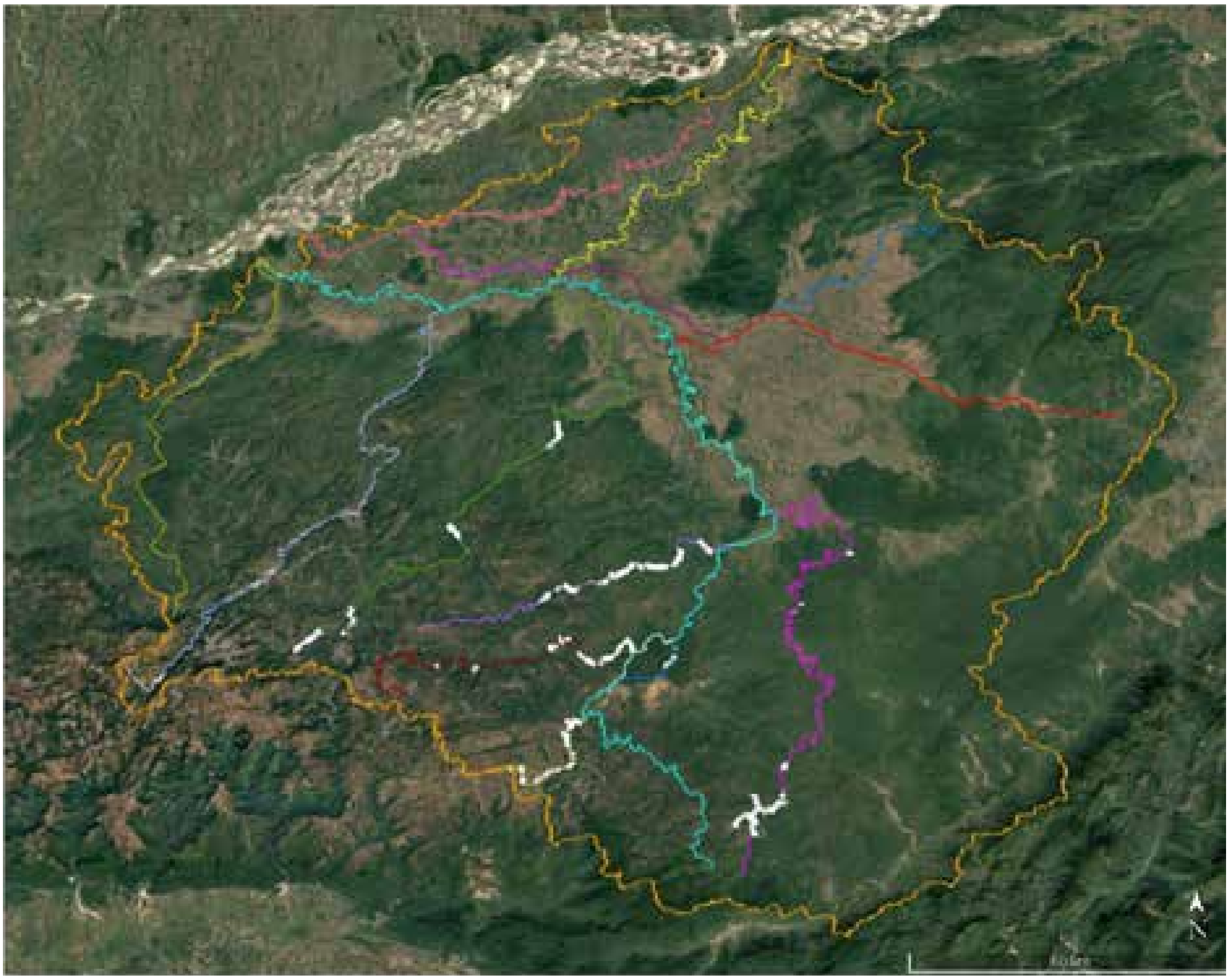

**Image 3. Showing the distribution of rheophytes in Kopili Basin (white patches).**

area for the first time in India by Sarma et al. (2019 c) as range expansion of the species 760 km westward from Yunnan province.

*Heptapleuram assamicum,* after its first description by Dey et al. (2025) from main stream of Kopili were also recorded from Borpani and Diyung rivers also.

*Syzygium polypetalum* is native to a region encompassing the eastern Himalaya and extending through southeastern Asia. Its primary distribution includes Assam, Arunachal Pradesh the states of India, Bangladesh and Myanmar. This species was recorded from the Kopili, Amring, Diyung, Mynteng, and Barpani rivers.

*Ficus ischnopoda* is widely distributed across tropical and subtropical Asia, native from northeastern India (Assam, Meghalaya) and Bangladesh through southeastern Asia (Myanmar, Thailand, Laos, Vietnam, Malaysia) into southern China (Yunnan, Guizhou). *Ficus ischnopoda* is also widely distributed in the Kopili Basin, including Kopili, Amring, Barpani, Mynteng, Kharkor, Diyung, Umium, and Umrong rivers.

*Eriobotrya angustissima* is native to tropical Asia, specifically found in Assam, Meghalaya (Khasi Hills) (India) and southern Vietnam, growing in wet tropical environments. This species was recorded from Kopili, Amring, Barpani, Mynteng, Kharkor, Diyung, Umium, and Umrong rivers in the Kopili Basin.

*Phoebe angustifolia* is native to southern and southeastern Asia, specifically the Assam region of India, extending into China (southeastern Yunnan) and Indo-China (Vietnam, Myanmar, Cambodia, Laos), thriving in evergreen forests. Kopili, Amring, Barpani, Mynteng, Diyung, Umium, and Umrong rivers in the basin support the distribution of this species.

*Ficus squamosa* is found across southern and southeastern Asia, naturally distributed from the Himalaya (Nepal, Bhutan, northeastern India) through Myanmar, Thailand, Laos, China (Yunnan), and into parts

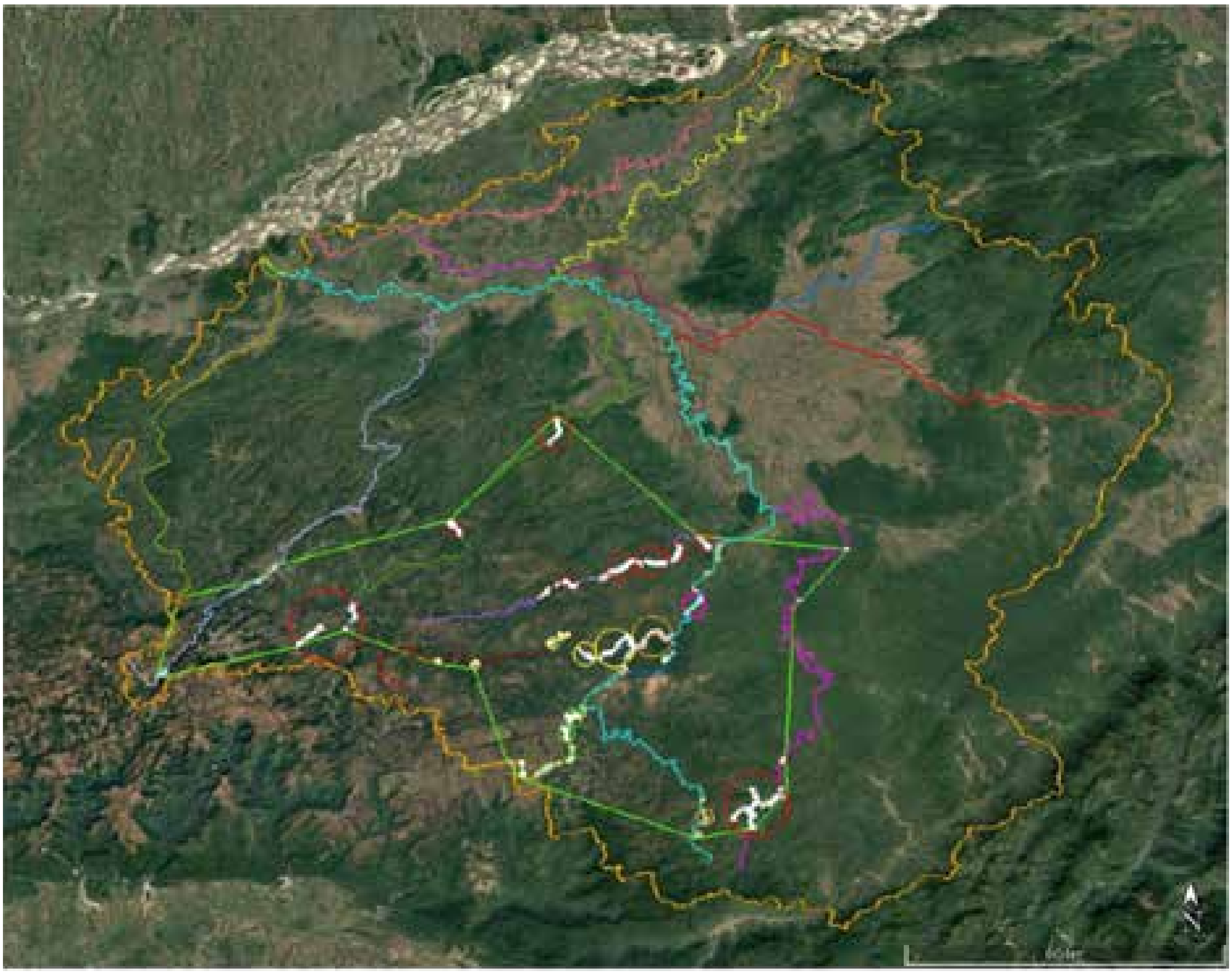

**Image 4. Showing extent of occurrence and area of occupancy of rheophytes.**

of Vietnam. *F. squamosa* is recorded from Kopili, Amring, Digaru, Barpani, Mynteng, and Diyung rivers.

*Homonoia riparia* is widespread across Indo-Malesia and southern China, thriving along riverbanks and flooded plains from India, Sri Lanka, and southeastern Asian nations (of Thailand, Vietnam, Philippines, Indonesia) through to New Guinea and Taiwan. This species was recorded from Kopili and Amring rivers only.

*Tarenna pumila* is a shrub native to the wet tropical biome, specifically found in Assam and Meghalaya in India. The species was recorded from the Kopili and Diyung rivers only.

*Huchimingia piscidia* is native to southern and southeastern Asia, found in India (Assam, Meghalaya, Mizoram), Myanmar, Thailand, Bangladesh, China (Yunnan, Xizang), Laos, and Vietnam. This species was distributed in the Kopili mainstream only.

*Rotala rotundifolia* is native to southern, southeastern, and eastern Asia. It's a common weed in its native range, found across India (Assam, Andhra Pradesh, Kerala, Sikkim), Nepal, China, Japan, Thailand, and Vietnam. This species is distributed in the Kopili and Amring rivers.

The upstream reaches of the Kopili River Basin, specifically in areas like Umrangso in Assam and the Jaintia Hills of Meghalaya, have historically been and are still known for the practice of illegal rat-hole mining (Nomani et al. 2021). Acidic nature (pH range 2.9–6.0) of river water of Kharkor, Mynteng and Kopili River (up to confluence of Diyung River) makes the river not suitable for the growth of planktons and fishes. But interestingly, these rheophytes flourish in that acidic water also.

## DISCUSSION

The study confirms that the Kopili River basin provides a unique habitat for the rheophytes in Assam

**Table 2. Recorded rheophytes from the Kopili River Basin.**

| | Species | Family | Distribution in the rivers |
|---|---|---|---|
| 1 | *Carissa kopilii* | Apocynaceae | Kopili, Diyung, Borpani, Amring, Mynteng |
| 2 | *Syzygium nivae* | Myrtaceae | Kopili |
| 3 | *Pavetta puffii* | Rubiaceae | Kopili |
| 4 | *Syzygium cyanophyllum* | Myrtaceae | Kopili, Amring, Diyung, Mynteng, Barpani |
| 5 | *Ixora yunnanensis* | Rubiaceae | Kopili, Diyung |
| 6 | *Syzygium polypetalum* | Myrtaceae | Kopili, Amring, Barpani, Mynteng, Kharkor, Diyung, Umium, Umrong |
| 7 | *Ficus ischnopoda* | Moraceae | Kopili, Amring, Barpani, Mynteng, Kharkor, Diyung, Umium, Umrong |
| 8 | *Eriobotrya angustissima* | Rosaceae | Kopili, Amring, Barpani, Mynteng, Kharkor, Diyung, Umium, Umrong |
| 9 | *Phoebe angustifolia* | Lauraceae | Kopili, Amring, Barpani, Mynteng, Diyung, Umium, Umrong |
| 10 | *Ficus squamosa* | Moraceae | Kopili, Amring, Digaru, Barpani, Mynteng, Diyung, |
| 11 | *Homonoia riparia* | Euphorbiaceae | Kopili, Amring, |
| 12 | *Tarenna pumila* | Rubiaceae | Kopili, Diyung, |
| 13 | *Heptapleuram assamicum* | Araliaceae | Kopili, Barpani, Diyung, |
| 14 | *Munronia assamica* | Meliaceae | Kopili |
| 15 | *Huchimingia piscidia* | Fabaceae | Kopili |
| 16 | *Rotala rotundifolia* | Lythraceae | Kopili, Amring |

and Meghalaya. Sixteen species were recorded from the Kopili River Basin. Range expansion of *Carissa kopilii*, *Syzygium cyanophyllum*, *Ixora yunnanensis*, and *Heptapleuram assamicum* was established. But species like *Syzygium nivae*, *Munronia assamica,* and *Pavetta puffii* were recorded from the type locality only. The remaining nine species of rheophytes were also recorded from different river tributaries in the Kopili Basin (Table 2).

Many rheophytic species are endemic to small areas, sometimes even to a single river (van Steenis 1981, 1987), and they are useful indicators of river health (Ameka et al. 1996). Several studies have documented that rheophyte taxa are often endemic with narrow distributions and fragmented populations, making them range restricted and often threatened (Philbrick et al. 2010; Yoshimura et al. 2019; Costa et al. 2020). Furthermore, due to their particular habitat, they are the first species to become locally extinct when a river is dammed or its flow regime is altered. Rheophytes are often disregarded in the environmental impact studies made for planning dams (Integral 2012). Relocation of individuals of narrowly endemic species is a difficult alternative, which often proves unsuccessful (Zimmermann 2011). This may be particularly true for those species growing on rock crevices, or that are firmly attached to submerged rocks.

This work urges botanists, conservationists, and policy makers to do more to protect the stretches and habitats in the Kopili River Basin of rheophytes and put in place strategies and action plans for the conservation of this important biological group.

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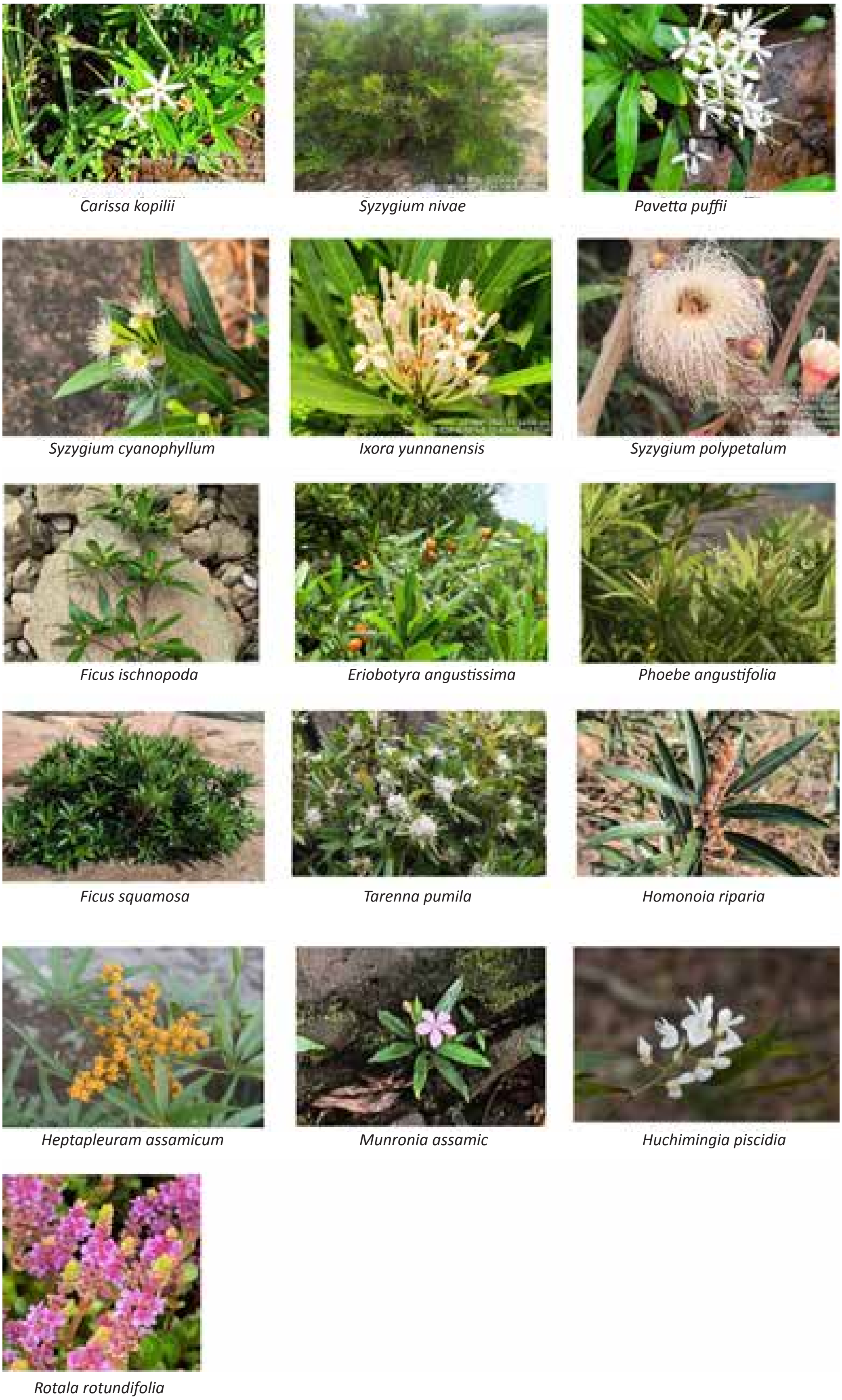


**Image 5. Rheophytes of the Kopili River Basin. © Jayanta Das.**

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SHORT COMMUNICATION

# First photographic record of Smooth-coated Otter *Lutrogale perspicillata* from the canals in Upper Ganga Ramsar Site, Uttar Pradesh, India

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**Abstract:** Smooth-coated Otter *Lutrogale perspicillata* is one of the three species of otters found in India. Photographs from the Lower Ganga Canal confirmed the presence of the species in the Ganga River in January of 2021 and 2023. This is the first confirmed record of a Smooth-coated Otter from the canal network of the middle stretch of the Ganga River. This observation indicates the rich aquatic and riparian habitat of the Ganga River, associated canal network along the Upper Ganga River Ramsar Site that needs to be conserved on priority.

**Keywords:** Biodiversity, Carnivora, conservation, distribution, Mammalia, Mustelidae, Narora Barrage.

Otters are semi-aquatic mammals of the family Mustelidae (Hung & Law 2016). Three species of otters are reported from the Indian subcontinent—Asian Small-clawed Otter *Aonyx cinereus*, Smooth-coated Otter *Lutrogale perspicillata*, and Eurasian Otter *Lutra lutra* (Hussain 1993; Khoo et al. 2021). Otters, as a top predator of their ecosystems, are highly vulnerable to human-induced changes in the ecosystem (Peterson & Schulte 2016). The Smooth-coated Otter is an elusive and amphibious carnivore species (Hussain 1993). It has a widespread distribution range in India owing to its diverse habitat choices, ranging from forested rivers and freshwater wetlands to mangroves (Hussain & Choudhury 1995, 1997). The population of Smooth-coated Otters is believed to have declined significantly in the past three decades owing to the intentional killing by fishermen, habitat loss, and destruction (Nawab & Hussain 2012). Although otters exhibit a higher tolerance towards human presence, they continue to experience conflict with humans over fish resources and are subject to indiscriminate killing (Shariff 1984; Foster-Turley 1992). As a result, the species is listed as 'Vulnerable' in the IUCN Red List of Species and Appendix I of CITES (Hussain & Choudhury 1997; Nawab & Hussain 2012; Peterson & Schulte 2016; Khoo et al. 2021). Despite the alarming rate of population declines, the information about otters' occurrence in India remains sparse and not well-documented (Hussain & Choudhury 1997; Khoo et al. 2021).

Presently, otter distribution is fragmented into small populations across its range (Hussain 1999 ). Most of the sighting records in the upper gangetic plains are confined to the Terai Region of Uttarakhand, Uttar Pradesh, Bihar, and Nepal (Hussain 2002; Nawab & Hussain 2012; Gupta et al. 2020; Basak et al. 2021). Beyond the Terai Region, scattered populations of Smooth-coated Otters have been reported from the Ganga River in State Wildlife

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**Competing interests:** The authors declare no competing interests.

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Barasingha Sanctuary (formerly Hastinapur Wildlife Sanctuary), Ghaghara, Girwa, Babai, Rapti, Chambal rivers and streams of Son River in India and the Narayani River in Nepal (Hussain 1993; Acharya 1998; Khan et al. 2014; Rathar et al. 2019; Bashyal & Yadav 2020; Gawan et al. 2022; Acharya et al. 2023).

## Materials and Methods

The survey was conducted along the banks of the Ganga River between Brijghat and Narora (Image 1). The grassland patches and riparian areas along the Ganga River were surveyed to assess the presence of Smooth-coated Otter. The stretch of the Ganga River between Brijghat and Narora is designated as the Upper Ganga River Ramsar Site (Ramsar site no. 1574). The river stretch has fragmented grassland patches along the banks and on islands. The major vegetation of these grassland patches includes *Typha* sp., *Phragmites* sp., and *Sachharum* sp. This stretch of the river is inhabited by the Gangetic Dolphin *Platanista gangetica*, 76 species of waterbirds, Gharial *Gavialis gangeticus*, Mugger *Crocodylus palustris*, and six species of turtles (WII-GACMC 2018; Usmani et al. 2025). The major terrestrial species include Sambar *Rusa unicolour*, Hog Deer *Axis porcinus,* Chital *Axis axis*, and Leopard *Panthera pardus* (Usmani 2010).

Previous studies and surveys of otters in Uttar Pradesh were restricted to the State Wildlife Barasingha Sanctuary, and no rigorous attempt was made to understand the status of otters in further downstream areas. As a part of the long-term study to document the biodiversity of the Ganga River and its tributaries, we conducted boat-based visual encounter surveys to collect information on the presence of otters. Along with the field information, secondary information on the presence of the otter was gathered from locals, especially farmers and fishermen. Photographs of species and their pugmarks were shown for identification. Google Earth images were used to identify the potential habitat along the Ganga River. Each patch of potential habitat

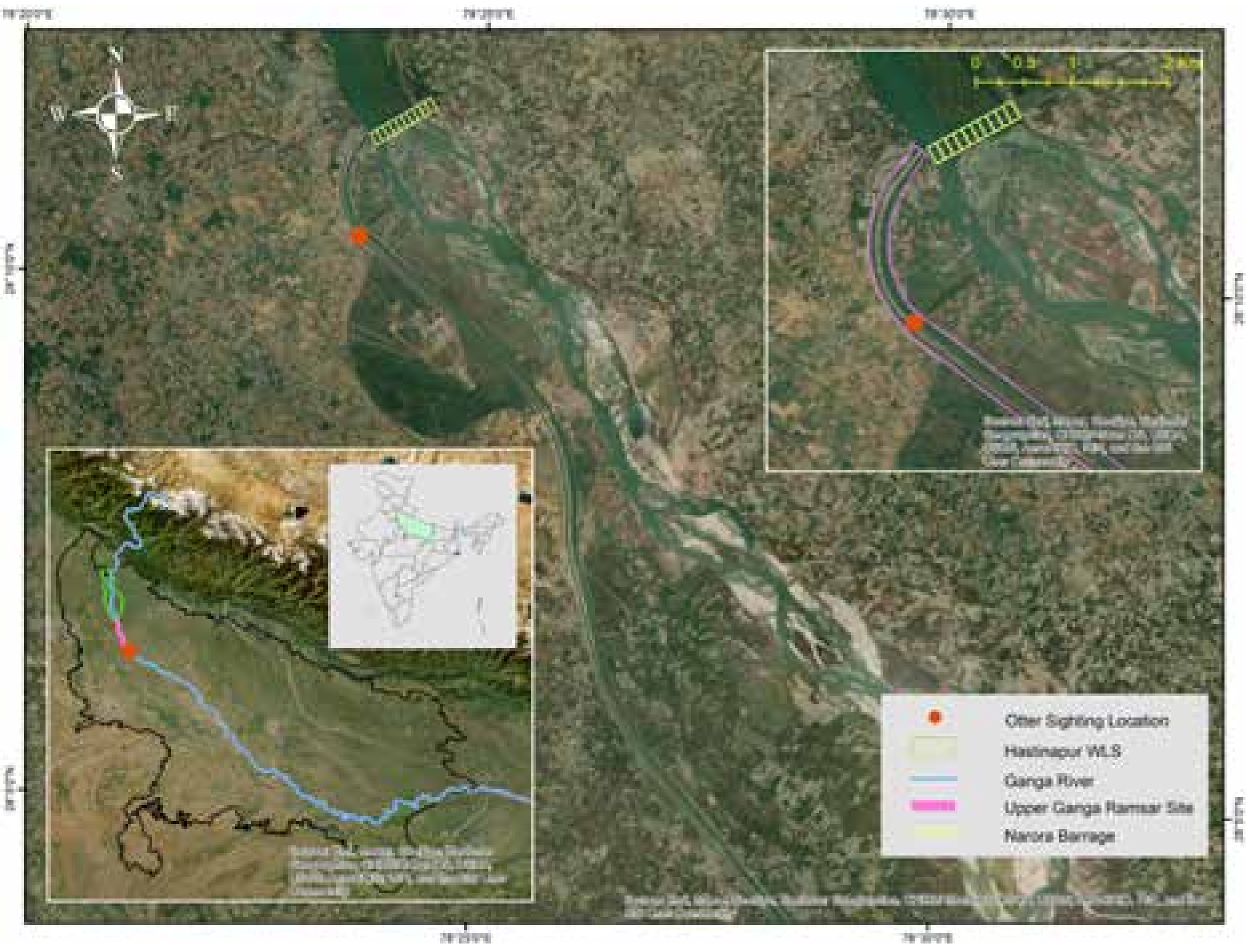


**Image 1. The location of Smooth-coated Otter sighting near the Narora Barrage.**

Image 2–4. Smooth-coated Otter seen in January 2023. © Aftab Alam Usmani.

was extensively surveyed both by walking and using a boat for otters. The entire surveyed area was outside the protected area.

## Results

An adult otter individual was seen on the afternoon of 16 January 2023 in the concretized section of the Lower Ganga Canal approximately 1 km from the Lower Ganga Barrage at Narora, District Bulandshahr, Uttar Pradesh ($28.174^0$ N, $78.393^0$ E) (Image 1). The otter was seen crossing the canal and moving towards the Ganga river (Images 2–4). Another individual was sighted fishing in the canal on 5 January 2021 (Images 5 & 6), approximately 100 m away from the previous observation ($28.175^0$ N, $78.393^0$ E). The Lower Ganga Canal supports a rich diversity of fish species (n = 15) that constitutes the primary prey base for otters, and its densely vegetated banks provide suitable shelter and resting sites for the otters (Nawab & Hussain 2012).

## Discussion

Anecdotal sightings of otters have been reported from the Ganga River in Haridwar, Uttarakhand. Indirect evidence of Smooth-coated Otters was also recorded from the State Wildlife Barasingha Sanctuary (Bashir et al. 2012; Khan et al. 2014). Studies conducted thereafter assumed the otter to be locally extirpated in the Ganga River downstream of State Wildlife Barasingha Sanctuary to Kanpur Barrage (Rao 2001). However, recent sightings of smooth-coated otters in 2021 and 2023 have proved the presence of the species in the irrigation canal network in the area.

The stretch of the Ganga River around Narora has abundant sandy banks with gradual slopes and vegetation cover, which provides a good habitat for smooth-coated otters. The sites are suitable due to low disturbances,


Image 5–6. Smooth-coated Otter seen in January 2021. © Aftab Alam Usmani.

abundant prey base, and banks with densely covered vegetation (Stephen et al. 2022; Gwachha et al. 2023; Moun et al. 2024). These factors have contributed to the survival of the Smooth-coated Otters in this area. The stretch falls near the exclusion zone of the Narora Atomic Power Plant (NAPS), which is characterised by dense vegetation cover, low human disturbances, and a high prey base. The area is surrounded by agricultural landscapes with interspersed, densely populated villages and towns with a population density of 836 individuals/ $km^2$ (GUP 2021). The canal and the Ganga River in this area are extensively exploited for fishing using gill nets and cast nets. The common fish fauna of the area includes *Labeo rohita*, *Labeo catla*, *Sperata seenghala, Puntius sophore*, *Bagarius bagarius,* and *Wallago attu*.

Intensive fishing, uncontrolled burning, occasional sand mining, conversion of grass patches into croplands along the Ganga River and canal, and intentional killing of otters by the fisherman community, are the major threats to the otter in the area (Nawab & Hussain 2012; WII-GACMC 2018). Habitat loss and degradation by the construction of dams and barrages may further accelerate the extinction threat of declining otter populations (Nawab 2007). Fragmented habitat patches might not be sufficient to shelter a functional social otter group or breeding otters with poor dispersal ability (Collinge 1996; Lambeck 1997).

The Ganga River and associated aquatic habitat in this area also face a wide range of disturbances, including occasional cases of poaching, uncontrolled burning, agricultural encroachment, intensive grazing, and unsustainable vegetation extraction (Hussain & Choudhury 1997; Nawab & Hussain 2012; Peterson & Schulte 2016; Khoo et al. 2021). The otter population in this area is highly vulnerable to these stressors, and conservation interventions are required for the long-term survival of otters in the region between Narora and Kanpur. Further, efforts to engage local communities are essential for the conservation and long-term service of the species. The Upper Ganga Canal provides stable aquatic habitat with dense riparian vegetation on the banks, supporting diverse fish assemblages. Water availability fluctuates seasonally based on the irrigation schedule, with reduced flows during non-cropping periods limiting habitat extent. Major threats to the canal include intensive fishing and the introduction of invasive species.

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SHORT COMMUNICATION



# First camera-trap evidence of a ferret badger *Melogale* sp. (Mammalia: Carnivora: Mustelidae) from the community forests of Manipur, India

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**Abstract:** Individuals of *Melogale* sp. were photographed on multiple occasions through camera traps deployed in the community forest of Godha Village under Phungyar Sub-Division of Kamjong District, in Manipur, India. The species were photographed from fragmented forest patches along the village's vicinity. The species was identified only at the genus level based on morphometric characteristics and may either be Small-toothed Ferret Badger *Melogale moschata* or Large-toothed / Burmese Ferret Badger *M. personata* as it was not possible to confirm at species level simply based on camera-trap images. The study represents the first confirmed camera-trap record of *Melogale* sp. from the community forest of Manipur ascertaining the distribution records of these lesser-known species from northeastern India. It further supports their nocturnal foraging behaviour and elusive nature in the wild.

**Keywords:** Burmese Ferret Badger, Chinese Ferret Badger, distribution, fragmented forest, Large-toothed Ferret Badger, lesser-known carnivore, *Melogale moschata*, *Melogale personata*, northeastern India, Small-toothed Ferret Badger.

Ferret badgers, namely, the Chinese or Small-toothed Ferret Badger *Melogale moschata* and the Large-toothed or Burmese Ferret Badger *M. personata* are among the lesser-known species from the family Mustelidae that are indigenous to eastern and southeastern Asia. While a number of reports are available on the distribution, ecology, and diet on other groups of badgers such as the Hog Badger *Arctonyx collaris* and the Honey Badger *Mellivora capensis*; the genus *Melogale* remains the least studied of badgers (Shepherd 2012; Thomas et al. 2021). They are often overlooked by the scientific research community mainly due to their elusive nocturnal behaviour and wide distribution pattern compared to other popular small carnivores in the landscapes (Duckworth et al. 2016a, 2024).

Both species of ferret badgers, i.e., *M. moschata* (Gray, 1831), and *M. personata* (I. Geoffroy Saint-Hilaire, 1831) are reported to be native and also extant across Province of China, Cambodia, northeastern India, Lao People's Democratic Republic, Myanmar, Taiwan, Thailand, Viet Nam, and a few uncertain populations in Bhutan (Storz & Wozencraft 1999; Duckworth et al. 2016a,b, 2024). More recent data suggests the presence of *M. personata* from the Himalayan foothills in Nepal as new range extension (Bhatta et al. 2021; Pathak et

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al. 2022). Till date, from India there are confirmed distribution records of *Melogale* sp. from different parts of the northeastern states such as from the Balpakram National Park, and a village community forest in Meghalaya to East Kameng District of Arunachal Pradesh (Kakati et al. 2014), Dampa Tiger Reserve in Mizoram and community forest in Mokokchung District of Nagaland (Choudhury 2013; Ved & Zathang 2014), Gumti Wildlife Sanctuary, and from the surrounding 'jhum' fields in Tripura (Patil et al. 2025). The assessment of IUCN Red List of Threatened Species categorises both the Burmese Ferret Badger and the Chinese Ferret Badger as 'Least Concern' species with uncertain population size and trend (Duckworth et al. 2016b, 2024). Although categorized as 'Stable' population, the lack of distinct morphological traits makes it difficult to differentiate them in wild without physical examination, thus proving challenges in accurate determination of their actual population status and distribution pattern, home range or habitat usage.

In this study, we present conclusive evidence for the occurrence of the *Melogale* sp. from the community forest of Kamjong District in Manipur India. The study will further aid to its geographic and ecological distribution in southern Asia, particularly in the northeastern states of India where hunting and traditional bushmeat consumption are integral part of the communities which may pose long-term conservation challenges.

## Material & Methods

### Study area

Camera trapping was carried out in Godah Village (23.893$^{0}$ N & 94.343 $^{0}$E) under Phungyar Sub-division of Kamjong District which was newly created on 08 December 2016. The district shares a long international border with Myanmar in the east and is also bounded by Ukhrul in the north, Imphal-East on the west, and Chandel in the south (Image 1). The terrain of the district is hilly with varying heights of 913–3,114 m. The forest type in the study area is of tropical deciduous forest comprising of a mosaic of forest patches consisting of secondary forest, slash-and-burn fields, and woody shrubs with dominant plant species such as *Dipterocarpus turbinatus*, *Schima wallichii*, *Castanopsis indica*, and bamboo species like *Dendrocalamus strictus* and *Melocanna baccifera*. Kamjong District is mainly inhabited by the Tangkhul Nagas, comprising 94% of the total population with the Kukis comprising 4.59% of the district. The climate of the district is of temperate nature with a minimum and maximum degrees of 3–33 $^{0}$C.

### Methods

The study was a pilot scale approach designed to document the presence of small carnivores in the community forest (4 $km^2$) targeting especially the Chinese Pangolin *Manis pentadactyla* using grid size of 1 × 1 km cells. In the survey, one passive camera-trap

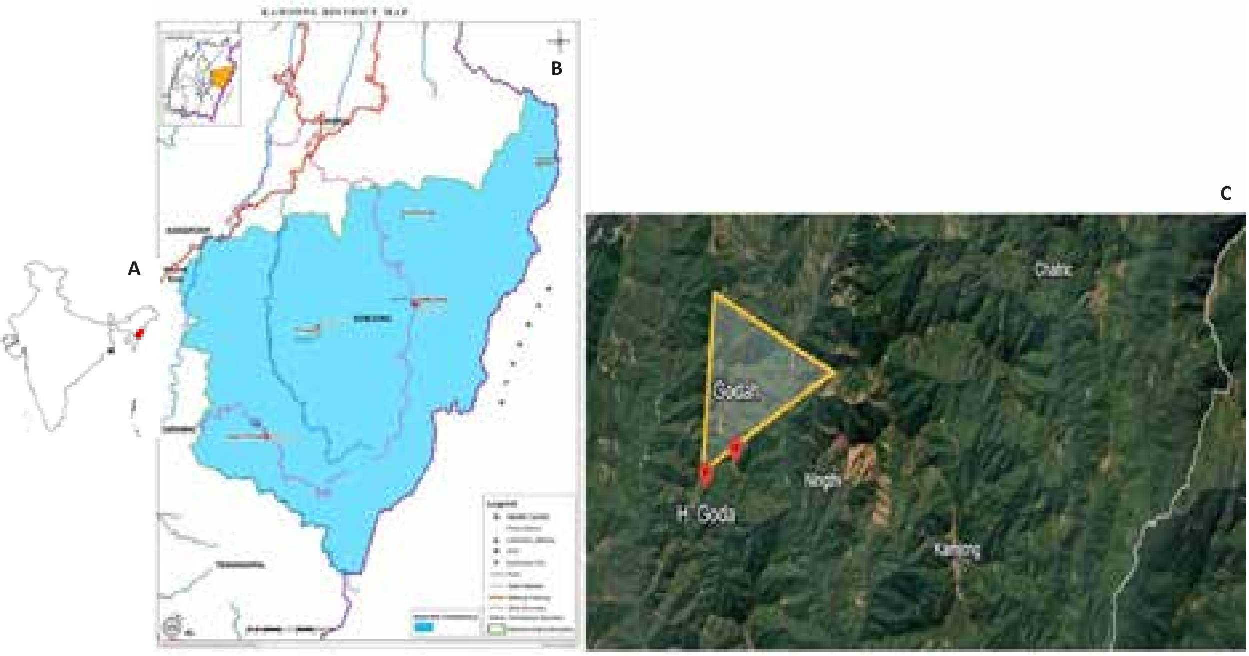


**Image 1. Map of the study site showing Godah Village in Kamjong District of Manipur, India. A—India (highlighting Manipur State | B—Kamjong District, Manipur | C—Kodah community forest.**

was deployed per grid, camera traps (Model Cuddeback X-Change IR) were installed for a period of 30 days from 02 August to 02 September 2025, along forest trails and other crossing points at appropriate height. Cameras were checked at regular intervals for battery, physical obstacles, and proper functionality.

## Results

During the study period, a total of 40 independent images and 38 short-timed videos of ferret badger *Melogale* sp. were recorded from 31 camera-trap nights from the four camera trap locations (Image 1). The images obtained through camera trapping process confirms the presence of Melogale sp. from the community forest. It also represents their higher degree of adaptability to degraded forest and anthropogenic pressure. All the images were recorded between 2000 h and 2300 h ascertaining their nocturnal behaviour and feeding ecology. A pair of ferret badgers were also photographed together during the survey period. The habitat type of the trap locations where the ferret badgers were recorded consists of bamboo brakes and regenerated secondary forest formed upon shifting cultivation (jhum).

## Discussion

Increase in wildlife research, modern day tools & techniques, and the reach to different parts of the globe had led to reporting of many of the lesser-known species in wild. *Melogale* sp. which are seldom studied in their natural habitat remains a prime example. While the presence of *Melogale* spp. from Manipur was first reported by Ramakantha (1992), the study herein provides the first camera-trap images of *Melogale* spp. from the state, re-affirming their distribution.

Echoing to previous finding on the habitat use by

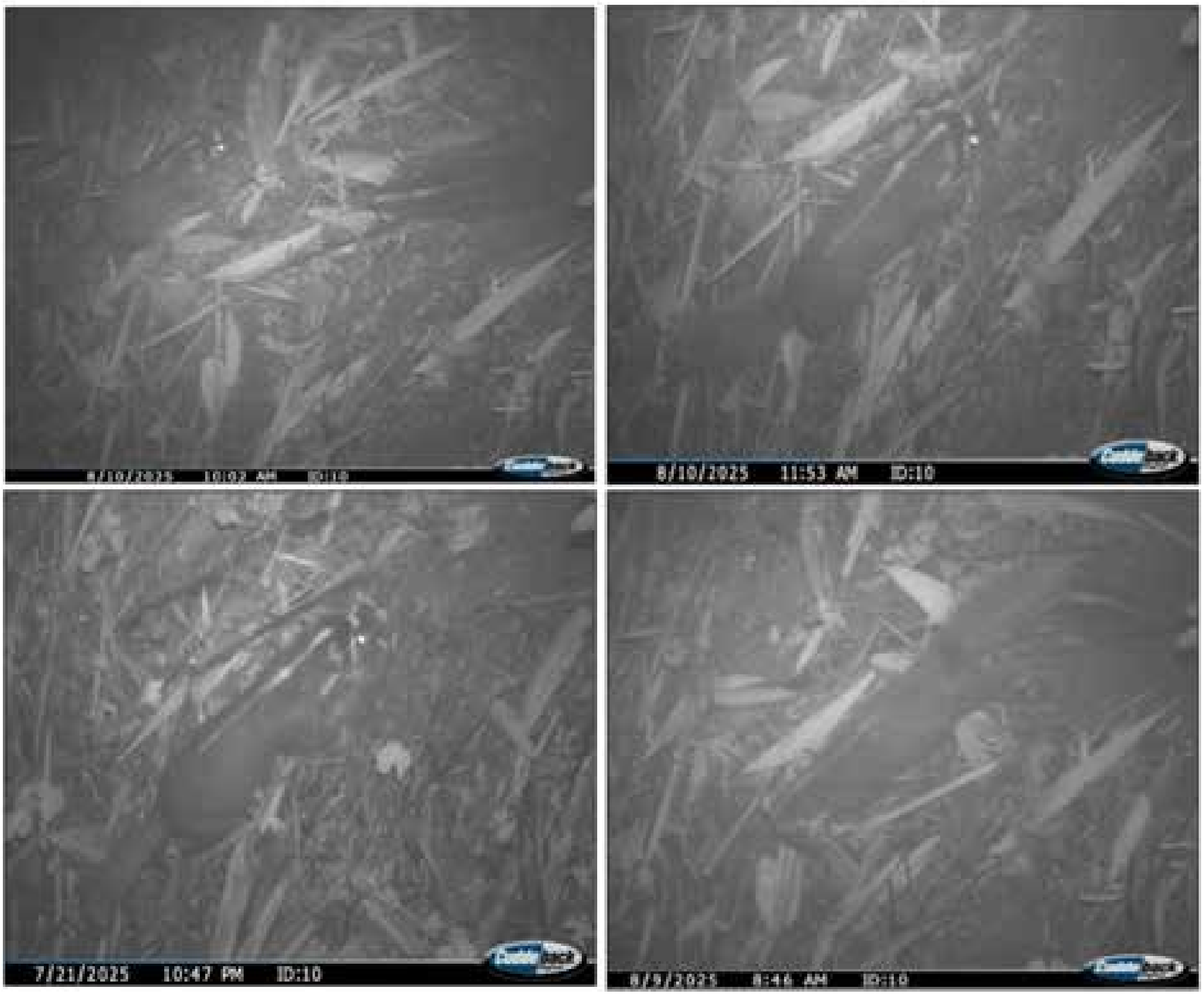


**Image 2. Camera trap images of ferret badger on various occasions during the study period.**

ferret badger from the northeastern states of India (Kakati et al. 2014; Pathak et al. 2022; Patil et al. 2025), our study also reports the use of secondary forest in the vicinity of the village by ferret badgers. Successful adaptation to human environment and lack of direct conflict with humans can also be attributed to the selection by ferret badgers (Wang & Fuller 2003). The presence of ferret badgers in areas close to humans can often be beneficial as they are known to be frugivorous and endozoochorous seed dispersers. Ferret badgers often support in germination and regeneration of plant species like *Clematoclethra scandens*, *Actinidia chinensis*, *Hovenia dulcis*, and *Dendrobenthamia japonica* (Zhou et al. 2008). While ferret badgers are yet to be listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) list; trading and regular consumption of ferret badgers as bushmeat or as live pets particularly in the Indo-Chinese region continues to persist and poses future conservation challenges (Boyd et al. 2003; Shepherd 2012; Thomas et al. 2021). In India, as both species of ferret badgers have been observed with their ranges majorly overlapping across the Asian mainland (Ved & Zathang 2014; Patil et al. 2025), more reporting on ferret badgers and detail studies are needed to affirm their distribution and habitat preference. As differentiation between the small-toothed/Chinese and large-toothed or Burmese Ferret Badger continue to confuse researchers until physical examination of the molar teeth, our study also endorses targeted research programmes and conservation initiatives to conserve these species in the long run.

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SHORT COMMUNICATION



# Species composition of butterflies associated with nectar feeding on *Libidibia coriaria* (Jacq.) Schltdl (Magnoliopsida: Fabales: Fabaceae)

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**Abstract:** Butterflies are vital bioindicators and pollinators, with their diversity often reflecting ecosystem health. This study assessed the species richness of butterflies visiting *Libidibia coriaria* during its flowering season within the Kerala Agricultural University campus. A total of 41 butterfly species were recorded, representing approximately 29.5% of the 139 butterfly species previously documented from the campus. The high species richness observed around *L. coriaria* underscores its ecological importance as a key nectar source that sustains butterfly foraging activity.

**Keywords:** Bioindicators, butterfly host, conservation, Divi-divi, foraging behaviour, Kerala Agricultural University, nectar feeding, phenology, plant-pollinator interactions, urban health.

Butterflies, often considered the winged jewels of the insect world, play a vital role as pollinators in diverse ecosystems worldwide. Both in their adult and larval stages, butterflies depend on specific plants for their feeding needs. This intricate relationship between butterflies and plants results in varied distribution patterns of butterflies across different habitats and vegetation types (Huang et al. 2024). As such, the mutualistic connection between butterflies and plants reflects the diversity of plant life in an area and highlights butterflies as indicators of ecosystem health (Nimbalkar et al. 2010). *Libidibia coriaria*, commonly known as Divi-Divi, is a small to medium-sized evergreen tree belonging to the family Leguminosae. It is distributed throughout central America and northern South America. It has been introduced in India in 1834 as a shade tree in urban landscapes (Chacko et al. 2002). The flowers are small, yellow, and fragrant, and arranged in axillary to subterminal small panicles or clusters, much exceeded by subtending leaves (Deepakkumar & Ramanan 2016). The morphology of flowers, particularly their size and shape, along with the structure of the pollinators' feeding apparatus, determines the effectiveness of plant-pollinator interactions. The flowers of *L. coriaria*, when in bloom, have exposed reproductive structures. Butterflies visiting these flowers move through the inflorescences, during which their legs, proboscis, and head come into contact with the reproductive organs, thereby facilitating pollination (Meerabai 2021). The present study was undertaken to analyse the species composition and feeding behaviour of butterflies associated with nectar foraging on the flowers of *Libidibia coriaria*.

## Study area

The observations were taken from the *Libidibia coriaria* trees planted in the main campus of Kerala

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Agricultural University (KAU), situated in Vellanikkara, Thrissur District, Kerala, at a geographic coordinate range of 10.544–10.553 °N and 76.288–76.284 °E (Figure 1). The main campus is also located near the Peechi-Vazhani Wildlife Sanctuary, which is part of the Western Ghats, a globally recognised biodiversity hotspot. During the study period, the average temperature ranged 24.02–31.76 °C, with a mean annual rainfall of 14.1 mm (KAU Weather Station 2024).

## Methods

Four individuals of *Libidibia coriaria*, planted along the avenues of the KAU main campus, were selected for the observations. Data were collected twice daily, from 08.30–11.00 h and 15.30–17.00 h, during the flowering period of *L. coriaria* (i.e., August–September). Digital photographs were taken using a Nikon Z 50 mirrorless camera, and the butterflies visiting the flowers were recorded. For every species observed, the duration of each floral visit was noted, and based on these data, the minimum and maximum time spent by each species on the flowers were documented. Species identification was carried out using field guides by Kunte (2000), Kehimkar (2008), and Bhakare & Ogale (2018).

## Result and discussion

A total of 41 butterfly species, comprising 1,106 individuals and representing five families, were recorded during the study period (Table 1; Image 1–34). The families Nymphalidae, Hesperiidae, and Papilionidae were the most species, each accounting for 24.39% of the total species documented (n = 10) followed by Pieridae (n = 6) and Lycaenidae (n = 5) (Figure 2).

**Nymphalidae**—*Hypolimnas bolina* was the most frequent floral visitor (n = 150), with a nectar-feeding duration ranging from 40–47 s per visit, whereas *Danaus genutia* exhibited the longest nectar-feeding duration among the recorded nymphalids (53–57 s per visit).

**Lycaenidae**—Among the Lycaenidae, *Rapala manea* was the most dominant nectar feeding species (n = 60), exhibiting the longest feeding duration of 88–96 s per visit followed by *Jamides celeno* (19–23 s per visit) and *Acytolepis puspa* (16–22 s per visit).

**Hesperiidae**—Nectar-feeding durations were longest

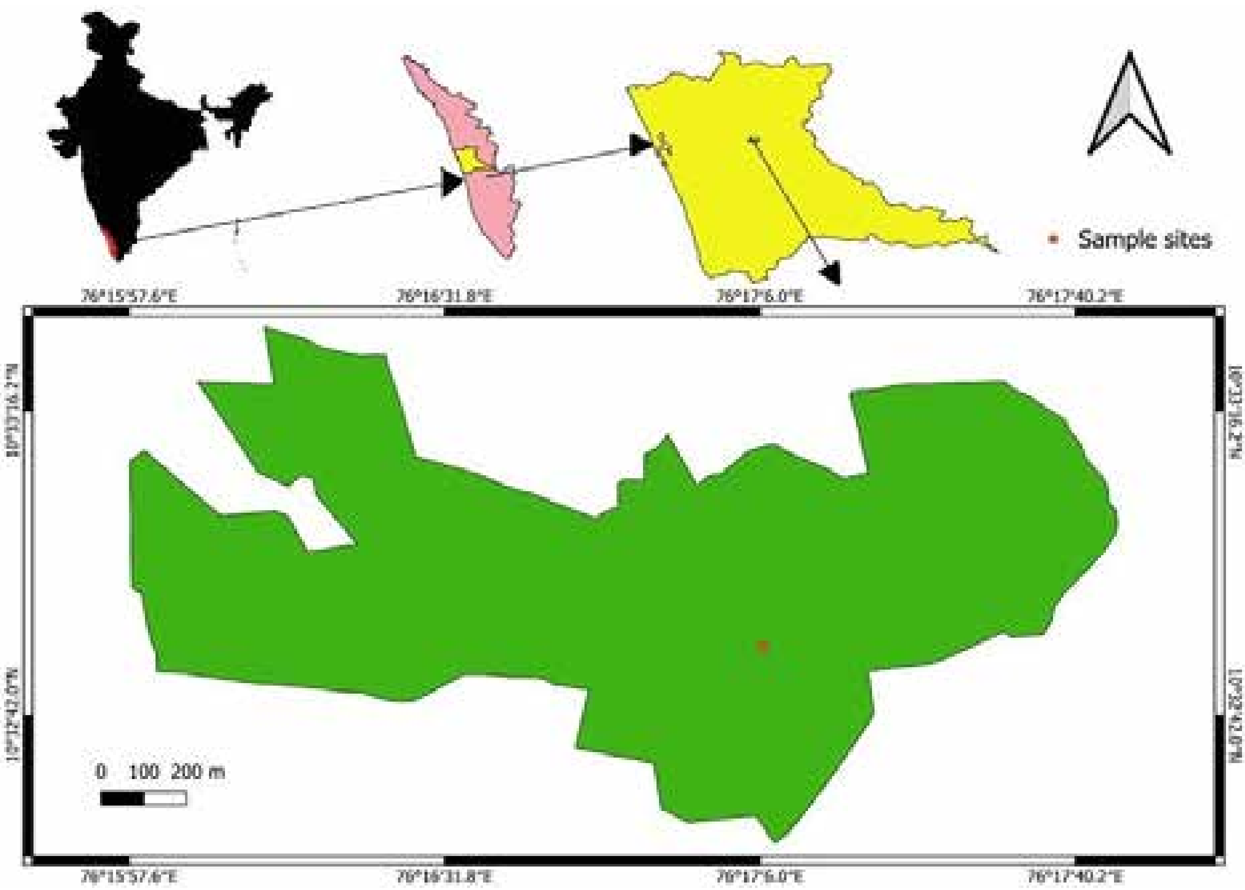


**Figure 1. Location map of the Kerala Agricultural University main campus.**

**Table 1. Species composition of butterflies recoded during the nectar feeding on *Libidibia coriaria*.**

| | Common name | Scientific name | No. of individuals recorded | Time spent on nectar feeding (s) |
|---|---|---|---|---|
| **Family: Papilionidae** | | | | |
| 1. | Crimson Rose | *Pachliopta hector* (Linnaeus, 1758) | 30 | 90–98 |
| 2. | Common Rose | *Pachliopta aristolochiae* (Fabricius, 1775) | 20 | 72–80 |
| 3. | Tailed Jay | *Graphium agamemnon* (Linnaeus, 1758) | 56 | 12–16 |
| 4. | Common Jay | *Graphium doson* (C. & R. Felder, 1864) | 34 | 11–18 |
| 5. | Common Bluebottle | *Graphium sarpedon* (Linnaeus, 1758) | 15 | 15–18 |
| 6. | Common Mormon | *Papilio polytes* (Linnaeus, 1758) | 2 | 10–12 |
| 7. | Blue Mormon | *Papilio polymnestor* (Cramer, 1775) | 2 | 6 |
| 8. | Lime Butterfly | *Papilio demoleus* (Linnaeus, 1758) | 1 | 5 |
| 9. | Southern Birdwing | *Troides minos* (Cramer, 1779) | 3 | 5–7 |
| 10. | Common Mime | *Papilio clytia* (Linnaeus, 1758) | 10 | 10–13 |
| **Family: Pieridae** | | | | |
| 11. | Common Emigrant | *Catopsilia pomona* (Fabricius, 1775) | 219 | 97–115 |
| 12. | Great Orange Tip | *Hebomoia glaucippe* (Linnaeus, 1758) | 1 | 6 |
| 13. | Three-spot Grass Yellow | *Eurema blanda* (Boisduval, 1836) | 2 | 9–12 |
| 14. | Common Grass Yellow | *Eurema hecabe* (Linnaeus, 1758) | 22 | 9–13 |
| 15. | Common Jezebel | *Delias eucharis* (Drury, 1773) | 73 | 35–39 |
| 16. | Mottled Emigrant | *Catopsilia pyranthe* (Linnaeus, 1758) | 3 | 9–12 |
| **Family: Nymphalidae** | | | | |
| 17. | Great Egg Fly | *Hypolimnas bolina* (Linnaeus, 1758) | 150 | 40–47 |
| 18. | Common Leopard | *Phalanta phalantha* (Drury, 1773) | 7 | 5–12 |
| 19. | Chocolate Pansy | *Junonia iphita* (Cramer, 1779) | 24 | 12–19 |
| 20. | Striped Tiger | *Danaus genutia* (Cramer, 1779) | 7 | 53–57 |
| 21. | Rustic | *Cupha erymanthis* (Drury, 1773) | 5 | 6–9 |
| 22 | Common Castor | *Ariadne merione* (Cramer, 1777) | 10 | 7–13 |
| 23 | Tamil Yeoman | *Cirrochroa thais* (Fabricius, 1787) | 4 | 7–10 |
| 24. | Glassy Tiger | *Parantica aglea* (Stoll, 1782) | 4 | 9–12 |
| 25. | Blue Tiger | *Tirumala limniace* (Cramer, 1775) | 2 | 37 |
| 26. | Common Crow | *Euploea core* (Cramer, 1780) | 7 | 19–21 |
| **Family: Lycaenidae** | | | | |
| 27. | Slate Flash | *Rapala manea* (Hewitson, 1863) | 60 | 88–96 |
| 28. | Common Cerulean | *Jamides celeno* (Cramer, 1775) | 11 | 19–23 |
| 29. | Common Hedge Blue | *Acytolepis puspa* (Horsfield, 1828) | 7 | 16-–22 |
| 30. | Redspot | *Zesius chrysomallus* (Hübner, 1819) | 4 | 4–12 |
| 31. | Red Pierrot | *Talicada nyseus* (Guérin-Meneville, 1843) | 1 | 4 |
| **Family: Hesperiidae** | | | | |
| 32. | Common Banded Awl | *Hasora chromus* (Cramer, 1780) | 32 | 84–91 |
| 33. | Dark Palm Dart | *Telicota ancilla* (Moore, 1878) | 4 | 96–117 |
| 34. | White Banded Awl | *Hasora taminatus* (Hübner, 1818) | 18 | 61–67 |
| 35. | Chestnut Bob | *Iambrix salsala* (Moore, 1865) | 81 | 90–96 |
| 36. | Restricted Demon | *Notocrypta curvifascia* (Felder & Felder, 1862) | 38 | 67–76 |
| 37. | Brown Awl | *Badamia exclamationis* (Fabricius, 1775) | 51 | 11–87 |
| 38. | Rice Swift | *Borbo cinnara* (Wallace, 1866) | 96 | 80–88 |
| 39. | Ceylon Swift | *Parnara bada* (Moore, 1878) | 1 | 19 |
| 40. | Indian Palm Bob | *Suastus gremius* (Fabricius, 1798) | 6 | 70–76 |
| 41. | Conjoined Swift | *Pelopidas conjuncta* (Herrich-Schäffer, 1869) | 1 | 12 |

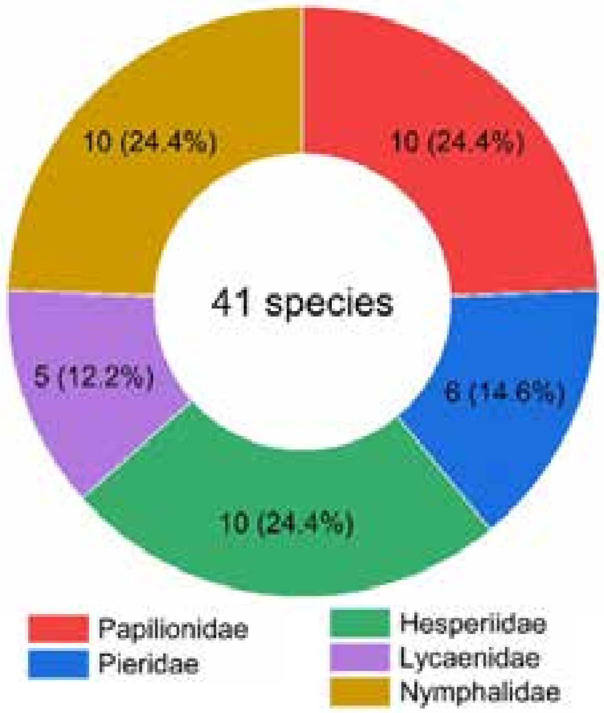


**Figure 2. Family-wise distribution of butterflies associated with nectar feeding on *Libidibia coriaria*.**

in *Telicota ancilla* (n = 4), with visits ranging from 96–117 s, suggesting that skippers, particularly this species, engage in more prolonged floral foraging. In addition to *T. bambusae*, other hesperiids such as *Lambrix salsala* (90–96 s), *Hasora chromus* (84–91 s), and *Borbo cinnara* (80–88 s) also demonstrated consistently longer feeding durations compared to most other butterfly species recorded in the study.

**Pieridae**—Among the Pierids, *Catopsilia pomona* (n = 219) spent the longest time on nectar feeding, with durations ranging from 97–115 s per visit. This was followed by *Delias eucharis* (35–39 s per visit) and *Eurema hecabe* (9–13 s per visit), reflecting considerable variation in foraging duration among species within the family.

The temporal distribution and relative abundance of butterfly families observed throughout the flowering period of *Libidibia coriaria* is illustrated in Figure 3. Nymphalidae and Pieridae exhibited sustained and widespread presence across most days, indicating their continuous activity and possibly broader adaptability to the flowering period of *Libidibia coriaria*. Papilionidae and Hesperiidae exhibited relatively narrower fluctuations in

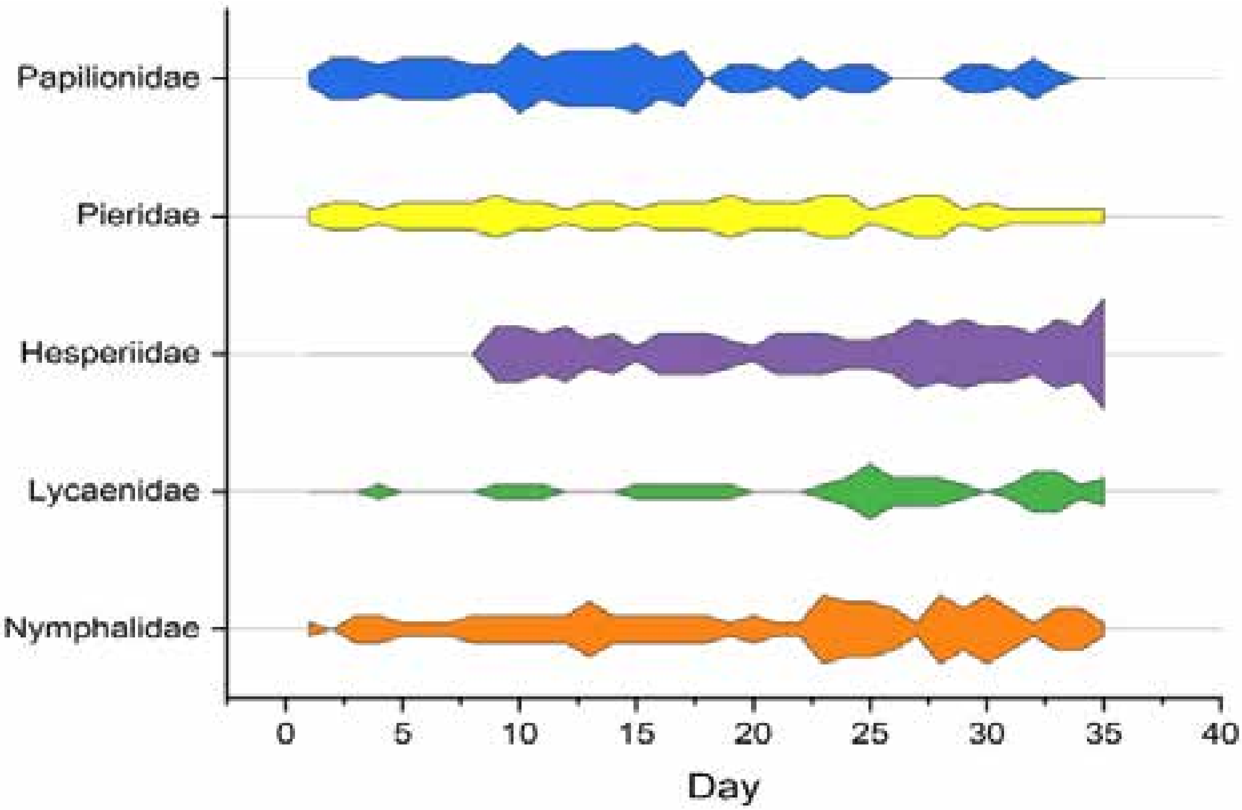


**Figure 3. Temporal distribution and relative abundance of butterfly families associated with nectar feeding on *Libidibia coriaria*.**


Image 1. *Acytolepis puspa*.


Image 2. *Ariadne merione*.


Image 3. *Badamia exclamationis*.


Image 4. *Borbo cinnara*.


Image 5. *Catopsilia pomona*.


Image 6. *Cirrochroa thais*.

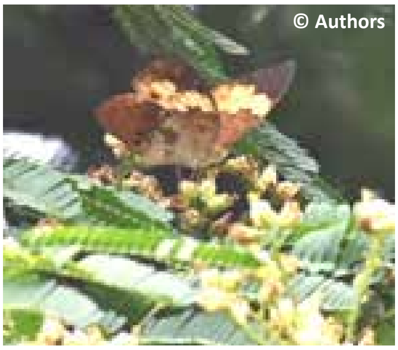


Image 7. *Cupha erymanthis*.


Image 8. *Danaus genutia*.


Image 9. *Delias eucharis*.


Image 10. *Euploea core*.


Image 11. *Eurema blanda*.


Image 12. *Eurema hecabe*.


Image 13. *Graphium agamemnon.*


Image 14. *Graphium doson.*


Image 15. *Hasora chromus.*


Image 16. *Hasora taminatus.*


Image 17. *Hypolimnas bolina.*


Image 18. *Iambrix salsala.*


Image 19. *Jamides celeno.*


Image 20. *Junonia iphita.*


Image 21. *Notocrypta curvifascia.*

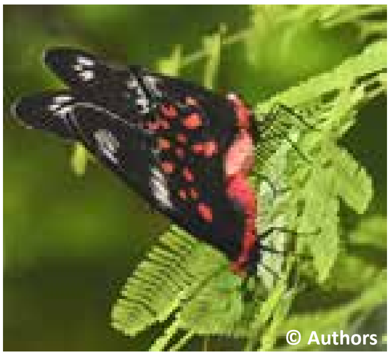


Image 22. *Pachliopta hector.*

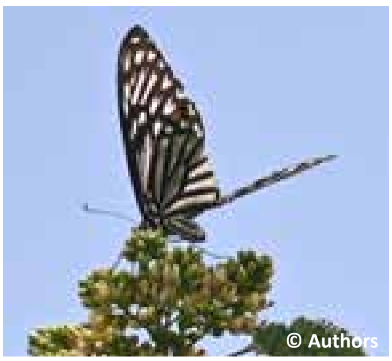


Image 23. *Papilio clytia.*


Image 24. *Papilio polytes.*


Image 25. *Parantica aglea.*


Image 26. *Parnara* sp.


Image 27. *Pelopidas conjuncta.*


Image 28. *Phalanta phalantha.*


Image 29. *Rapala manea.*


Image 30. *Suastus gremius..*


Image 31. *Talicada nyseus.*

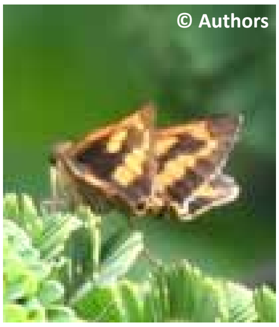


Image 32. *Telicota ancilla.*

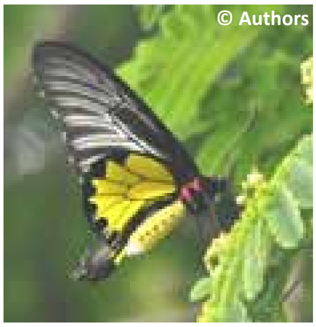


Image 33. *Troides minos.*


Image 34. *Zesius chrysomallus.*

abundance, indicating distinct periodic peaks in activity. Papilionidae were more active during the blooming stages of *Libidibia coriaria*, while Hesperiidae showed increased activity during the later stage of flowering.

## Conclusion

A total of 41 butterfly species documented in this study represents approximately 29.5% of the 139 species previously recorded from the KAU campus (Aneesh et al. 2013), highlighting the ecological significance of *Libidibia coriaria* as an important nectar resource. These findings emphasize the species' role in supporting butterfly diversity and foraging activity during its flowering phase. Notably, the strong association between floral resource availability and butterfly presence aligns with the observations of Martínez-Adriano et al. (2018), who reported that plant species serve as limiting factors for butterfly diversity and emphasized the functional role butterflies play in pollination networks, particularly in tropical habitats.

Despite being an introduced species, *L. coriaria* supports high butterfly diversity during its flowering phase, likely due to its abundant floral display, accessible floral morphology, and favourable nectar composition. This study underscores the importance of maintaining a diversity of nectar resources, to sustain pollinator networks, enhance habitat quality, and support long-term biodiversity conservation.

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SHORT COMMUNICATION



# New distribution records of five species of freshwater palaemonid prawns (Crustacea: Decapoda) in Nagaland, India

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**Abstract:** Freshwater palaemonid prawns of Nagaland is studied based on the collections made during different surveys from 1998 to 2022 by various survey teams of Zoological Survey of India, Kolkata. Though 20 species of palaemonid prawns are reported from northeastern states of India, there are no previous reports from Nagaland. During the present study five species of palaemonid prawns—*Macrobrachium cacharense* (Tiwari, 1952), *M. dayanum* (Henderson, 1893), *M. kempi* (Tiwari, 1949), *M. lamarrei lamarrei* (H. Milne Edwards, 1837), and *M. platyrostris* (Tiwari, 1952)—are reported and forms first report from this underexplored state of India.

**Keywords:** Caridae, Crustacea, *Macrobrachium*, northeastern India, Palaemonidae.

Freshwater prawns are popular crustaceans belonging to the order Decapoda, family Palaemonidae. They play an important role in the ecosystem for nutrient recycling. Being a source of good protein for human consumption they have a great economic value. The family Palaemonidae is represented by 160 genera and the genus *Macrobrachium* with 291 species (DecaNet eds. 2025) with 58 species in India (Valarmathi 2025).

Nagaland is a mountainous state rich in biodiversity lying between the parallels 95–94º E and 25.2–27.0º N. Though in other northeastern states 20 species of palaemonid prawns have been reported (Valarmathi & Mitra 2021), Nagaland remains unexplored.

The present report is the outcome of the analysis of prawns collected during the surveys from 1998 to 2022 by various teams of Zoological Survey of India.

## Material and Methods

Freshwater prawns were collected by using D-shaped scoop nets and local fishermen nets from hill streams, river banks, and small water drainages of Dimapur, Kiphire, Longleng and Peren districts of Nagaland. The collected prawns were anaesthetised by keeping them in an airtight container with a cotton ball immersed in clove oil, fixed in formaldehyde and preserved in 70% alcohol. Specimens were studied by using Leica, EZ4 microscope, Leica, Mc120D and Nikon DSLR camera were used for taking images. The species were identified using relevant literature (Jayachandran 2001; Henderson 1893; Tiwari 1949, 1952). The identified specimens were deposited with registration number in the National Zoological Collection of Crustacea Division, Zoological Survey of India (ZSI), Kolkata.

## Result

The present study reveals the occurrence of five species of *Macrobrachium* in Nagaland namely *Macrobrachium cacharense* (Tiwari, 1952), *M. dayanum* (Henderson, 1893), *M. kempi* (Tiwari, 1949), *M. lamarrei lamarrei* (H. Milne Edwards, 1837), and *M. platyrostris* (Tiwari, 1952), previously not recorded from the state.

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**Competing interests:** The author declares no competing interests.

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**Systematics**
Subphylum Crustacea Brünnich, 1772
Class Malacostraca Latreille, 1802
Subclass Eumalacostraca Grobben, 1892
Superorder Eucarida Calman, 1904
Order Decapoda Latreille, 1802
Suborder Pleocyemata Burkenroad, 1963
Infraorder Caridea Dana, 1852
Superfamily Palaemonoidea Rafinesque, 1815
Family Palaemonidae Rafinesque, 1815
Genus *Macrobrachium* Spence Bate, 1868

**1. *Macrobrachium cacharense* (Tiwari, 1952)**
(Image 1D)

1952. *Palaemon hendersoni cacharensis* Tiwari, *Ann. Mag.Nat.Hist*., V (ser.12): 32

2001. *Macrobrachium hendersoni cacharensis* Jayachandran, Prawns Biodiversity, Taxonomy, Biology and Management. Oxford & IBH Publishing Co. Pvt. Ltd. Calcutta. 107.

Material examined: C9795/2 -1 male, 2 females, 23.viii.2022, Stream near Longleng River, Nagaland, coll. Thangavel Kubendran.

Diagnosis: Rostrum short, convex reaching to the tip of the antennular peduncle; dorsal margin with 8–9 teeth of which 2–3 are on the carapace, ventral margin with 2–3 teeth. Second pereiopods larger, chela with characteristic grooves and pubescence restricted to 2/3$^{rd}$ of the proximal part of the fingers.

Distribution: India (Assam, Meghalaya, & Nagaland).

Remarks: This species was described as a sub species of *M. hendersoni* by Tiwari (1952) from Cachar District, Assam and it differs from typical *M. hendersoni* by the nature of the rostrum as well as the by lack of flute and pubescence in the distal 1/3$^{rd}$ of the chela of the 2$^{nd}$ pereiopod, *M. cacharense* is endemic to northeastern India.

**2. *Macrobrachium dayanum* (Henderson, 1893)**
(Image 1B)

1893. *Palaemon dayanus* Henderson, *Trans. Linn. Soc. London*, 5(2): 443; Plate 40, figs 7-13.

1950. *Macrobrachium dayanum* Holthuis, *Siboga Exped.Monogr*., 39(9): 197.

Material examined: C7420/2 -1 male, 1 female, 26.iii.2017, Dhansiri River, Ntanki National Park, Peren, Nagaland, coll. Panakkool Thamban Aneesh; C8420/2, 1 male, 5.vi.1998 from Broader cam experimental fish farm, Dimapur, Nagaland, coll. Dr. A.K. Karmakar.

Diagnosis: Rostrum longer than antennular peduncle and reaching the end of the antennal scale or little beyond it; dorsal margin of the rostrum with 5–11 teeth of which 1–3 are behind the orbit. In mature adults second pereiopods are comparatively stronger, the grooves and pubescence are more prominent in the fingers of the chela whereas in sub adults it is feeble and the chela is distinctly longer than carpus.

Distribution: India (Assam, Arunachal Pradesh, Bihar, Jharkhand, Goa, Madhya Pradesh, Meghalaya, Nagaland, Odisha, Punjab, Tripura, Uttarakhand, Uttar Pradesh, & West Bengal); Pakistan; Myanmar (Cai & Ng 2002); and Germany (Klotz et al. 2013).

Remarks: This species is widely distributed in central, northern and northeastern India.

**3. *Macrobrachium kempi*** (Tiwari, 1949)
(Image 1C)

1949. *Palaemon kempi* Tiwari, *Rec. Indian Mus.*, 45(for 1947): 330

2001. *Macrobrachium kempi* Jayachandran, Prawns Biodiversity, Taxonomy, Biology and Management. Oxford & IBH Publishing Co. Pvt. Ltd. Calcutta. 126.

Material examined: C7421/2, 7 males, 10 females, 26.iii.2017 from Dhansiri River, Ntanki National Park, Peren District, Nagaland, coll. Panakkool Thamban Aneesh.

Diagnosis: Rostrum short reaching up to the middle or end of the 3$^{rd}$ antennular peduncle; dorsal margin with eight teeth of which two are behind the orbit, ventral margin with 2–3 teeth. The second pereiopods are stronger, carpus is shorter than finger, palm and merus; fingers without grooves; inner palm with dense felt of hairs.

Distribution: India (Meghalaya); Bangladesh.

Remarks: This species was described by Tiwari (1949) based on the specimens collected from Chittagong, Bangladesh, and Ghosh et al. (1999) reported this species from Meghalaya, the species has been rarely reported.

**4. *Macrobrachium lamarrei lamarrei*** (H. Milne Edwards, 1837)
(Image 1E)

1837. *Palaemon lamarrei* H. Milne Edwards., *Hist. nat. Crustaces*, II: 397.

1950. *Macrobrachium lamarrei*: Holthuis, *SibogaExped. Monogr.,* 39(9): 119.

2001. *Macrobrachium lamarrei lamarrei*: Jayachandran Palaemonid Prawns Biodiversity, Taxonomy, Biology and Management. Oxford & IBH Publishing Co. Pvt. Ltd. Calcutta. 128.

Material examined: C9180/2, 2 males, 9 females, 18.ix.2021, Kiusam water channel near Bemi hills, Kiphire, Nagaland, coll. Santanu Mitra; C9181/2, 11 males, 13 females, Madziphima tributaries of Dhanusiri River, Dimapur, Nagaland, coll. Santanu Mitra.

Diagnosis: Rostrum extends to or longer than antennal

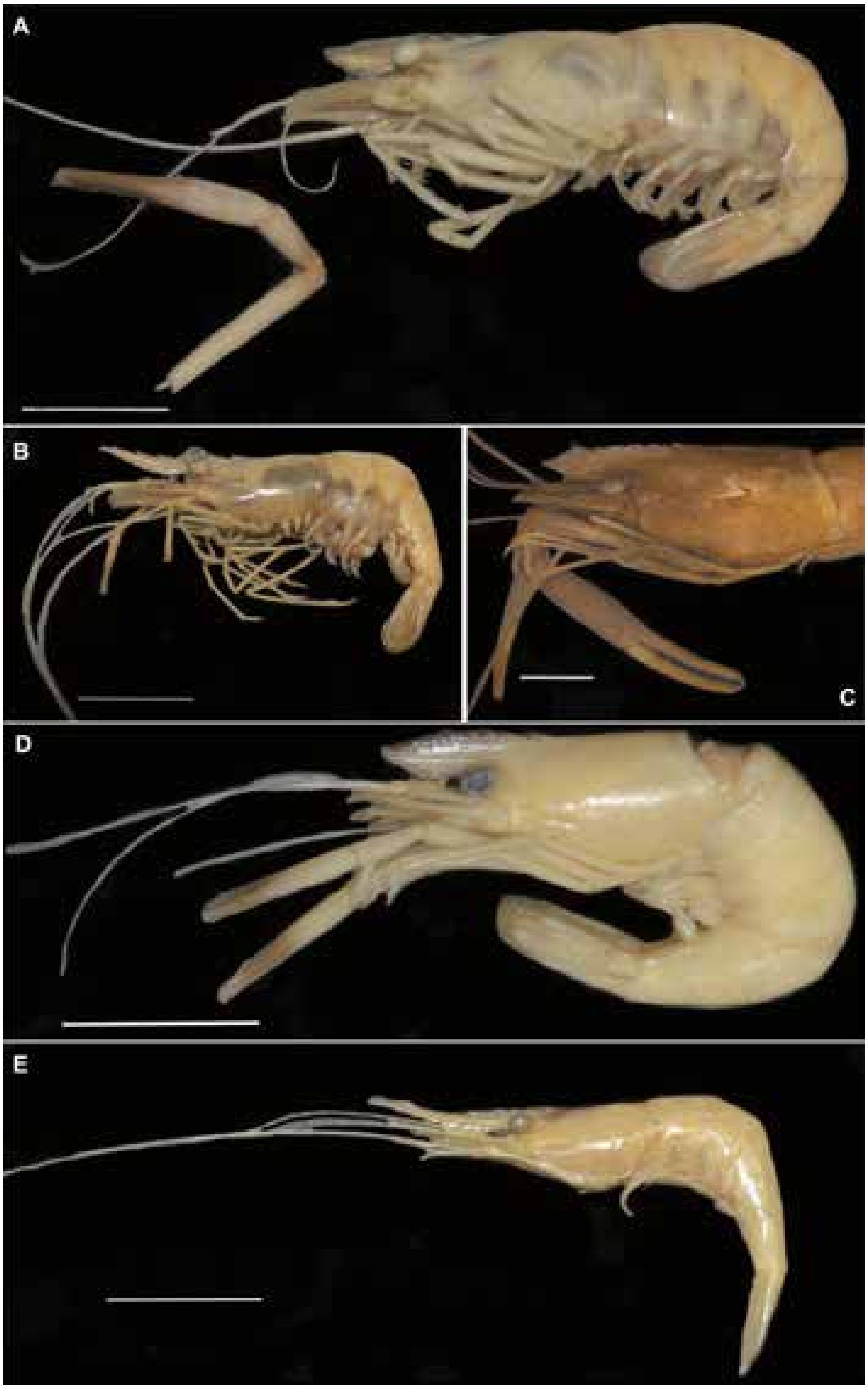


**Image 1. A—*Macrobrachium platyrostris* (Tiwari, 1952) | B—*M. dayanum* (Henderson, 1893) | C—*M. kempi* | D—*M. cacharense* (Tiwari, 1952) | E—*M. lamarrei lamarrei* (H. Milne Edwards, 1837). Scale bars: 10 mm. © K. Valarmathi.**

scale. Rostral formula 4-7+1-2 / 4-9 (1-2). Upper margin of the rostrum with proximal group of 4–7 teeth, widely separated from the distal 0-2 sub-terminal tooth. The second pereiopods are simple and similar in both the sexes, finger is shorter than palm; chela nearly ½ of the carpus; merus longer than chela but shorter than carpus.

Distribution: India: This is a very common and widely distributed species in various states of the country (but

**Key useful for species of *Macrobrachium* of Nagaland**

| | | |
|---|---|---|
| 1. | Rostrum longer than or equal to antennal scale | 2 |
| - | Rostrum always shorter than antennal scale | 3 |
| 2. | Second pereiopods slender and carpus is 1.5 to 2 times longer than chela, no pubescence and grooves in the fingers, ventral margin of the rostrum with 5–9 teeth | *M. lamarrei lamarrei* |
| - | Second pereiopods comparatively strong, carpus shorter than chela, fingers with pubescence and mild grooves, ventral margin of the rostrum with 4–7 teeth | *M. dayanum* |
| 3. | Fingers in the male second chela with grooves and without hairs on inner palm | 4 |
| - | Fingers in the male second chela without grooves and with hairs on inner palm | *M. kempi* |
| 4. | In adult male entire fingers of the second chela are with many grooves filled with hairs | *M. platyrostris* |
| - | In adult male, the fingers of the second chela are with many grooves and only 2/3rd filled with hairs | *M. cacharense* |

this is the first report to Nagaland); Bangladesh; Myanmar; and Pakistan.

Remarks: This common species adapts to most of the aquatic habitats like freshwater, estuarine and even subterranean water (Holthuis 1950).

**5. *Macrobrachium platyrostris*** (Tiwari, 1952)
(Image 1A)

1952*. Palaemon hendersoni platyrostris* Tiwari, *Ann. Mag. Nat. Hist*., V (ser.12): 32

2001. *Macrobrachium hendersoni platyrostris* Jayachandran Palaemonid Prawns Biodiversity, Taxonomy, Biology and Management. Oxford & IBH Publishing Co. Pvt. Ltd. Calcutta. 108.

Material examined: C9794/2, 1 male, 4 females, 23.viii.2022, Dikhu River, Near Tamlu, Longleng District, 96.695˚N; 94.803 ˚E, coll. Thangavel Kubendran.

Diagnosis: Rotrum short reaches up to the end of antennular peduncle, the dorsal margin of the rostrum is with 7–10 teeth of which 2–3 behind the orbit. Second pereiopods larger, chela with characteristic grooves and pubescence in the entire fingers.

Distribution: India (Assam, Arunachal Pradesh, Himachal Pradesh, Jharkhand, Manipur, Meghalaya, Nagaland, Tripura, Uttarakhand, & West Bengal); Myanmar (Cai & Ng 2002); China.

Remarks: This species was described as a subspecies of *M. hendersoni* by Tiwari (1952) from Assam and it differs from typical *M. hendersoni* by the length and depth of the rostrum and number of rostral teeth.

## Discussion

The prawns collected from rivers and streams, especially during rainy seasons in large quantity were consumed by people in most of the north-eastern states. They are also smoke dried and stored for future use or sold (INR 1,000 per kg). Konyak et al. (2023) while studying the aquatic biodiversity in Dzuna River, Jotsoma, Nagaland has reported the availability of palamonid prawns in this river but they had mentioned it to be *Palaemon* sp. So all the five species of palaemonid prawns encountered during this study forms the first report to this poorly explored state. Among these five species of *Macrobrachium*, *M. cacharense,* and *M. kempi* are very rare species. The present work recommends for intensive studies for freshwater species from Nagaland.

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SHORT COMMUNICATION



# Range extension of the lichenized ascomycete, *Cladonia fruticulosa* Kremp., 1882 (Lecanoromycetes: Lecanorales: Cladoniaceae), from Similipal Biosphere Reserve of Odisha

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**Abstract:** The lichen diversity of the Similipal Biosphere Reserve in Odisha remains underexplored, particularly for fruticose lichens genus *Cladonia* P. Browne. The present study aims to document a specimen collected from the high-altitude region of the reserve. Morphological observations, chemical analysis, and molecular phylogenetic methods were employed for species identification. Detailed descriptions, illustrations, habitat, and ecology are provided. Previously, no specific fruticose lichen species was reported from Similipal, and the present identification evidence confirms the first record of this species from Odisha.

**Keywords:** Diversity, documentation, fruticose, habitat, high altitude, identification, lichen, morphology, phylogeny, species.

The Similipal Biosphere Reserve (SBR) situated in the northern part of Odisha in eastern India represents a significant centre of biodiversity, characterized by diverse flora and fauna (Sahu et al. 2023). The reserve encompasses heterogeneous vegetation types, high relative humidity, and largely undisturbed forest ecosystems, including stream corridors, woodland patches, valleys, and mountainous terrains. The altitude gradient and microclimatic conditions within the landscape create favourable conditions for lichen colonization and succession (Rinas 2023). Lichens, the symbiotic associations between a mycobiont (fungus) and a photobiont (green alga and/or cyanobacterium), are widely recognized as reliable bioindicators of air quality and climatic conditions (Nash 2008). The moist tropical climate of Similipal, together with its complex topography and stable forest canopy, supports a rich assemblage of epiphytic, saxicolous, and terricolous lichen taxa (Singh & Sinha 2010; Singh & Kumar 2012). Despite the ecological importance of lichens, systematic studies on lichen diversity in Similipal Biosphere Reserve remain limited, especially for fruticose species of the genus *Cladonia*. Many areas of the reserve, particularly the core forest zones, remain poorly explored for their lichen flora. Considering the diverse habitats and favourable climate, the region may harbour previously unreported lichen taxa. Therefore, the present study aimed to survey lichen diversity in the core zone of the reserve and the fruticose lichen *Cladonia fruticulosa* was recorded from terricolous and muscicolous substrates representing a new addition to the lichen biota of Odisha.

## Materials And Methods

### Study area and lichen collection

The Similipal Biosphere Reserve (SBR), located in

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**Competing interests:** The authors declare no competing interests.

Mayurbhanj District, Odisha, India (21.116°'–22.200° N 85.966°–86.700° E), represents a heterogeneous landscape comprising dry and moist deciduous forests, grasslands, riverine systems, valleys, and undulating mountainous terrain. The elevation range is between a minimum of 40 m and a maximum of 1,178 m. The reserve harbours rich and diverse flora and fauna, including a significant assemblage of lichenized fungi. The area experiences a moist tropical climate with annual rainfall ranging 1,200–2,000 mm. The mean maximum temperature reaches 38–44 °C during summer (May–Jun), while minimum temperatures decline to about 08–12 °C in winter (Dec–Jan). Such weather conditions, together with topographic heterogeneity and stable forest cover, provide favourable microhabitats that support lichen colonisation and succession, resulting in varied distribution patterns across substrates.

Lichen specimens were collected from different substrates using random sampling technique from transition, buffer, and core zones of SBR. The transition zone included Lulung, Sitakund, Kachudahan, Palasibeda, Digdiga, Namtidar, Tunki, Taldiha, Devkund, and Upparbarakamuda. The buffer zone comprised Bhajam, Chandanchaturi, Champajhar, Khadkei, Nigirdha, Tulasibani, Manada, and Brundeiposi. The core zone encompasses Dholabani, Kailani, Jamuani, Andharajuli, Bakua, Ghar Similipal, Jodapal, Dhudruchampa, Kukurbhuka, Hatibandha, Utras, Bariooan, Ektali, Upparbarakamuda, Jenabil, Bhanjabasa, and Meghasani.

**Morphological and chemical characterization**

Lichen specimens were critically examined and differentiated based on morphological, anatomical, and chemical characters following Awasthi (2007). Macromorphological characters were analysed under a stereomicroscope (Stemi 305, Carl Zeiss), while anatomical features were analysed using a dissecting microscope (Dewinter, DGI 1000). Routine reagents, i.e., K reagent (Potassium hydroxide, KOH 10%), C reagent (Potassium hypochlorite, KClO, 5.25%) and paraphenylenediamine (PD) were used for spot tests. The voucher specimens are deposited in the National Botanical Research Institute, Lucknow (LWG).

**Molecular characterization**

Molecular characterization was carried out through rRNA sequencing, including 18s, 28s, 5.8s, 1.5s, and ITS sequences. Genomic DNA was extracted from 10 mg of lichen thallus following the precipitation method of Park et al. (2014). The thallus was placed in micro vial along with three to four sterile 2.5 mm glass beads, under liquid nitrogen and disrupted the powder by using a mini-beadbeater-24 for 30 s. This freeze-thaw disruption cycle was repeated until the sample was ground into a fine powder. Subsequently, 300 µL of KCl extraction buffer was added, and the tube was vigorously inverted by hand approximately 20 times to ensure thorough mixing. An equal volume (300 µL) of chloroform was then added, and the sample was gently inverted about 20 times before centrifugation at 12,000 rpm for one minute at room temperature. The upper aqueous phase was transferred to a 1.5 ml microcentrifuge tube, and DNA was precipitated by adding 180 µL of chilled isopropanol (60%), followed by gentle inversion. The mixture was centrifuged again at 12,000 rpm for one minute, and the DNA pellet was washed with 300 µL of chilled 70% ethanol. After drying the pellet at 50–65 °C then resuspended in 100 µL of 1× TE buffer and incubated again at 50–65 °C for five minutes to ensure complete dissolution. The purified DNA was stored at 4 °C for short-term use or at -20 °C for long-term preservation.

**PCR amplification and sequencing**

PCR amplification was performed following the protocol of White et al. (1990) using universal fungal primers targeting the small subunit (SSU), large subunit (LSU), and internal transcribed spacer (ITS) regions. For SSU amplification, primers SR1R (5′-TACCTGGTTGATCCTGCCAGT-3′) and SR7 (5′-GTTCAACTACGAGCTTTTTAA-3′) were used. LSU was amplified using primers LS1 (5′-GTACCCGCTGAACTTAAGC-3′) and LS5 (5′-TCCTGAGGGAAACTTCG-3′). The ITS region was amplified using ITS5 (5′-GGAAGTAAAAGTCGTAACAAGG-3′) and ITS4 (5′-TCCTCCGCTTATTGATATGC-3′) (White et al. 1990), along with the fungal-specific primer nu-SSU-1583-59 (5′-CAACGAGGAATTCCTAGT-3′) (DePriest 1993). PCR products were electrophoresed on 1.5% agarose gel at 120 V for 25 min to confirm amplicon size and integrity. Amplified products were purified using Exonuclease I and recombinant Shrimp Alkaline Phosphatase, and sequenced bidirectionally on an ABI 3730 Capillary Electrophoresis Genetic Analyzer. Forward and reverse sequences were edited and assembled into a consensus sequence (481 bp) using MEGA 11 and Sequencher v5 software. To align the sequences with other sequences obtained from NCBI GenBank, Clustal W was employed (Tamura et al. 2021) using MEGA 11.

## Results

***Cladonia fruticulosa*** Kremp., Verh. Zool.-Bot. Ges. Wien 30: 331 (1880)

Thallus fruticose; basal squamules persistent, 2–4 mm long, 1–2 mm in diam., faintly to deeply lacinate, rarely granular-sorediate on borders or below; podetia growing from basal squamules, 0.5–2 cm rarely 4 cm tall, 0.5–1.0 mm diam., simple, rarely branched, scyphose, often partly squamulose, corticate or upper part ecorticate or almost completely ecorticate; ecorticate area partly granular-sorediate; scyphi 0.5–4 mm in diam., deformed or well defined, often with marginal scyphi; apothecia 1–2 mm in in diameter, convex, pedicellate or marginal on scyphi, pale brown to dark brown; pycnidia on scyphi, 0.3–0.5 × 0.2–0.3 mm, flask-shaped, dark brown (Image 1).

Spot tests: K$^{-,}$ UV$^{-,}$ C$^{-}$, I$^{-}$ (All tests negative).

Specimen examined: India, Odisha, Mayurbhanj District; elevation 1,133 m; substrate-moss, rock and red soil; date of collection22.ii.2024; collected by Shubham Pradhan, Satyabrata Dash, Bijayananda Sahoo and Biswajit Rath; Accession No-LIC-69571; Herbarium acronym-LWG.

### Phylogenetic analysis

The evolutionary history was inferred by using the maximum likelihood method. The bootstrap consensus tree inferred from 1,000 replicates is taken to represent the evolutionary history of the taxa analysed. The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test 1,000 replicates) are shown below the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pairwise distances estimated using the Tamura-Nei model. This analysis involved 26 nucleotide sequences. There was a total of 535 positions in the final dataset. Evolutionary analyses were conducted in MEGA11 (Tamura et al. 2021) (Figure 1).

## Discussion

The family Cladoniaceae has been comprehensively investigated in the Indian subcontinent by several authors, notably Upreti (1987) and Awasthi (1988). According to the updated account of Singh & Sinha (2010), the family in India comprises four genera: *Cladia* (one species), *Cladonia* (58 species), *Gymnoderma* (one species), and *Pilophorus* (one species). A significant contribution to the taxonomy of Indian *Cladonia* was made by Ahti et al. (2002), who provided the first detailed account of several species from India, including the description of *Cladonia singhii* Ahti & Dixit from the eastern Himalayan region. In addition, seven species of *Cladonia corniculata*, *C. kanewskii*, *C. laii*, *C. luteoalba*, *C. mauritiana*, *C. mongolica*, and *C. rei* were newly incorporated into the recent checklist of lichens of the Indian subcontinent. Furthermore, the occurrence of *Cladonia cartilaginea* in India was confirmed by Ahti et al. (2002), thereby refining the known distributional range of the genus in the region. A detailed account of the altitudinal distribution and edaphic preferences of several *Cladonia* species in India was provided by Řídká et al. (2014). *Cladonia furcata* was recorded on soil substratum at 3,250 m from Tungnath (Rudraprayag District), Uttarakhand, whereas *Cladonia rangiferina* occurred on terricolous substrata at 2,553 m between Bogdiyar and Naher Devi in Pithoragarh, Uttarakhand. *Cladonia praetermissa* was collected on soil at 1,665 m in Anuppur District, Madhya Pradesh. *Cladonia scabriuscula* exhibited a broader ecological amplitude, growing on soil substratum at 1,014 m in North Cachar (Assam) and at 1,410 m in Satara (Maharashtra). *Cladonia verticillata* was reported as terricolous at 1,890 m in Champawat, Uttarakhand, while *Cladonia fruticulosa* was documented on soil at 2,607 m in the Nilgiri Hills of Tamil Nadu. These records emphasize the predominance of terricolous (soil-inhabiting) habitats among Indian *Cladonia* species and demonstrate their adaptability across a wide altitudinal gradient from subtropical to alpine ecosystems.

Additional regional records further substantiate the expanding distributional range of *Cladonia* species in India. Reports from Sikkim by Sinha & Ram (2011) contributed to the floristic documentation of the genus in northeastern India. *Cladonia coniocraea* and *C. fruticulosa* were reported from the Mandi District of Himachal Pradesh by Thakur et al. (2020). Subsequently, Gogoi et al. (2022) documented *C. fruticulosa*, *C. scabriuscula*, *C. subradiata*, and *C. cervicornis* from Assam, indicating a broader ecological amplitude of the genus across the Indo-Burma biodiversity region.

The present detection of *C. fruticulosa* at 1,133 m altitude on red soil substratum in northern Odisha represents the first confirmed record from this phytogeographical sector. Previous diversity assessments within the Similipal Biosphere Reserve and adjoining habitats by Pradhan et al. (2025, 2026) did not include this species in their respective checklists. Therefore, the present report significantly augments the known distribution of *C. fruticulosa* in India and contributes to a more comprehensive understanding of *Cladonia* diversity in eastern habitats.

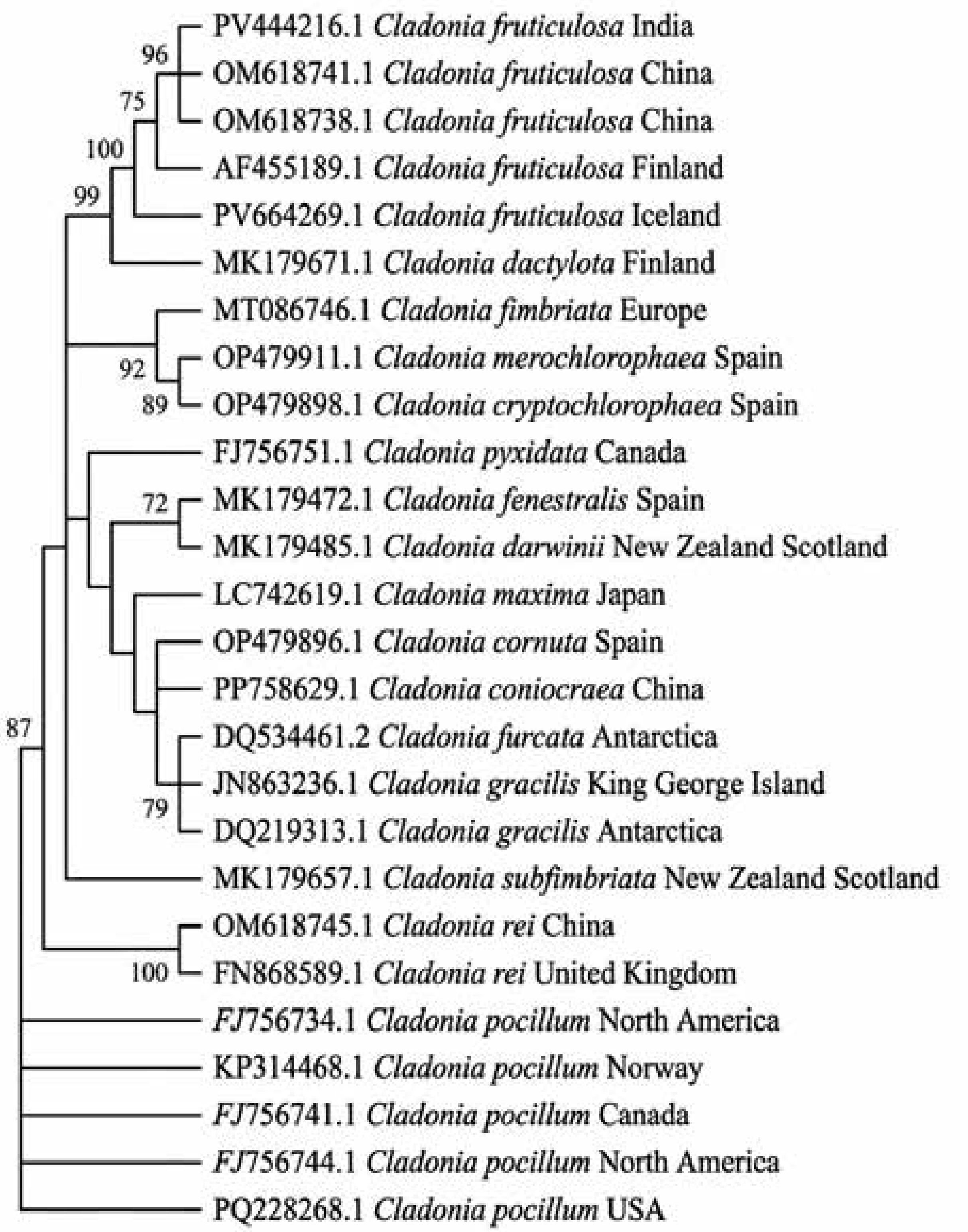


**Figure 1. Evolutionary analysis by the maximum likelihood method.**

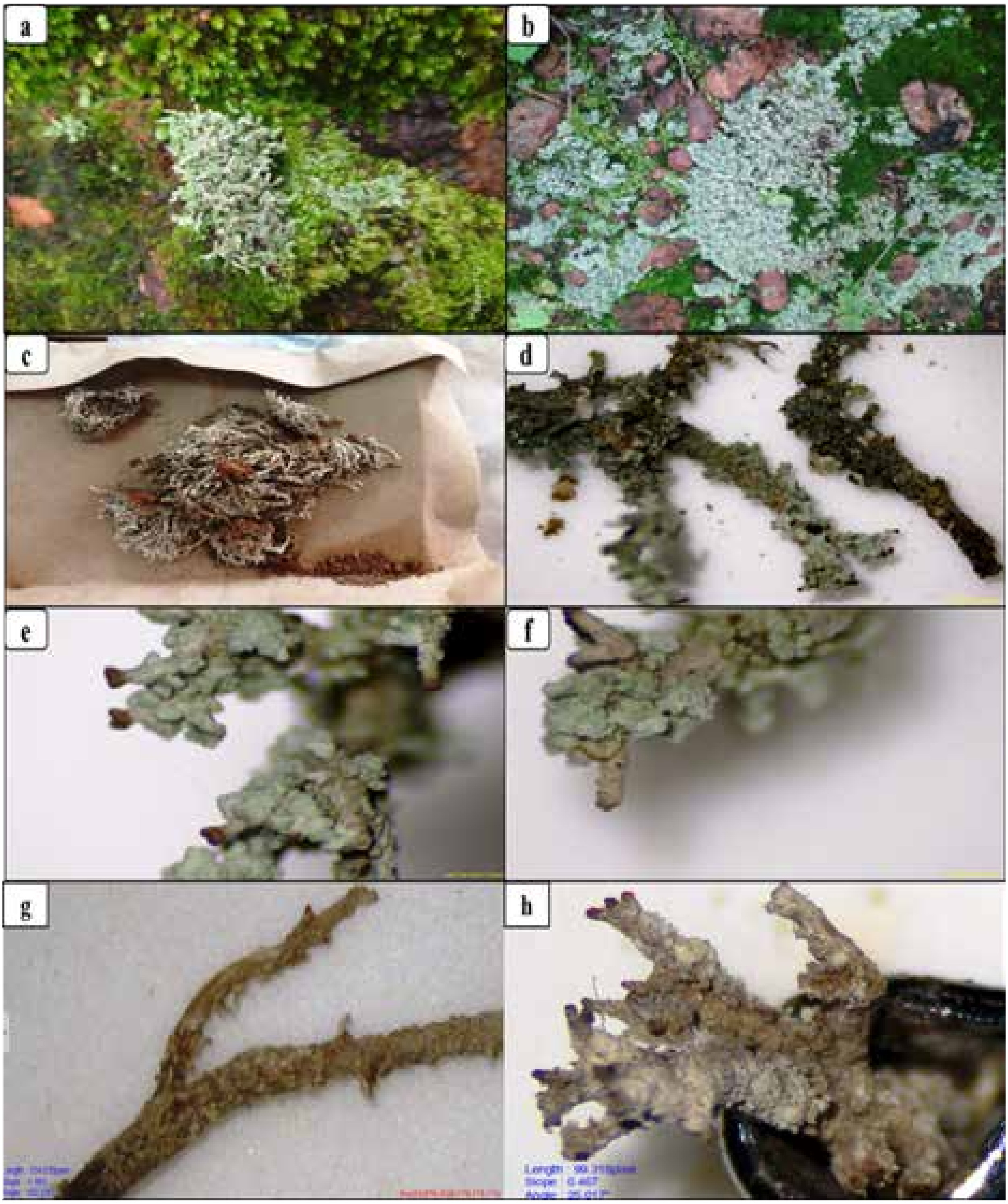


**Image 1. *Cladonia fruticulosa* (Kremp): (a & b)—occurrence of lichen in moss and rocky substrate | (c)—dried specimen | (d)—bivalent branching of thallus | (e)—branching tip showing podetia | (f)—barrel-shaped pycnidia on the tip of podetia | (h)—closure view of branching pycnidia. © Shubham Pradhan.**

## Conclusions

The present study records *Cladonia fruticulosa* Kremp. for the first time from the Similipal Biosphere Reserve, extending its known distribution in eastern India. Its occurrence at higher elevations indicates a preference for well-drained, open forest microhabitats with specific edaphic and microclimatic conditions. This record refines the regional species inventory of *Cladonia* and contributes to the taxonomic study of fruticose lichens in tropical forest ecosystems.

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NOTE



# First photographic record of *Chitoria sordida sordida* (Moore, 1866) (Insecta: Lepidoptera: Nymphalidae: Apaturinae) from Arunachal Pradesh, India

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As showcased in Image 1, wedged between Patkai Ranges and Dapha Bum ridge of Mishmi Hills, Namdapha National Park and Tiger Reserve is located at 27.383–27.650° N and 96.250–96.966° E in Arunachal Pradesh's Changlang District. It has a subtropical climate that varies with elevation ranging 200–4,571 m (Arunachal Online 2024).

The genus *Chitoria* Moore, 1896 consists of 10 species: *sordida* (Moore, 1866), *ulupi* (Dohertty, 1889), *pallas* (Leech, 1890), *fasciola* (Leech, 1890), *subcaerulea* (Leech, 1891), *modesta* (Oberthür, 1906), *chrysolora* (Fruhsttorffer, 1908), *naga* (Tytler, 1914), *cooperi* (Tytler, 1926), and *leei* (Lang, 2009). Of these 10 species, three of them—*ulupi* (Dohertty, 1889), *sordida* (Moore, 1866) and *naga* (Tytler, 1914)—are reported from India (Irungbam et al. 2016). Further, among these, the range of *Chitoria sordida* is known to extend from northeastern India (Sikkim, Darjeeling, Assam, and Manipur) to as far as northern Myanmar (Moore 1865; Tytler 1914; Antram 1924; Kehimkar 2008). The species is represented by two subspecies, namely *Chitoria sordida sordida* (Moore, 1866) and *Chitoria sordida vietnamica* (Nguyen, 1979). While subspecies *Chitoria sordida vietnamica* is reported from northern Vietnam to eastern Laos and Thailand, at altitudes above 1,000 m, the subspecies *Chitoria sordida sordida* is reported from limited northeastern Indian states, Bhutan, and northern Myanmar at a much lower altitude of 500 m (Nguyen 1979; Masui 2004; Wangdi et al. 2012).

The Himalayan Sordid Emperor *Chitoria sordida sordida* (Moore, 1866) is a brush-footed butterfly belonging to the genus Chitoria, subfamily Apaturinae, family Nymphalidae and the Apaturini tribe (Bingham 1907). It is reported to be found in the tropical forests of the north-eastern states of India and Bhutan (Bingham 1907; Irungbam et al. 2016). This species is legally protected under Schedule II, of the Indian Wildlife (Protection) Amendment Act, 2022. For the geographical realm of India, verifiable scientific publications confirm the presence from Sikkim, Darjeeling (West Bengal), Assam, and Manipur (Tytler 1914; Masui 2004; Irungbam et al. 2016). These observations were documented at

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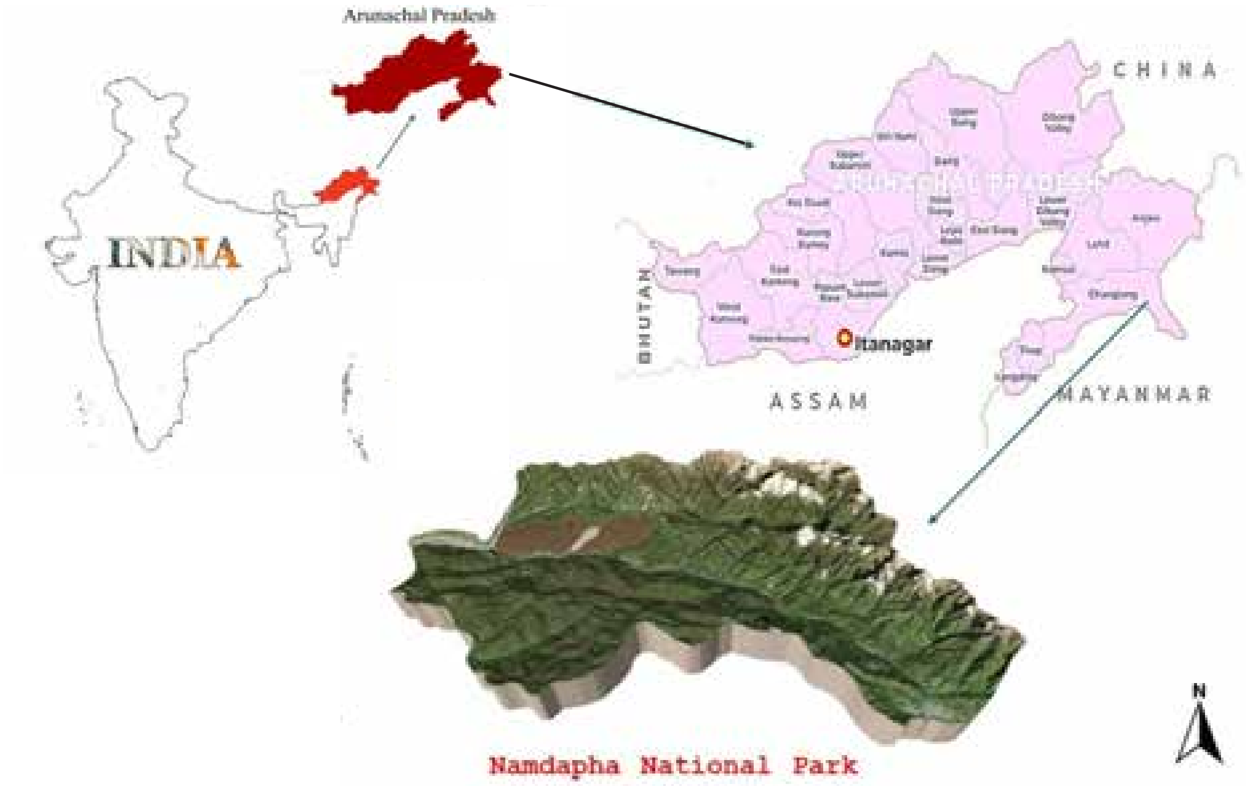


**Image 1. Location of Namdapha National Park and Tiger Reserve in Arunachal Pradesh, India.**

**Image 2. Location of Lunkai Nalla within Namdapha National Park and Tiger Reserve. Source: Google Earth.**

elevations less than 500 m (Kehimkar 2008; Irungbam et al. 2016). Sightings at these locations are apparent as Sikkim, West Bengal, and Assam share borders with southern Bhutan (Irungbam et al. 2016). As per the web portal of Indian Foundation for Butterflies, the most recent observations are from West Sikkim during April

2018 and October 2021; and Rangli forest in West Bengal during July 2022 (Kunte et al. 2024).

Upon analysing the recent exploratory studies for Arunachal Pradesh, it can be affirmed that there are around 175 Nymphalidae species in this northeastern state of India. These noteworthy mentions are also supported with credible photographic evidence (Gogoi 2012; Sethy et al. 2014; Sondhi & Kunte 2016; Sharma & Goswami 2021; Roshan et al. 2023; Limbu & Achint 2024). None of these checklists mention *Chitoria sordida sordida*; hence, it can be confirmed that in conjunction with reliable historical notes, the taxon is reported for the first time from Arunachal Pradesh or Namdapha National Park and Tiger Reserve to-date (Tytler 1914; Masui 2004; Singh & Chib 2014). Also, Namdapha National Park and Tiger Reserve shares its border with China and Myanmar, and not Bhutan. Hence, this sighting is a remarkable discovery. The recording and critical identification of *Chitoria sordida sordida* (Moore, 1866) is thereby an important addendum to the existing bio-inventory of both Namdapha National Park and Tiger Reserve, and Arunachal Pradesh (Roshan et al. 2023; Upadhaya & Sheikh 2025). The taxonomic status is mentioned herewith.

**Systematic Position**
**Class:** Insecta Linnaeus, 1758
**Order:** Lepidoptera Linnaeus, 1758
**Family:** Nymphalidae Rafinesque, 1815
**Subfamily:** Apaturinae Boisduval, 1840
**Genus:** *Chitoria* Moore, 1896
**Species:** *Chitoria sordida* Moore, 1866

The sighting of the single individual of *Chitoria sordida sordida* (Moore, 1866) was made on 16 October 2024 at Lunkai Nalla (27.493° N, 96.386° E) situated within the Namdapha National Park and Tiger Reserve, Arunachal Pradesh. As showcased in Image 2, Lunkai Nalla is basically a small stream powered by the Deban Nalla and Noa-Dihing River which runs turbulently through the forest.

The identification of *Chitoria sordida sordida* was done by consulting the pictorial field guides, catalogues, and identification keys in accordance with available literature and standard taxonomic keys (Evans 1927, 1932). The critical external morphological features analysed included the wing colouration, wingspan, and antennae structure. The female butterfly with wingspan of approximate 74 cm had broader oblique discal band on the forewing and a distinct rounded hindwing. While the antennae appeared brown, it was paler below the club. The head, thorax, and abdomen appeared brown


**Image 3. *Chitoria sordida sordida* at Lunkai Nalla: A—slightly extended 'open wing shot' | B—fully 'closed wing shot' | C—fully 'open wing shot'.**

and were paler beneath (Bingham 1907; Moore & Swinhoe 1890). No specimen was collected.

The single female individual was witnessed flying swiftly across the banks of the stream, before moving onto rocky surfaces for basking alongside other species such as, *Rohana parisatis* Westwood, 1851, *Heliophorus epicles* Godart, 1824, *Mimathyma ambica* Kollar, 1844, and *Cigaritis lohita* Horsfield, 1829. The single individual butterfly upon disturbance from other butterflies was found to intermittently hover around *Celtis sinensis* before returning to bask on the rocks (Image 3) with sufficient sunlight. The individual was also observed to momentarily shift on occasion, to wet rocks. It was also noticed that the species preferred the vicinity of the stream-sides and was avoiding even the gentle water patches and thick forest outgrowth on the sides of the stream.

## Conclusion

The paper provides brief notes on the addition of *Chitoria sordida sordida* (Moore, 1866) (Nymphalidae: Apaturinae) to lepidopteran fauna checklist for Arunachal Pradesh, India. The discovery of *Chitoria sordida sordida* (Moore, 1866) in Namdapha National Park and Tiger Reserve, Arunachal Pradesh, India; throws up further exploratory opportunities for more probable sightings of the same species, as well those of others which are yet to be documented. This addendum to existing inventory is critical for deciphering the ecosystem dynamics, and for re-evaluating conservation strategies. This finding also hints at possibility of range extensions in the wake of climate change-mediated alterations in the environmental factors.

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NOTE



# Westward range extension of the Greater Bluewing *Rhyothemis plutonia* Selys, 1883 (Insecta: Odonata: Libellulidae) into Uttarakhand, India

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*Rhyothemis* Hagen, 1867 (family Libellulidae) is a genus of vibrantly coloured dragonflies represented by four species in the Indian subcontinent: *R. plutonia* Selys, 1883; *R. phyllis* Sulzer, 1776; *R. triangularis* Kirby, 1889; and *R. variegata* Linnaeus, 1763 (Subramanian & Babu 2024). *Rhyothemis plutonia*, commonly known as the Greater Bluewing, has been recorded primarily from the northeastern states of India and the adjoining regions of Nepal and Bangladesh (Subramanian 2009; Kalkman et al. 2020; Joshi et al. 2024; GBIF 2025). This note reports the first confirmed record of this species from Uttarakhand, thereby establishing a significant westward range extension.

Jim's Jungle Retreat (JJR) is a ~13-acre rewilded property situated near Dhela Village (29.408 °N, 79.009 °E; ~310 m), within the buffer zone of Corbett Tiger Reserve, Uttarakhand. The property, developed on previously degraded land two decades ago, now supports a planted forest matrix interspersed with seven artificial, permanent, lentic waterbodies of varying sizes. The surrounding landscape is dominated by agricultural fields, human habitation, and Eucalyptus monocultures. To date, 35 odonate species have been documented from JJR based on the author's unpublished observations. The site's largest waterbody, known as 'Champion's Pool' (CP; ~350 m² surface area, ~1 m maximum depth), supports *Hydrilla* sp. and *Azolla* sp. as the dominant aquatic vegetation, with marginal vegetation dominated by grasses, *Murraya koenigii* and *Pogostemon benghalensis*.

On 10 July 2025 at 1020 h, a dragonfly was observed perched on a grass clump at the margin of CP. It was photographed using a Nikon D5600 DSLR and Nikkor 70–300 mm telephoto lens, without capture or handling of the insect (Image 2 & 3). It was moderately sized, with a dark head, legs, and body; metallic-blue wings; a dark pterostigma; and hyaline apices on the forewings. The cerci were distinctly longer than the paraprocts, and the presence of secondary genitalia confirmed that the specimen was male. Identification as *R. plutonia* was made based on these morphological features and comparison with congeners following Fraser (1936). The species was not observed in subsequent surveys at the site. A distribution map and calculations of great-circle distances to the nearest prior records were prepared using QGIS v.3.34.12-Prizren (QGIS 2025). Coordinates were approximated where exact values were unavailable. This record represents the first confirmed occurrence

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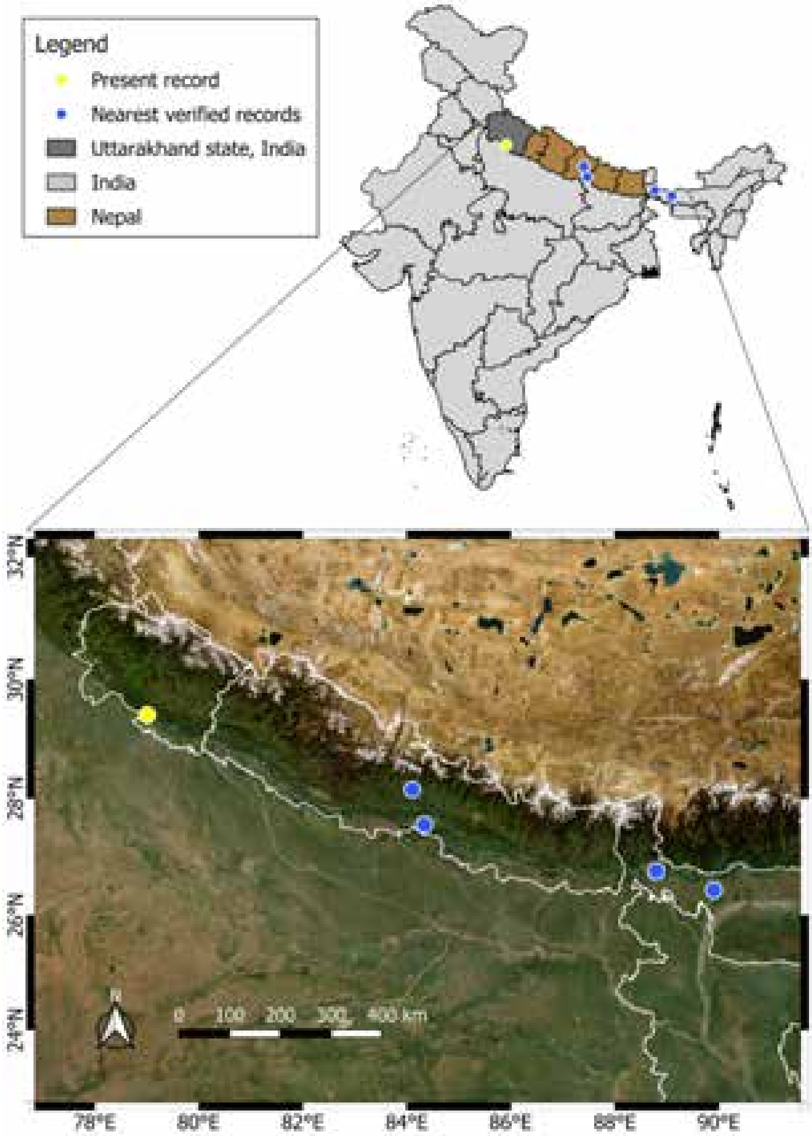


**Image 1. Present record from Jim's Jungle Retreat, Uttarakhand (yellow dot), and four closest prior verified records (blue dots).**

**Table 1. Closest verified records of *Rhyothemis plutonia* relative to Jim's Jungle Retreat, Dhela, Uttarakhand (29.408°N, 79.009°E). Coordinates in decimal degrees (WGS84); approximated where exact values were unavailable.**

| Locality and state | Country | Coordinates | Distance (km) | Reference |
|---|---|---|---|---|
| Rupa Lake near Pokhara, Gandaki | Nepal | 28.152°N, 84.107°E | 518 | Vick 1985 |
| Narayani near Chitwan National Park, Bagmati | Nepal | 27.553°N, 84.336°E | 562 | Hoyer 2016 |
| Gorumara National Park, West Bengal | India | 26.756°N, 88.798°E | 1,005 | Dawn 2015 |
| Srirampur, Assam | India | 26.433°N, 89.902°E | 1,121 | Gassah 2019 |

of *R. plutonia* in Uttarakhand, raising the state's known odonate diversity to at least 128 species (Subramanian & Babu 2024). The species is absent from all published literature and distributional accounts for the state of Uttarakhand (Subramanian & Babu 2018; De et al. 2021; Singh 2022; Joshi et al. 2024; iNaturalist 2025). The nearest verified records lie over 500 km to the east in Nepal and northeastern India (Image 1, Table 1). Only a single male individual has been recorded, with no females or evidence of reproductive activity, suggesting

**Images 2–3. Male *Rhyothemis plutonia* at Jim's Jungle Retreat, Uttarakhand, in lateral and ventral aspects. © Omkar Damle.**

the absence of a local breeding population at present. Continued field surveys are, therefore, necessary to determine whether this observation represents a vagrant individual or an overlooked peripheral population. Nevertheless, the addition of *R. plutonia* to the Uttarakhand state fauna highlights the potential for further significant discoveries in this relatively understudied region. It also emphasizes the need for systematic surveys to clarify the distributional limits, population status and ecology of odonates in western Himalaya.

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