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Cover: Watercolour illustrations—Striped Tiger *Danaus genutia*, Common Silverline *Cigaritis vulcanus*, Tamil Lacewing *Cethosia mahratta*. © Mayur Nandikar.

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ARTICLE

The past and current distribution of the lesser-known Indian endemic Madras Hedgehog *Paraechinus nudiventris* (Mammalia: Eulipotyphla: Erinaceidae)

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Abstract: The Madras Hedgehog *Paraechinus nudiventris* (Horsefield, 1851) is a species endemic to a few isolated patches in southern India threatened by habitat loss and direct take. Little is known about its historical distribution or present climatic needs, both of which could provide important baselines for conservation and habitat restoration. The current distribution of *Paraechinus nudiventris* was modelled using occurrences collected in the field and from community reports. Based on the current climatic niche estimated from Maxent, Madras Hedgehog distribution was projected into southern India during the last interglacial gap (120,000–140,000 YBP), and last glacial maximum (22,000 YBP) and mid-Holocene (~6,000 YBP). During the (Last Interglacial Gap) LIG the suitable habitat was restricted to the Palghat gap in the southern Western Ghats mountains and a small region in south Sri Lanka, although it is unclear whether the suitable climates in Sri Lanka were occupied and then extirpated, or never colonized. The present climatic niche of the species is confined to lower elevations and semi-arid plains of southern and central Tamil Nadu in India. The contemporary models can be used to update the IUCN range map for *P. nudiventris* in India, as well as identify suitable habitats for this species to guide local conservation strategies.

Keywords: Conservation, endemism, IUCN, Maxent modeling, paleo distribution, Southern Indian Hedgehog, Teri red sands.

Tamil: மெட்ராசு முள்ளெலி எனப்படுபவை தென்னிந்தியாவில் ஆங்காங்கே காணப்படும் ஓரிடவாழ்வி ஆகும். இவை வாழிடச் சிதைவாலும் பிற நேரடி தாக்குதலாலும் பெரிதும் அச்சுறுத்தலுக்காளாகியுள்ளன. இவற்றின் விரவலைப் (பரவல்) பற்றியும் அவை வாழ ஏற்றச் சூழல் எவை என்பது பற்றியும் நாம் அறிந்தவை வெகு சொற்பமே. இது குறித்தான அடிப்படைத் தரவுகளைக் கூடுதலாக அறியும்போது அவற்றைப் பாதுகாப்பதற்கும் அவற்றின் வாழிடத்தை மீட்டெடுப்பதற்கும் உதவக்கூடும். தற்போதைய இதன் விரவல் கள நிலவரத்தின் அடிப்படையில் அவை வாழ்ந்துவருவதற்கான அடையாளங்களை வைத்தும் மக்களிடம் மேற்கொண்ட வாய்மொழித்தகவலின் அடிப்படையிலும் உருவாக்கப்பட்டது. அவை வாழ ஏற்றச் சூழல் எவை என்பதை அளவிட மேச்சென்ட் தரவுகள் உதவியுடன் கணக்கிடப்பட்டுள்ளது. தென்னிந்தியாவில் மெட்ராசு முள்ளெலியின் விரவலானது கடந்த பனிப்பாறை ஊழிக்கால இடைவெளியிலும் (120,000–140,000 YBP), பனிப்பாறை ஊழிக்கால இறுதியிலும் (22,000 YBP) மற்றும் மத்திய ஹோலோசீன் கால (~6,000 YBP) த்திலும் நிகழ்ந்திருக்கலாம். இறுதிப் பனிப்பாறை ஊழிக்காலத்தில் பால்க்காட்டுக் கணவாய்க்குத் தென்மேற்கே அமைந்துள்ள மேற்குத்தொடர்ச்சி மலைக்கு இடைப்பட்டப் பகுதியிலும் தென் இலங்கையிலும் இதன் வாழிடம் நிலைகொண்டிருந்திருக்கலாம். பொருத்தமான காலநிலை அமையாததால் முன்பு இலங்கையில் வாழ ஏற்ற சூழல் இருந்து பின்னர் மட்டுப்பட்டு இருக்கலாமோ என்ற விவரம் தெரியவில்லை. தற்போது இவை மையத் தமிழ்நாட்டிலும் தென் பகுதியிலும் உள்ள அடிவாரச் சரிவிலும் வறண்ட பாலை நிலப்பகுதியிலும், வாழத் தகுந்த சூழல் நிலவுகிறது. இந்த ஆய்வின் வழியே கிடைக்கப்பெற்ற தகவல்கள், IUCNல் - மெட்ராசு முள்ளெலியின் பரப்புப் படத்தை மேம்படுத்தவும், இந்த அழிந்துவரும், அரிய இனத்திற்கான ஏற்ற வாழிடங்களை அடையாளங்காட்டி, உள்ளூர் அளவில் பாதுகாப்பு முயற்சிகளை ஊக்குவிக்க உறுதுணையாய் இருக்கும்.

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INTRODUCTION

Studying the baseline distribution of a species is critical for assessing the conservation status of species (Braun 2005; Solberg et al. 2006). The prediction of a species' distribution is crucial to many applications in ecology, evolutionary history, and conservation science (Guisan & Zimmermann 2000; Elith et al. 2006). Despite being intensively studied, detailed large-scale information on various mammal taxa's distribution has been lacking, which can hinder conservation efforts (Gaston 1991; Rondinini et al. 2011). One of the biggest challenges for conservation is to maintain the integrity and functionality of ecosystems while biodiversity is increasingly threatened by many factors. Species distribution models (SDMs) have been widely used to predict and map species' geographic ranges through time (Elith & Leathwick 2009).

During the Last Interglacial period, the rise of sea level caused floods in low areas and isolated populations on temporary islands. Therefore, the current distribution of many species might have occurred due to the Quaternary sea level change and Tertiary geology (Cuffey & Marshall 2000; Rohling et al. 2007; Goelzer et al. 2016). Local geological events and past climatic oscillations are important evolutionary mechanisms that have highly shaped the genetic structure of species (Parmesan & Yohe 2003; Woodruff 2010). In the Asian context, habitat change caused by Quaternary climatic oscillations altered the population structure and evolutionary history of various terrestrial fauna (An 2000; Barry et al. 2002; Blois & Hadly 2009; Ohnishi et al. 2009). However, very little information is available on Indian small mammal species and their paleo-distribution.

The Madras Hedgehog (MH; *Paraechinus nudiventris* Horsefield, 1851), also known as the Bare-bellied Hedgehog, is an endemic species restricted to a few isolated patches of different habitats (Image 1) in the southern Indian states of Tamil Nadu, Kerala, and Andhra Pradesh (Wroughton 1907; Webb–Peploe 1949; Prater 1971; Frost et al. 1991; Xuelong & Hoffman 2013; Marimuthu & Asokan 2014; Kumar & Nijman 2016). It is currently listed as 'Least Concern' by the IUCN Red List (Chakraborty et al. 2017). MH population is declining primarily due to trade, habitat loss, medicinal uses, and hunting (Kumar & Nijman 2016). The MH is declining fast enough to qualify for listing in a more threatened category (Xuelong & Hoffman 2013). MH is only known from the southcentral, southern parts of Tamil Nadu grasslands and dry open landscapes, with a few sightings from high altitude mountains of the Western Ghats (Kumar et al. 2019b). In recognition of such uncertainties, the IUCN has recommended further study, field exploration, and initiation of conservation measures. The first approach to understanding the status of MH is to assess their current distribution, a task previously conducted in certain areas in Tamil Nadu (Kumar & Nijman 2016). The habitat of the Madras Hedgehog includes thorny areas, semi-drylands, bushy deserts, grasslands, edges of cultivated areas, and dried ponds. Thus, knowledge regarding their ecological niche and their present and past distribution is key to better understanding the impacts of climate change and the magnitude of population decline. However, the geographical range and niche of MH remain unclear, and an updated range map for this species is urgently needed to aid conservation planning. Therefore, the identification of climatically suitable areas for the survival and persistence of MH is needed for the conservation of the species. In addition to its restricted distribution and declining population, understanding the Madras Hedgehog's ecological niche and distribution is crucial for effective conservation planning.

Nocturnal behaviour: Madras Hedgehogs are primarily nocturnal, making daytime observations challenging. This behaviour hinders direct visual surveys and necessitates alternative sampling methods that account for their activity patterns. Cryptic nature: The species is known for its cryptic and elusive behaviour, often concealing itself in burrows or dense vegetation. This makes visual detection difficult, requiring specialized techniques for accurate identification and sampling. Limited habitat access: Madras Hedgehogs inhabit diverse landscapes, including areas with restricted access, such as rocky terrains and dense vegetation. Sampling in these habitats poses logistical challenges that need to be addressed for comprehensive data collection. Low population density: The species may have relatively low population densities, making encounters infrequent. This scarcity can impact the efficiency of traditional sampling methods, emphasizing the need for strategic approaches to account for low encounter rates. Seasonal variation: Seasonal changes in behaviour, reproductive patterns, and habitat use may influence the effectiveness of sampling efforts. Considering these variations is crucial for capturing a holistic understanding of the species distribution throughout the year. Madras Hedgehogs might exhibit genetic and morphological variations across their distribution range. Considering all these and integrating these variations into sampling strategies will potentially enhance the accuracy of SDMs, providing a more nuanced depiction of their ecological niche.

There are currently a number of correlative statistical approaches to elucidate the interaction between environmental factors and species' ranges (Guisan & Thuiller 2005). Species distribution models (SDMs) (aka "habitat suitability models", "habitat distribution models" or "climatic niche models" have become a standard approach for estimating the climatic correlates to a species' distribution (Guisan & Zimmermann 2000). SDMs are nowadays a standard for virtually all conservation management projects; it is also used by IUCN (www.iucnredlist.org) to map species' global distribution range. These techniques can be extensively applied to the lesser known and threatened species for conservation concerns. SDMs have been applied in various fields of applied ecology and conservation biology, and are particularly useful for the study of lesser-studied species. A major role of conservation planning is to design reserve networks that protect biodiversity in situ. Research within the field of conservation planning has focused on the development of theories and tools to design reserve networks that protect biodiversity in an efficient and representative manner (Williams & Araujo 2000; Araujo et al. 2002; Cabeza et al. 2004). Among the SDMs, the maximum entropy modelling (Maxent) technique, which requires presence-only occurrence records, is used for the estimation and prediction of a species' geographical range (Phillips et al. 2006). Moreover, the increasing availability of species occurrence data has extended its application in conservation biogeography, especially regarding rare and declining species with incomplete information (Phillips et al. 2006). Consequently, Maxent is an important tool to gain insights into current ranges and potential range -shifts due to climate change effects over time (Franklin 2010). In this study, we aimed to answer the following questions. (I) What are the climatic and topographic conditions related to the Madras Hedgehog species' distribution? (II) Where else do these climatic conditions occur on the landscape presently? (III) Where were these climatic conditions found in the past? We then use the answers to these questions to provide insight into biogeography and conservation of the MH.

METHODS

Sample Collection

First, MH occurrence records were collected from field surveys carried out between June 2013 to June 2022 in different parts of Tamil Nadu. A thorough review of the literature, and museum occurrence datasets of Kerala, Tamil Nadu, Puducherry, and Andhra Pradesh were screened and analyzed through expert consultation and observer interviews. Surveys were also distributed to gather additional locations. Additionally, reports from newspapers regarding hedgehog sightings in the last 23 years (2000–2022) were searched for. The datasets were cross-verified and confirmed through direct field visits (at select locations) and people surveys (conducted in areas where field verification was not possible). Thirteen districts in Tamil Nadu (Dindugal, Salem, Theni, Erode, Madurai, Karur, Namakkal, Tiruppur, Coimbatore, Tirunelveli, Tuticorin, Kanyakumari, and Virudunagar) were visited, and surveys were conducted to find direct

Image 1. a–b. Madras hedgehog *Paraechinus nudiventris*: a—Juvenile in dry thorny forest, Madurai | b—Adult in rolled up position, Kuthirai Mozhi Theri (Red Sand Dunes), Tuticorin. © Abinesh Muthaiyan.

and indirect evidence of *P. nudiventris*. All the geo-coordinates of the locations were collected from the field (15 locations); a few from the newspaper (34 locations) and literature occurrence points (19 locations) were retrieved from Google Earth. The remaining 32 locations were received from our community interviews with cattle herders and 'Nari Kuravar' tribes. The distribution of the species was then modeled using Maxent, a maximum–entropy approach for species habitat modeling (Phillips et al. 2006), and bioclimatic predictor variables from the BIOCLIM v1.4 databases (Hijmans et al. 2005).

Environmental parameters

Ecological niche modeling methods were applied, where environmental data are extracted from current occurrence records, museum records, local newspapers, field surveys, and urban trade surveys. The relationship between known occurrences of Madras hedgehogs (n = 136) and bioclimatic variables in the present time was examined using Maxent and model selection with AICc using the "dismo" package in R (Hijmans et al. 2011) and custom functions based on (Warren & Seifert 2011). The selected bioclimatic variables included mean annual temperature (BIO1), "isothermality" (BIO3, a measure of the range in daily average temperature versus annual average temperature range), mean temperature of the coldest quarter (BIO11), annual precipitation (BIO12), and precipitation of the wettest quarter (BIO16). These variables were chosen based on prior knowledge of the species' natural history.

Modeling and analysis

The climate niche of *P. nudiventris* was modelled to approximate its current distribution. We then used the relationship between MH occurrence and the climatic variables found there to project their distribution during the mid-Holocene, last glacial maximum (LGM), and last interglacial period distribution (LIG). LGM climate data were down-scaled from the general circulation model (GCM) based on three models. These three models differ in temperature and precipitation. LGM climate as simulated by CCSM3 is cooler and drier than MIROC. The use of the three different climate models enabled us to assess and account for modeling the uncertainty due to LGM and LIG climate data.

The occurrence records of hedgehogs were collected from four South Indian states viz. Kerala, Puducherry, Tamil Nadu and Andhra Pradesh. Due to the concentrated nature of many hedgehog locations in southern India, we also examined model sensitivity in relation to differing levels of "thinned" data using a function from (Smith 2017). Specifically, models were examined with all of the points included; all points more than 10 km apart were included (n = 77), and all points more than 50 km apart were included (n = 19). The study area extent was defined as an area around all of the known occurrences buffered by the maximum pair-wise nearest neighbor distance between occurrences in the full dataset (695.6 km). For each separate set of thinned points, all combinations of predictors were tested, testing a regularization parameter of one, two, and three. Models were ranked based on AICc and candidate models were identified as having greater than 0.05 model weight or less than two ΔAIC from the top model. With the top model identified, we evaluated model fit using a 10-fold cross-validation and examined the area under the curve (AUC), with 0.7 representing 'fair', 0.8 representing 'good', and anything above 0.9 'excellent' Zhang et al. 2018).

RESULTS

The models using the un-thinned data tended to over-represent areas where Madras hedgehogs are known to occur. The predictors included in the top models from thinning up to 10 km and up to 50 km were substantially the same (Table 1), therefore we focus on the results from the 10 km thinned results as a balance between including as much information as possible without over-fitting our results. The top model included: isothermality and either annual precipitation or precipitation during the wettest quarter (Figure 1). MaxEnt provided satisfactory results, with the area under the receiver operating characteristic curve (AUC) values partitioning data into model training and model testing was 0.938. The most suitable climate for Madras Hedgehogs was found within western and southern Tamil Nadu. However, a second, disjunct area of suitable climate appeared in western Andhra Pradesh / eastern Karnataka. There are no known records of Madras Hedgehog in this area. We tested various combinations of predictors across different beta parameters (1, 2, and 3). Results (Table 1) revealed that model selection reduced predictors to just two for isothermal and annual rainfall, a promising indication. Additionally, response curves (Figure 2) showed minimal complexity, contrasting with typical noisy curves associated with overfitting.

Distribution of suitable habitats in the current climate environment

The model results indicated three main regions of *P.*

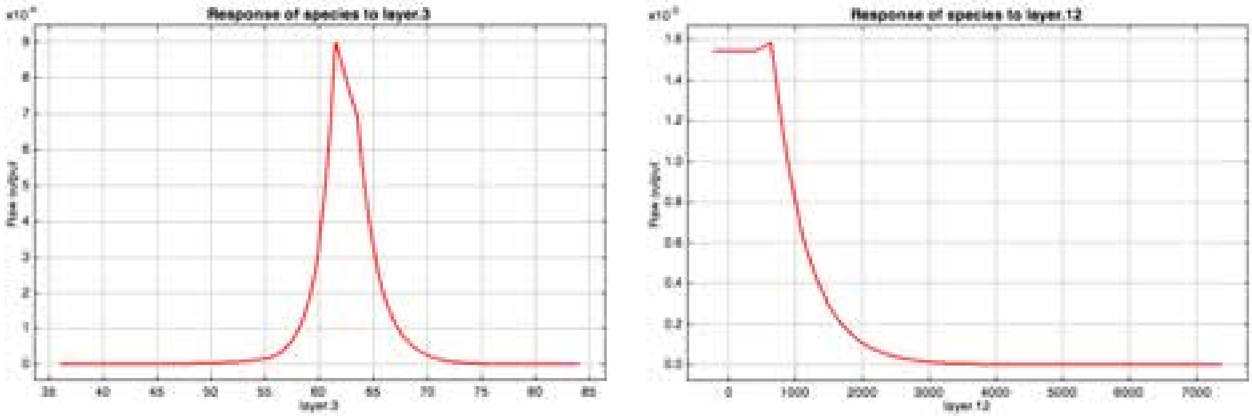

Figure 1. Climatic suitability for Madras Hedgehog *P. nudiventris* relative to Isothermality (C*10, left) and mean annual precipitation (mm, right).

nudiventris distribution (Figure 2). Western and Southern districts of Tamil Nadu in India. Such as Tirunelveli, Kanyakumari, Tuticorin, Viruthunagar, Theni, Madurai, Dindugal, Tiruppur, Coimbatore, Nilgiris, Erode, Salem, Tiruppur, Karur and Namakkal Districts. And a patchy isolated suitable habitat in Andhra Pradesh (Adoni Yemmiganur). Potentially suitable habitat was predicted in areas in Sri Lankan Island districts such as Kurunegala, Puttalam, Anuradhapura, Vavuniya, Thalamannar, and Mullitheevu. The present study predicts the suitable habitat in the coastal Teri dunes, near coastal dunes and inland dunes at the foothills of Western Ghats of Southern and Western Tamil Nadu. Additionally, the Korangaadu grasslands, semi-arid pasture lands, and drylands are predicted as suitable habitat for hedgehogs in Tamil Nadu. The coastal dunes are continuous coast-parallel deposits from Kanyakumari to south Rameshwaram also a suitable habitat. The model predicted the minimal presence of MH within high altitude forests, with the majority located in plains, dry semi-arid bushes on the fringes of urban areas, and grasslands adjacent to sandy red soils.

Table 1. Model selection results for Madras Hedgehog (*P. nudiventris*) Maxent BIOCLIM models, including models constructed for all points; models constructed with points thinned to a minimum of 10km distance; and models constructed with points thinned to a minimum of 50km distance

Model	β	K	AICc	ΔAICc
All points				
Isothermality + Precip Wettest Quarter	1	16	3127.92	0
Thinned 10km				
Isothermality + Annual Precipitation	1	9	1878.05	0
Annual Temperature + Isothermality + Annual Precipitation	1	12	1881.58	3.53
Annual Temperature + Isothermality + Mean Temp Coldest Quarter + Annual Precipitation	1	14	1883.39	5.3
Annual Temperature + Isothermality + Mean Temp Coldest Quarter + Precip Wettest Quarter	2	8	1884.39	6.33
Thinned 50km				
Isothermality + Annual Precipitation	1	7	1872.34	0
Annual Temperature + Isothermality + Mean Temp Coldest Quarter + Annual Precipitation	1	13	1876.32	3.98
Annual Temperature + Isothermality + Annual Precipitation	1	10	1877.9	5.56

Predicted paleo-distribution

The size of suitable habitat in previous climates varied substantially (Figure 3). In the mid-Holocene, the Madras Hedgehog may have been more widespread, including into, areas of south and western Tamil Nadu districts along the plains and foothills of the Western Ghats mountains (Figure 3a). However, during the LIG period, their potential habitat appeared to be restricted to a very small range in the Palghat Gap of the southern Western Ghats in low plains between Kerala and Tamil Nadu. Another small suitable area in southern Sri Lankan Island was also surprisingly revealed. The area of suitable habitat of *P. nudiventris* decreased gradually in LIG (Figure 3b). During the LGM period, the most suitable habitat was only in four distinct areas in southern India and Sri Lanka (Figure 3c). During the LGM, sea levels would have been low enough to allow MH to cross to Sri Lanka, where a large area with suitable climate was found.

DISCUSSION

Over-fitting with MaxEnt often is a concern. We have used the model selection approach and varied the "beta" parameter. The beta parameter in MaxEnt controls the

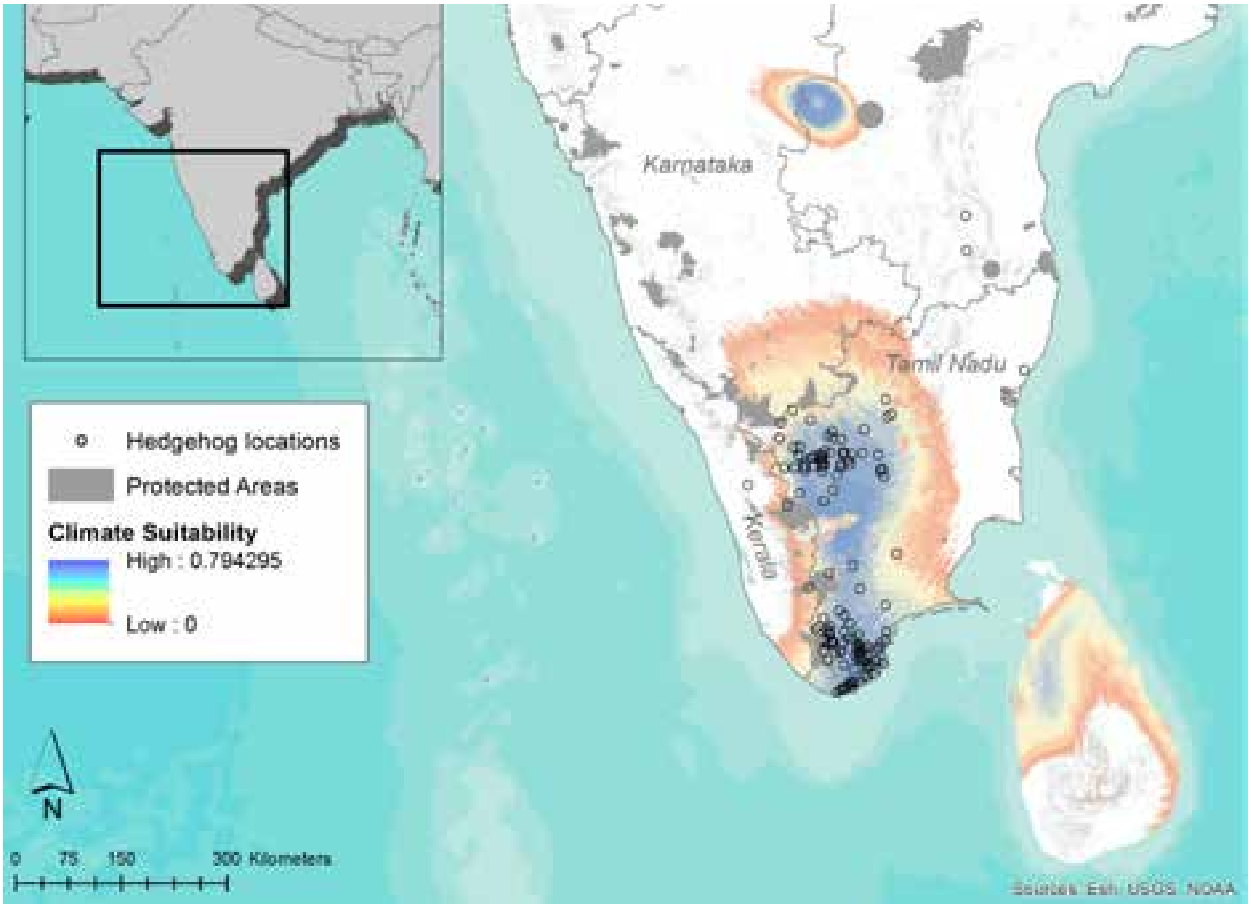

Figure 2. Climatic suitability model for Madras hedgehog (P. nudiventris) using BIOCLIM (Isothermality and Mean Annual Precipitation) and Maxent. All known occurrences are shown, but points were thinned to a minimum distance of 10 km for this model. The potential highly suitable distribution areas are shown in blue. The map was processed in ArcGIS version 10.2 (ESRI, Redlands, California, USA) (http://www.esri.com/).

complexity of the model – a higher number means fewer parameters and less over-fitting. We ran all of our models with each combination of predictors across a number of beta parameters (one, two, and three). As Table 1 shows, the model selection approach reduced the total number of predictors to just two, isothermality and either annual precipitation or precipitation of the wettest quarter. This shows a good sign that it is not over-fitting. In addition, the Figure 2, the response curves show very little complexity. The typical problem with MaxEnt is shown in response curves that are very "noisy" – these look more like a typical parametric response. In short, we used the best available tools to reduce over-fitting using MaxEnt, and our results suggest that we have minimized that problem.

Environmental variables

Current distribution records and previous literature provide evidence that medium-altitude mountains, shrublands, grasslands and dry semi-arid regions are very suitable for MH in southern India (Wroughton 1907; Webb-Peploe 1949; Manakadan 2013; Marimuthu & Asokan 2014; Kumar & Nijman 2016; Kumar et al. 2019a, b; Kumar et al. 2020). Both the variables are more related to the habitat of the species. However, for our study, we modelled the macro climate. Although most predicted habitat from southern Tamil Nadu shrub lands, sandy red dunes along grasslands and near water sources, these habitat features are present throughout most of southern India. The percent arid vegetation was a positive limiting factor for this species inferred in Table 1. These results are consistent with our fieldwork observations. Questionnaire surveys found only a few individuals inside high altitude forests; the majority were found in plains, dry semi–arid bushes on the edges of urban environments, grasslands near sandy red soils.

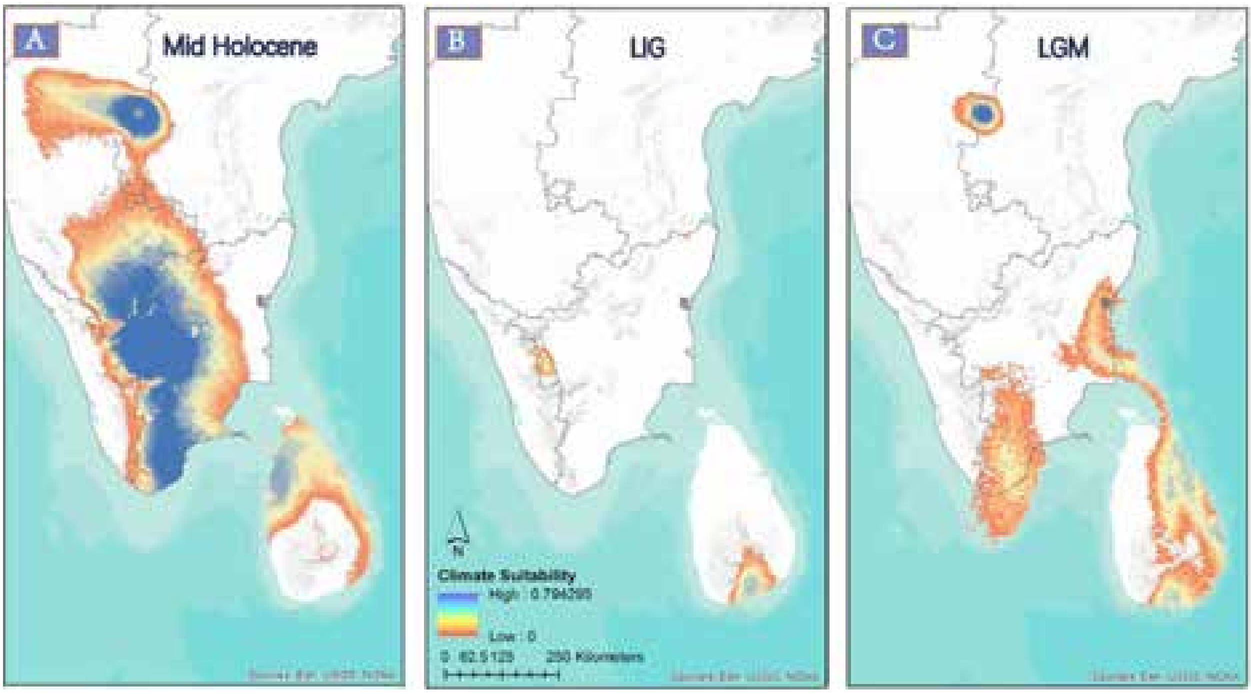

Figure 3. Madras Hedgehog (MH) distribution models created with Maxent at three spatial projections. The predicted distributions of Madras Hedgehog *P. nudiventris* projected to southern India and Sri Lanka under (A) Mid Holocene (B) Last Inter Glacial (LIG) and (C) Last Glacial Maximum (LGM). The colour shows habitat suitability value, with orange corresponding to low suitability, and blue with high suitability. These models were created using low-resolution climate data (BIOCLIM), while the models were created with higher-resolution data for Isothermality and mean annual precipitation. Suitability values are represented from low (orange) to high (blue). The representation of sea level during the LGM is from WorldClim ((Hijmans et al. 2005), http://www.worldclim.org). All models were developed using the ''maximum entropy model'' as implemented in the software MAXENT 3.3.3e.

Distribution ranges and ecological drivers

The occurrence of *P. nudiventris* from Keelakarai near Gulf of Mannar coast (Wroughton 1907), edges of Tuticorin coastal areas (Kumar & Nijman 2016), clearly show a unique pattern of occupying the sandy areas of the coastal plain districts in Tamil Nadu. Tirunelveli District holds the alluvial zone, red soil zone (Sand dunes and Teris) in the Tamirabarani river basin (Mani 1974) which holds a few isolated populations of *P. nudiventris*. "Teri" habitat heavily populated with insects, grasshoppers, and fan throated lizards, would be an excellent foraging ground for hedgehogs. The thorny bushes provide them with shelter and protection from the hot sun and predatory animals. As per the predicted results, the suitable habitat within low to medium rainfall plains, warm temperature drylands, water bodies occupied vegetated areas, and edges of coastal lands could act as a survival ground for the hedgehogs apart from the mountains.

In the year of 1917, there were about nine million of palmyras in lower elevations of Tirunelveli district (Pate 1917). This clearly indicates a higher number of suitable hedgehog habitat in a wider range in Tamil Nadu. The present rarity of this species in Tamil Nadu is therefore due to the rapid loss of the palmyra tree forests that is currently patchy and fragmented. Increasing human population and windmills is also a major threat of the rapid declining in hedgehog's population (Kumar & Nijman 2016; Kumar et al. 2019a,b).

The Sankarankovil, western Kovilpatti, uplands of Ambai, Tirunelveli, the greater part of Naanguneri, and north of Srivaikundam hold wide areas of red sandy lands, spotted with a number of small tanks, paddy lands and broken steep watercourses which the rains scour from year to year. This indicates that palymra forests along the red sand were a suitable habitat from that time itself. All of them provided good hiding places and enormous densities of invertebrates for MH. The most interesting division is red sand in the Teri landscape. They are in the southern part of Naanguneri Taluk and Tiruchendur Taluk occupying 388 km^2 of Palmyra forest (Pate 1917). Back to 1917, the Kuthirai Mozhi Theri formed as a reserved forest and the barren masses of sand were fertile patches of land found at intervals along their bases. Another interesting unique place occupied by the hedgehogs is Tharuvais, which comprises great inland lakes in Naanguneri Talk. The soil structure has changed a lot in the last 100 years due to flooding in many of the areas of the district.

Paleo – distribution ranges and potential refugium

The phylogenetic relationship and divergence of the genus *Paraechinus* are very poorly known. Based on molecular analyses of the hedgehog species, the spiny hedgehogs had formed four distinct lineages by the end of Miocene to early Pliocene, (Erinaceus, Atelerix, Hemiechinus and Paraechinus) over a two Myr time period (Bannikova et al. 2014).

Red dunes in the east coast were classified as inland, coastal and near-coastal (Teris) dunes (Joseph et al. 1997). The east and west coastal dunes of Tamil Nadu belong to the middle to late Holocene (Kunz et al. 2010; Alappat et al. 2011). But the extreme southeastern coast of Tamil Nadu holds the vast majority of the red sand soils called as Teri's, which are imprints of Late Pleistocene coastal sediments and originally developed because of the lower sea levels (Gardner & Martingell 1990; Jayangondaperumal et al. 2017). These shallow marine conditions have also been confirmed by previous studies in southern Tamil Nadu coastal districts. The large vertebrate fossils, gastropod and bivalve shells from the Tirunelveli-Tuticorin road, proboscidians fossil from Sayarmalai areas in southern Tamil Nadu (Tirunelveli) indicated that during the Pleistocene, the area was occupied by water and lagoons (Easterson 1966). During the last glacial maximum (LGM) continental shelves were exposed with a vast reservoir of sediments with strong landward winds (NE/E) to form Aeolian Teri and the north-east monsoon helped to form fluvial Teri sediments. The south-west monsoon direction also plays a vital role in carrying sediments from one place to another but this depends also upon the loose sediments, at the time of transport (Anburaj et al. 2015). During the mid-Holocene, these areas were covered by sand dunes. The North East wind and arid conditions reduced the red sands during the last glacial period. Later the higher humidity and denser vegetation cover intensified in the red dune areas. The modern sediments occur on the coastal edge of the earlier Holocene deposits. A stable, well-vegetated land surface, raised above but close to the sea (Gardner & Martingell 1990). As per the analysis, the widest, habitat is suitable in mid-Holocene, we believe the sand dunes were a good habitat for the fossorial hedgehog during that time. There was a single observation of a hedgehog in the eastern province of Sri Lanka (Green 1913). The lowered sea levels, at an easy land route across the Palk Strait, linking India and Sri Lanka (Voris 2000) could have acted as a dispersal mode for the hedgehogs. In the Western Ghats mountains of India, the three natural, geographical breaks such as the Goa gap (65–80 MYA, Palghat and Shenkottah gaps were formed 500 MYA (Soman et al. 1990; Unnikrishnan-Warrier et al. 2009; Nandini & Robin 2012). As per the SDM maps, the Palghat gap in the southern Western Ghats mountains and southern part of Sri Lankan Island likely acted as a refugium during LIG for the hedgehog, because of the floristic similarity of the wet forests of the Eastern Ghats and southern Sri Lanka (separated from India only by the Palk Strait) to the Western Ghats (Gunatilleke & Gunatilleke 1990). There were regular regional species exchanges between southern India and Sri Lanka, that might have influenced the range shifts and speciation events of the endemic plants in these regions (Bose et al. 2016).

The late Pleistocene deposition of sand in the upper terrace was associated with abundant sand supply owing to the lower sea level. The second stage of dune accretion at 4.5 ka was observed at the lower level relative to the present-day coast. It was presumably associated with late Holocene higher sea level in the coasts of southern India and deposition of sand in the backshore region on top of the previous indurated aeolian deposits. The elevated topography of the area acted as an obstruction to trap the sand-laden onshore winds and facilitated accumulation (Alappat et al. 2017).

The vegetation in the Shola habitat during the last glacial maxima (18,000 years ago) was affected by drier climate, and the landscape was dominated by C4 grasslands with forests restricted to more humid valleys or bogs (Farooqui et al. 2010). Since then, forests have been expanding as the climate has become more humid, and these fluctuations have possibly affected the population structure of the species found in these specific habitats (Gadagkar et al. 2010). The weakening of pre-monsoonal and post-monsoonal rainfall was most likely due to the LGM towards late Pleistocene and increased aridity during the late Holocene (Kumaran et al. 2013). While considering the Mid Holocene was more suitable for the hedgehog, the aridification could have driven their dispersal towards the different areas.

Monsoon rainfall plays a vital role in the spatial distribution of old and modern forests (Shukla et al. 2014; Srivastava et al. 2016). The west coast of India receives annually a maximum rainfall of 2,000–2,900 mm; the northeast receives 1,530–2,200 mm whereas central India receives a moderate rainfall of 700–1,200 mm and the northwestern and southwestern parts receive the least (Beltrando & Camberlin 1993; Srivastava et al. 2016). However, at present two monsoons are responsible for these precipitation patterns: The south-west monsoon (June–September) responsible for about 70–90% of the annual rainfall (Boucher 1998) and the north-east monsoon (October–December) contributes to 50% of annual rainfall (Kumar et al. 2006). During the last phase of the late Pleistocene and Holocene, the wet evergreen plant species in southern India were replaced by the moist deciduous species (Kumaran et al. 2013). Whereas, in southern Asia, the arrival of the south-west monsoon dates back to the early Miocene (Shukla et al. 2014). Srivastava and coworkers suggested that pre–monsoonal, monsoonal, and post-monsoonal rainfalls were responsible for the extended rainfall period in the late Pleistocene, which supported the growth of the wet evergreen element in India (Srivastava et al. 2016).

Conservation implications

The success of any conservation programme for a threatened species depends on a sound understanding of its habitat requirements. If the habitat that is critical for a species' persistence is understood, important areas can be identified and protected, and searches for further populations may be efficiently targeted (Somaweera et al. 2015). In the year 1917, the human population size was 513,234 in Tirunelveli district (Pate 1917), increasing to 2,723,988 in 2001 and 3,077,233 in 2011 (Census India 2011). Habitat and vegetation are key factors for small mammals, including insectivores such as the MH. The ongoing changing land use and effects of climate change in Tamil Nadu (Jha et al. 2000; Jayakumar & Arockiasamy 2003; Prakasam 2010; Kumar et al. 2011; Magesh & Chandrasekar 2017) could reduce the future distribution of this fossorial hedgehog species. Rapid human expansion and low land use policy could affect the land-use areas of cultivated land, barren land, shrubs, and water bodies, which are important for the survival of the hedgehog. The new data on the species will be key to deciding factors if a change in its conservation status is needed. We are especially concerned about our finding that a relatively lesser studied species may suffer severe reductions in its potential distribution, as per previous studies, those individuals reported from the open canopy, semi-arid, thorny, shrub and grasslands (Kumar & Nijman 2016). Compared with the high elevation, there are vast majority of individuals recorded from the lowlands and plains of Tamil Nadu, which is also predicted by our present analysis. Thus, the lowlands and semi-arid regions need protection and further surveys. The species is fragmented and within a restricted range in a few districts in Tamil Nadu, Kerala, and Andhra Pradesh. The population size, density, and rate of extinction are directly linked with the isolation and patch size of the animal. Small populations are generally susceptible to demographic stochasticity (Gibbs 1998; Hicks & Pearson 2003). Demographic stochasticity may also play a role in the hedgehog species population decline. The few fragmented/isolated populations in the range within Tamil Nadu might be in danger and dramatically in a declining phase. The uncontrolled collection of this species for food and medicine for the past 100 years, in the dry areas of Tamil Nadu, triggered the MH towards the verge of local extinction (Kumar & Nijman 2016). As a solitary nature, the ongoing threats limited the individual's intercourse possibilities in the highly fragmented landscapes of southern Tamil Nadu along with predatory pressure (Brawin Kumar pers. Obs.). This species is listed in Schedule II of the Wild Life (Protection) Act, 1972 (amendment, 2022).

From the prediction map, only ten of the locations fall inside the protected areas of southern India, and most of the high-altitude mountains are less suitable. The predicted cells are suitable in eastern and southern districts of Pothais (Tamil: low altitude hillocks), Tharuvais (Tamil: larger inland lake edges), Palmyra forests, Teri red sand dunes, grasslands, savannah, and shrub-dominated urban areas. The drylands of the plains act as a suitable habitat and these habitats are in danger. However, the conservation of drylands and their associated habitats such as grasslands (Paruthipaadu, Korangaadu) and unique soil types (Teri red soil) and lower elevation forests in Tamil Nadu hold a most suitable habitat for this hedgehog species. If conservation happens all associated flora and fauna will be conserved with great importance for them in this region. Moreover, the implementation of conservation education at local levels would be important to preserve the last remaining individuals of hedgehogs.

Overall, our model predictions for *P. nudiventris* is the well–established hypothesis that Indo-Sri Lankan faunal exchange is important for this lesser-known fossorial species. They were confined to small refugia during Pleistocene glacial periods in the low lands of southern Western Ghats, Palghat gap and in the south of the Sri Lankan Island. The refugium during the glacial periods shows a very large unsuitable environment for this species in most of the other areas in Tamil Nadu. The LIG could have played a major role in isolating populations and that played a profound phenomenon in phylogeographical patterns. We hypothesize that this may be the result of important geological and environmental changes that have happened in that time. Our results show a lowland migration pattern during the LIG and towards the Sri Lankan Islands, as refugia for *P. nudiventris*. In that context, larger high-altitude mountains could also have provided a suitable habitat during LGM for this arid-adapted species in southern India. The changes in alluvium soil, red sand dunes and vegetation are a positive mode for this species. Thus, they might have a wider distribution range than previously. The recent aridification could lead a demographic change in this species. More attention on the molecular-based phylogeographical works in this arid regional fauna could help to understand more about the biogeography of this region.

Future surveys could be strategically targeted in regions characterized by plains, dry semi-arid bushes, and savannahs, on the outskirts of urban areas, south Deccan plateau areas, Deccan thorn scrub forests and grasslands of Tamil Nadu and other adjacent states. Additionally, focusing on areas with a historical hedgehog presence, as indicated by our previous work, could enhance the effectiveness of future surveys.

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Threatened Taxa

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Author contributions: BK & WTB—concept, design, and supervision. BK & WTB—data collection & analysis. BK—manuscript writing. BK & WTB—manuscript review & comments. BK—funding acquisition.

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ARTICLE

Declining trends of over-summering shorebird populations along the southeastern coasts of Tamil Nadu, India

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Abstract: Over-summering of shorebirds refers to the phenomenon where certain species of shorebirds, primarily migratory, remain on their non-breeding grounds during the summer months for one or more years instead of migrating to their breeding grounds. The present study investigates the presence and abundance of over-summering shorebird species at four distinct sites covering 24 scanning points along the southeastern coasts of Tamil Nadu for 2017–2023. A total of 13 species were observed over-summering, with Lesser Sand Plover being the most dominant species, followed by Greater Sand Plover. Notably, 10 species were found across all four sites, while three species—Black-tailed Godwit, Bar-tailed Godwit, and Common Sandpiper—were exclusive to Dhanushkodi Lagoon, observed only during 2023. The study examined the year-wise abundance of these species, revealing a decline in over-summering shorebirds across all study sites. The Eurasian Curlew, Curlew Sandpiper, Bar-tailed & Black-tailed Godwits are the 'Near Threatened' species observed during the study. Furthermore, the research highlighted variations in Shannon species diversity index (H) location-wise and year-wise – Manoli Island (H = 2.25) in 2023; Dhanushkodi Lagoon (H = 1.8) in 2023; Valinokkam Lagoon (H = 1.63), and Pillaimadam Lagoon (H = 2.08) in 2017. Key findings are that among the study sites, in Pillaimadam Lagoon all 10 species' abundance declined; in Valinokkam Lagoon, Greater Sand Plover and Little Stint marginally increased, and eight species declined; Common Redshank and Ruddy Turnstone marginally increased in Manoli Island, while other eight species declined; Grey Plover population increased in Dhanushkodi Lagoon along with a marginal decrease in Common Redshank and Ruddy Turnstone as other species declined, over the years of study.

Keywords: Abundance, avian ecology, breeding patterns, coastal wetlands, conservation strategies, habitat degradation, monitoring, population dynamics, shorebird migration, species diversity.

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Author contributions: BH—conceptualization, design of work, writing, and editing; MH—data curation, analysis, mapping, and writing; RN—data compilation, writing; SR—writing.

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INTRODUCTION

Few species of long-distance migratory shorebirds tend to remain on the non-breeding grounds during the summer months, forgoing migration during the breeding season. This phenomenon is called over-summering (Cramp et al. 1985; Soto-Montoya et al. 2009) mostly influenced by environmental, physiological, and ecological factors. One of the major reasons that is attributed to these over-summering individuals is that they are either sexually immature birds (McNeil et al. 1994; Soto-Montoya et al. 2009) or avoid the risks of migration (McNeil et al. 1994; Vieira 2016). Compared to various shorebird ecological studies done across the globe, this strategy is an aspect least studied (Gutierrez 2017; Martínez-Curci et.al. 2020). The over-summering phenomenon is common in the families of Charadriidae and Scolopacidae (McNeil et al. 1994) and is documented in 15 other bird groups.

Of the 70 species of shorebirds recorded in India, 49 are migrants (Howes & Bakewell 1989). A few studies have been undertaken on the western Indian coast (Aarif et al. 2020; Anand et al. 2023; Shifa 2023) and the eastern coast (Balachandran 2006; Sandilyan et al. 2010; Byju et al. 2023a,b). Twenty shorebird species are found to over-summer in the eastern coast of India. The details are as follows: from Chilika Lake, Odisha, a few individuals of Grey Plover *Pluvialis squatarola*, Lesser Sand Plover *Charadrius mongolus*, Black-tailed Godwit *Limosa limosa*, Eurasian Curlew *Numenius arquata*, and Curlew Sandpiper *Calidris ferruginea*, in partial breeding, and some first-year birds are in nonbreeding plumage over-summering (Balachandran et al. 2009). Furthermore, from Point Calimere, Tamil Nadu, Grey Plover, Lesser Sand Plover, Whimbrel *Numenius phaeopus*, Eurasian Curlew, Common Greenshank *Tringa nebularia*, Terek Sandpiper *Xenus cinereus*, Little Stint *Calidris minuta*, Curlew Sandpiper (few adults in breeding plumage), Broad-billed Sandpiper *Limicola falcinellus*, and Ruff *Calidris pugnax* were reported to over-summer (Balachandran & Thirunavukarasu 2009). Balachandran (2006) listed the over-summering shorebirds from Pulicat Lake, Andhra Pradesh that included Pacific Golden Plover *Pluvialis fulva*, Black-tailed Godwit, Marsh Sandpiper *Tringa stagnatilis*, Common Sandpiper *Actitis hypoleucos*, Little Stint, and Ruff. In Gulf of Mannar, Tamil Nadu, Daniel et al. (2007) recorded that Bar-tailed Godwit *Limosa lapponica*, Grey Plover, Lesser Sand Plover, Greater Sand Plover *Charadrius leschenaultii*, Crab Plover *Dromas ardeola*, Whimbrel, Eurasian Curlew, Common Greenshank *Tringa nebularia*, Common Redshank *Tringa totanus*, Curlew Sandpiper, Little Stint, and Ruddy Turnstone *Arenaria interpres* were the shorebirds that were over-summering.

The survival of migratory birds is increasingly threatened by the over-exploitation of natural resources and associated development pressures. Factors such as habitat loss, degradation, pollution, illegal hunting and trade, poisoning, electrocution, and collisions with energy infrastructure pose significant risks to these birds. Global assessments highlighted the loss of habitats and the growing impacts of climate change on the economies and biodiversity of the Central Asian Flyway (CAF) (Mundkur et al. 2023). Shorebird abundance along the Indian coast is experiencing a tremendous decline due to several environmental and anthropogenic issues (Sandiliyan et al. 2010; Byju et al. 2023c). Understanding shorebird presence and richness is valuable information for conservation efforts (Newton 2010; Zöckler et al. 2010). The present study was conducted at four locations with good shorebird diversity: Valinokkam Lagoon with 35 shorebird species (Byju et al. 2023a), Dhanushkodi Lagoon with 32 shorebird species (Balachandran 1990), Manoli Island with 26 species (Byju et al. 2023c), and Pillaimadam Lagoon with 21 species (Balachandran 1990). The objective of the study was to document over-summering shorebird species from the mentioned different sites in the Ramanathapuram district on the southeastern coast of India and analyse the abundance pattern over the last six years.

MATERIALS AND METHODS

Study Areas

Ramanathapuram district in Tamil Nadu has five bird sanctuaries, which include two Ramsar sites and the Gulf of Mannar Biosphere Reserve (GoM), India's first Marine Biosphere Reserve. GoM is located off the southernmost tip of the country and consists of 21 islands ranging 0.2–8 km off the shore. Among the islands, most shorebird congregations are seen on Manoli Island (Byju et al. 2023c). The four study sites were selected based on the shorebird diversity in the region (Image 1). This includes: (i) Manoli Island (9.215N & 79.128E) is about 2 km long and 50 m broad, spanning an area of 25.90 ha, and contains tiny water ponds & open mudflats. The small water channels that run through the islands are surrounded by mangrove vegetation and coarse grass. The beach is sandy, and there is a lot of coral formation in the intertidal zone. The intertidal zone during the low tide served as the foraging area for the birds (Image 2);

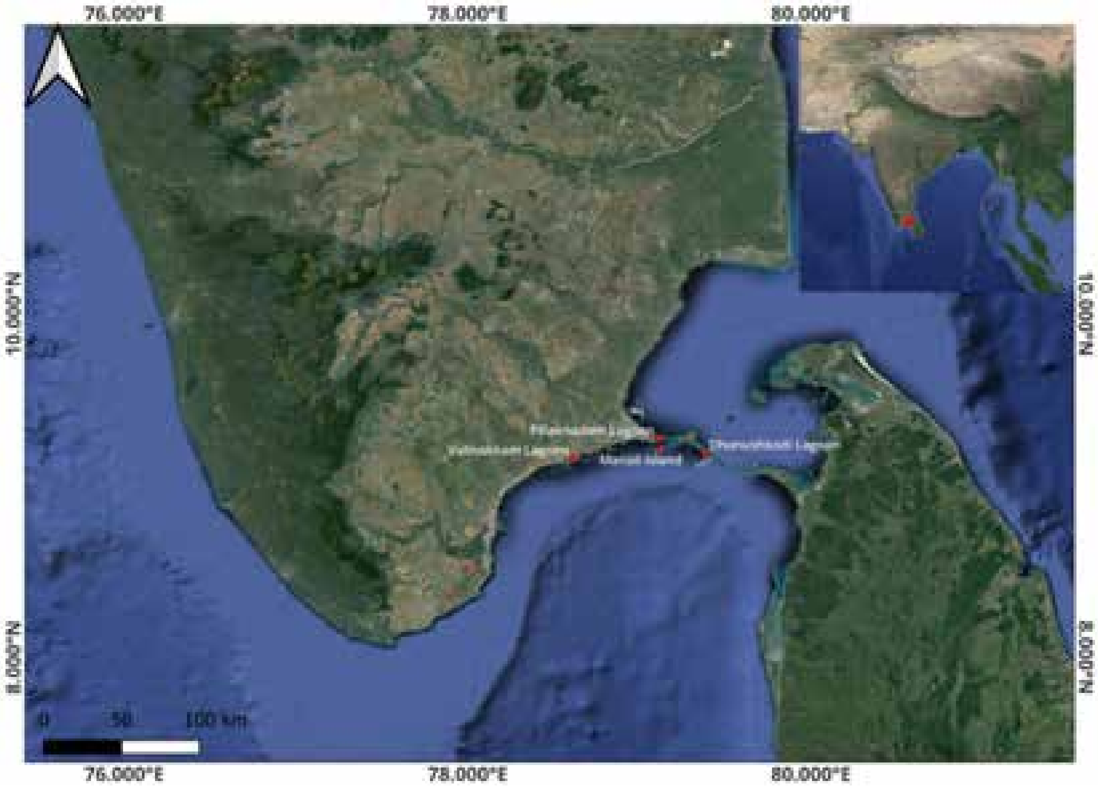

Image 1. Study areas—Pillaimadam Lagoon, Valinokkam Lagoon, Dhanushkodi Lagoon, and Manoli Island—on the southeastern coast of India.

(ii) Dhanushkodi Lagoon (9.198N & 79.383E) situated on Rameswaram Island, extends from Rameswaram Road to Arichalmunai. The total length of the lagoon is 15 km. The lagoon has mudflats and sandy areas. The width varies 0.7–1 km. The western side is mostly mudflats. The lagoon, tapering towards the eastern side, becomes an exclusive marine habitat. Most of the birds are seen mainly on the mudflats exposed after the high tides in the mid region of the lagoon (Image 3); (iii) Valinokkam Lagoon (9.166N & 78.614E) is an area with state, and private-run salt pans and prawn cultures. The excess water pumped from the sea is stored in bunds for salt extraction and pumped to form a man-made lagoon. This, over time, had developed into a mudflat. The salt pans extract salt, and seawater is pumped to the lagoon that maintains water in the artificial lagoon throughout the year. The mudflats available in the lagoon throughout the year due to the continuous pumping of water for salt extraction from the sea served as a foraging area for the birds (Image 4); and (iv) The Palk Bay bounds Pillaimadam Saltwater Lagoon (9.282N & 79.108E) near Mandapam on the north and the Rameswaram-Ramnad railroad on the south. It covers an area of about 450 ha. The lagoon is connected to Palk Bay by a bar mouth, through which it receives the tidal water. The lagoon is bordered by grassy areas on the landward side and sand dunes on the seaward site. Birds are mostly restricted to mudflat areas (Image 5).

Methods

The arrival of migratory shorebirds on the wintering grounds of southern India generally starts in August and the departure by May (Balachandran 1990; Aarif et al. 2021; Shifa 2023). The Gulf of Mannar (GoM) is a major wintering site (Balachandran 1990) on the southeastern coast, and all the locations chosen for study are either part of or near GoM. We surveyed the shorebirds once a week during the over-summering period (15 June to 31 July), based on the early literature on the arrival and departure of birds in the region (Balachandran 1990) from 2017 to 2023 by using direct visual counts (Howes & Bakewell 1989).

Observations were made using binoculars (Nikon 10*50), a camera (Canon 100–400 mm lens), and a spotting scope (Vanguard 14*70) between 06.00 h and 11.00 h at previously fixed 24 scanning points covering all four study locations at low tides. We started our count five minutes after reaching each scanning point so that the birds got acclimated to our presence at a distance varying from 100–300 m. As the bird numbers were fewer, except for a few species, double counts were ruled out with the help of other observers. Birds were identified using field guides (Grimmett et al. 2011; Hayman et al. 2011). We calculated the population abundance of each species as mean ± standard deviation between 2017 and 2023 and for each study site. Shannon diversity Index and Menhinick's species richness Index were calculated for each site from 2017 to 2023, using PAST software (version 4.17).

RESULTS

A total of 13 over-summering species were documented from four sites along the southeastern coasts of Tamil Nadu. We observed a few shorebird species—Ruddy Turnstone, Curlew Sandpiper, Grey Plover, Lesser Sand Plover, and Greater Sand Plover—with breeding plumage and mostly others in non-breeding plumage from all four study sites. Out of the 13 species, 10 (Lesser Sand Plover, Greater Sand Plover, Grey Plover, Whimbrel, Eurasian Curlew, Common Greenshank, Common Redshank, Little Stint, and Ruddy Turnstone) were documented from all four sites. Meanwhile, three species—Black-tailed Godwit, Bar-tailed Godwit, and Common Sandpiper—were recorded only from the Dhanushkodi Lagoon, in 2023. The year-wise abundance (2017–2023) expressed as mean ± standard deviation, of all over-summering species in each study site, is provided in Tables 1–4. The dominant over-summering species observed from all four sites was Lesser Sand Plover followed by Greater Sand Plover. Lesser Sand Plover was more abundant in Valinokkam and Dhanushkodi, whereas Greater Sand Plover was highest in Valinokkam and Pillaimadam.

The over-summering species richness and diversity across all the years at each of the four study sites are summarized in Table 5. A higher value of the Shannon Index (H) indicates greater diversity in the community. Among the four sites, the highest species diversity was observed in Manoli in 2023 (H = 2.25). In contrast, 2020 and 2021 were marked by low diversity values across all the sites. The highest diversity values were recorded in Dhanushkodi (H = 1.8) in 2023, and in Manoli in 2023 (H = 2.2), whereas in Valinokkam and Pillaimadam the highest diversity was recorded in 2017, with an H index of 1.63 and 2.08, respectively. Notably, the diversity index for Pillaimadam remained stable until 2022 but experienced a significant decline in 2023. Menhinick's index, which emphasizes species richness, also indicated that 2023 was a peak year for over-summering species richness across all sites. Manoli recorded the highest value (0.8), followed by Pillaimadam and Dhanushkodi (0.6), and Valinokkam recorded the lowest value (0.5).

Species trends also varied among sites and years of the study. In Valinokkam, eight over-summering species declined over the study period as shown in Figure 1. However, there was a marginal increase in the populations of Greater Sand Plover (Figure 6) and Little Stint (Figure 13). In Pillaimadam, all over-summering species experienced a drastic reduction throughout the study period (Figure 2). On Manoli Island, two species, Ruddy Turnstone (Figure 11) and Common Redshank (Figure 14) showed a marginal decline, while the decline in other over-summering species was more pronounced (Figure 3). In Dhanushkodi Lagoon (Figure 4), the Grey Plover population increased (Figure 5), while Common Redshank (Figure 11) and Ruddy Turnstone (Figure 14) showed marginal reductions. Notably, three new species—Bar-tailed Godwit (Figure 15), Black-tailed Godwit (Figure 16), and Common Sandpiper (Figure 17)—were recorded in 2023.

Table 1. Abundance of over-summering shorebirds documented in Valinokkam Lagoon (mean ± SD).

Common name	2017	2018	2019	2020	2021	2022	2023
Grey Plover	33 ± 5.66	29 ± 7.07	27.5 ± 9.19	24 ± 9.89	19 ± 9.89	15.5 ± 3.53	5 ± 1.41
Greater Sand Plover	40.5 ± 6.36	42 ± 12.73	34 ± 9.89	36 ± 16.97	18 ± 8.48	23.5 ± 2.12	45 ± 7.071
Lesser Sand Plover	269 ± 72.12	261 ± 70.71	260 ± 66.46	251 ± 70.71	250 ± 70.711	147 ± 35.35	65 ± 49.49
Whimbrel	29 ± 2.83	24.5 ± 0.71	22.5 ± 2.12	19 ± 2.82	15.5 ± 2.12	11 ± 0	1 ± 0
Eurasian Curlew	15 ± 1.41	14.5 ± 0.71	11.5 ± 0.70	10.5 ± 0.7	8.5 ± 2.12	5 ± 0	1 ± 0
Common Greenshank	12.5 ± 0.71	11.5 ± 0.71	10.5 ± 0.70	10 ± 0	5.5 ± 0.7	4.5 ± 0.7	2 ± 0
Common Redshank	17.5 ± 7.78	19.5 ± 12.02	17 ± 9.89	14.5 ± 9.19	13 ± 9.89	8 ± 5.65	11 ± 1.41
Curlew Sandpiper	15.5 ± 4.95	12 ± 1.41	10.5 ± 0.70	10 ± 2.82	9 ± 1.41	5.5 ± 0.7	1 ± 0
Little Stint	16 ± 4.24	14.5 ± 3.54	13.5 ± 3.53	12 ± 2.82	9 ± 5.65	7.5 ± 4.94	25 ± 9.89
Ruddy Turnstone	38.5 ± 9.19	36 ± 8.49	30.5 ± 7.77	24 ± 4.24	18.5 ± 4.94	17 ± 1.41	2 ± 0

Table 2. Abundance of over-summering shorebirds documented in Pillaimadam Lagoon (mean ± SD).

Common name	2017	2018	2019	2020	2021	2022	2023
Grey Plover	20 ± 1.41	19.5 ± 7.78	15 ± 1.41	12 ± 0	11.5±0.71	10.5 ± 0.71	1.5 ± 0.71
Greater Sand Plover	49 ± 9.9	38.5 ± 2.12	31 ± 0	26.5±0.71	22.5 ± 2.12	15.5 ± 0.71	0
Lesser Sand Plover	97 ± 0	90 ± 1.41	89 ± 11.31	79.5 ± 2.12	77 ± 1.41	56 ± 22.63	7.5 ± 10.61
Whimbrel	40 ± 2.83	36.5 ± 6.36	31.5 ± 6.36	24.5 ± 4.95	21.5 ± 0.71	15.5 ± 0.71	0
Eurasian Curlew	20 ± 2.83	15 ± 1.41	13 ± 1.41	13.5 ± 4.95	9.5 ± 2.12	11 ± 1.41	1.5 ± 0.71
Common Greenshank	13 ± 1.41	12 ± 1.41	11 ± 0	10 ± 0	9 ± 2.83	5 ± 0	2.5 ± 3.54
Common Redshank	14.5 ± 2.12	12.5 ± 2.12	11 ± 1.41	9 ± 2.83	9 ± 1.41	8 ± 0	2 ± 0
Curlew Sandpiper	19.5 ± 3.54	17.5 ± 4.95	9 ± 5.66	14 ± 2.83	11.5 ± 0.71	10.5 ± 0.71	0
Little Stint	9.5 ± 0.71	9.5 ± 2.12	11.5 ± 0.71	9 ± 5.66	8.5 ± 3.54	13 ± 8.49	0
Ruddy Turnstone	24.5 ± 3.54	21.5 ± 2.12	18.5 ± 3.54	15 ± 2.83	12.5 ± 2.12	11.5 ± 0.71	0.5 ± 0.71

Table 3. Abundance of over-summering shorebirds documented in Manoli Island (mean ± SD).

Common name	2017	2018	2019	2020	2021	2022	2023
Grey Plover	28.5 ± 6.36	23.5 ± 3.54	15 ± 1.41	11.5 ± 0.71	10 ± 0	9.5 ± 2.12	9 ± 1.41
Greater Sand Plover	23 ± 4.24	18 ± 5.66	17 ± 5.66	13 ± 2.83	10.5 ± 0.71	10 ± 2.83	10 ± 0
Lesser Sand Plover	83 ± 4.24	83 ± 4.24	74 ± 2.83	70 ± 2.83	61 ± 0	57.5 ± 0.71	40 ± 0
Whimbrel	30 ± 4.24	22.5 ± 2.12	15.5 ± 0.71	11.5 ± 0.71	10.5 ± 0.71	11.5 ± 2.12	6 ± 0
Eurasian Curlew	20 ± 4.24	15 ± 4.24	12 ± 1.41	12.5 ± 2.12	13.5 ± 2.12	10 ± 4.24	4.5 ± 0.71
Common Greenshank	21 ± 4.24	18.5 ± 3.54	15 ± 1.41	13.5 ± 0.71	11 ± 0	8.5 ± 2.12	5.5 ± 0.71
Common Redshank	17 ± 1.41	14.5 ± 0.71	11.5 ± 0.71	12 ± 1.41	10.5 ± 0.71	9 ± 2.83	11 ± 1.41
Curlew Sandpiper	20 ± 8.49	19.5 ± 2.12	14 ± 2.83	12 ± 1.41	10.5 ± 0.71	7 ± 1.41	4 ± 0
Little Stint	14 ± 2.83	11 ± 1.41	12 ± 1.41	10.5 ± 0.71	10 ± 0	8 ± 1.41	5.5 ± 0.71
Ruddy Turnstone	20 ± 0	20 ± 0	15 ± 1.41	13.5 ± 2.12	12 ± 1.41	11 ± 0	13.5 ± 2.12

Table 4. Abundance of over-summering shorebirds documented in Dhanushkodi Lagoon (mean ± SD).

Common name	2017	2018	2019	2020	2021	2022	2023
Grey Plover	16 ± 1.41	13.5 ± 4.95	11.5 ± 0.71	10.5 ± 0.71	10 ± 8.49	8.5 ± 7.78	30 ± 14.14
Greater Sand Plover	27.5 ± 7.78	18.5 ± 3.54	20 ± 7.07	14.5 ± 0.71	14.5 ± 4.95	11.5 ± 2.12	8 ± 4.24
Lesser Sand Plover	270 ± 282.84	251 ± 284.26	225.5 ± 246.78	241.5 ± 282.14	243 ± 134.35	131.5 ± 72.83	83 ± 80.61
Whimbrel	29 ± 5.66	26.5 ± 7.78	15 ± 0	13 ± 1.41	11 ± 0	9 ± 1.41	8 ± 0
Eurasian Curlew	14.5 ± 0.71	11 ± 1.41	11.5 ± 0.71	10 ± 0	9.5 ± 2.12	8.5 ± 0.71	2.5 ± 0.71
Common Greenshank	13.5 ± 0.71	13 ± 1.41	11 ± 0	10 ± 0	7.5 ± 0.71	5 ± 0	5.5 ± 7.78
Common Redshank	45.5 ± 43.13	17 ± 4.24	13 ± 2.83	14 ± 2.83	25 ± 9.9	10 ± 5.66	33 ± 12.73
Curlew Sandpiper	55.5 ± 13.44	50 ± 14.14	44 ± 14.14	38 ± 9.9	29 ± 4.24	18 ± 2.83	11.5 ± 4.95
Little Stint	28 ± 11.31	26 ± 1.41	21 ± 0	16.5 ± 0.71	13 ± 0	11 ± 0	0
Ruddy Turnstone	22 ± 9.9	20 ± 9.9	13 ± 0	11.5 ± 0.71	17 ± 12.73	25.5 ± 23.33	10 ± 5.66
Bar-tailed Godwit	0	0	0	0	0	0	1.5 ± 0.71
Black-tailed Godwit	0	0	0	0	0	0	2 ± 0
Common Sandpiper	0	0	0	0	0	0	0.5 ± 0.71

Table 5. Over-summering shorebird species diversity and richness in all four sites from 2017 to 2023.

Study sites	Year	2017	2018	2019	2020	2021	2022	2023
Valinokkam	Shannon index	1.634	1.608	1.533	1.489	1.304	1.497	1.531
	Menhinick index	0.321	0.328	0.338	0.349	0.370	0.452	0.563
Pillaimadam	Shannon index	2.088	2.065	2.048	2.046	2.049	2.04	0.7285
	Menhinick index	0.4131	0.434	0.4709	0.4957	0.5322	0.5625	0.6124
Manoli	Shannon index	2.092	2.06	1.975	1.966	1.929	2.004	2.259
	Menhinick index	0.4149	0.445	0.4811	0.5137	0.5338	0.5965	0.8085
Dhanushkodi	Shannon index	1.704	1.603	1.545	1.419	1.415	1.635	1.802
	Menhinick index	0.3096	0.3346	0.3601	0.363	0.363	0.4579	0.6069

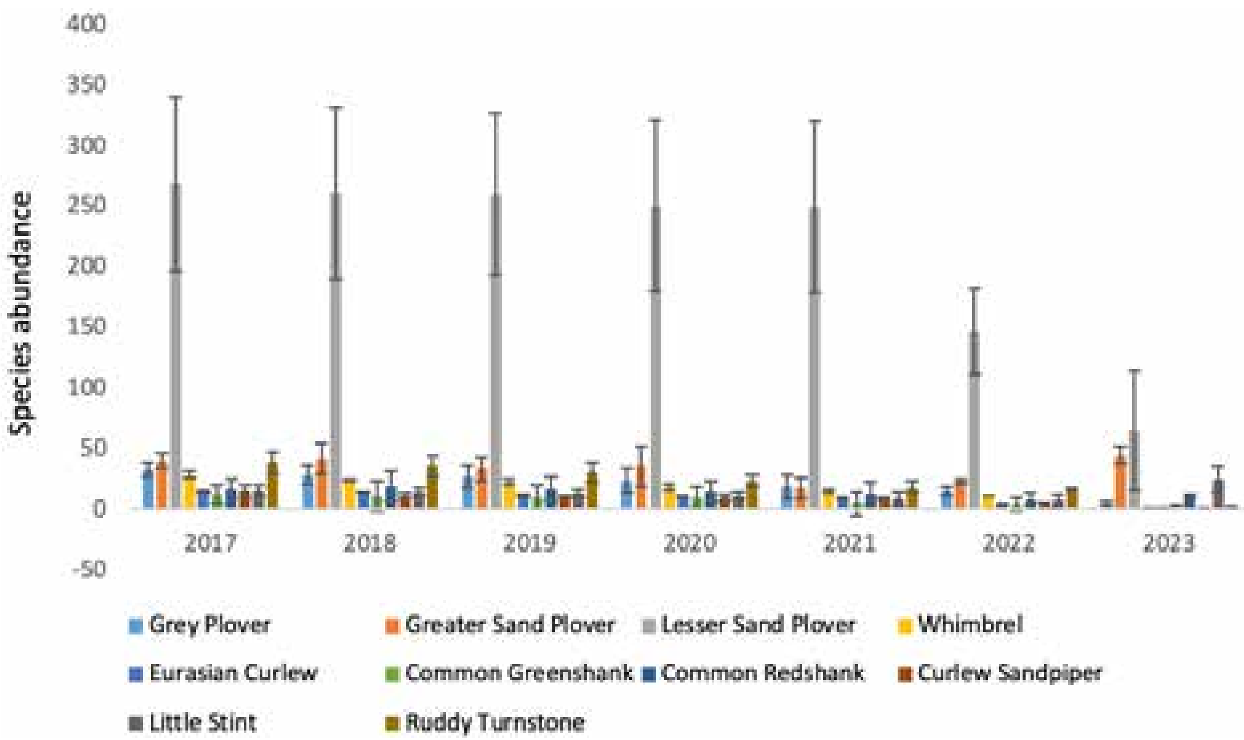

Figure 1. Abundance of over-summering shorebirds in Valinokkam Lagoon.

DISCUSSIONS

The occurrence and timely departure of shorebirds are intricately linked to the quality of stop-over and wintering sites (Smith et al. 2012). The understanding of the significance of over-summering as a life history strategy for migratory shorebirds remains limited (McNeil et al. 1994). The results of this study provide valuable insights into the species richness, diversity, and trends of over-summering shorebirds along the southeastern coasts of Tamil Nadu from 2017 to 2023. Some shorebird species, which winter in the southern hemisphere after breeding in the Arctic and northern temperate regions, exhibit delayed maturity. This delay is manifested as immatures staying on their wintering grounds in non-breeding plumage during their first breeding season, then migrating north to breed in their second or third years (Summers et al. 1995) to reduce migration risks (McNeil et al. 1994; Summers et al. 1995). We documented 13 species, with notable observations of shorebirds in breeding and non-breeding plumage. In the south-east of India, Lesser Sand Plover was the most abundant species followed by Greater Sand Plover in Point Calimere (Balachandran & Thirunavakarasu 2009), Chilika Lake (Balachandran et al. 2009), and Gulf of Mannar (Daniel et al. 2007). In our study too, these

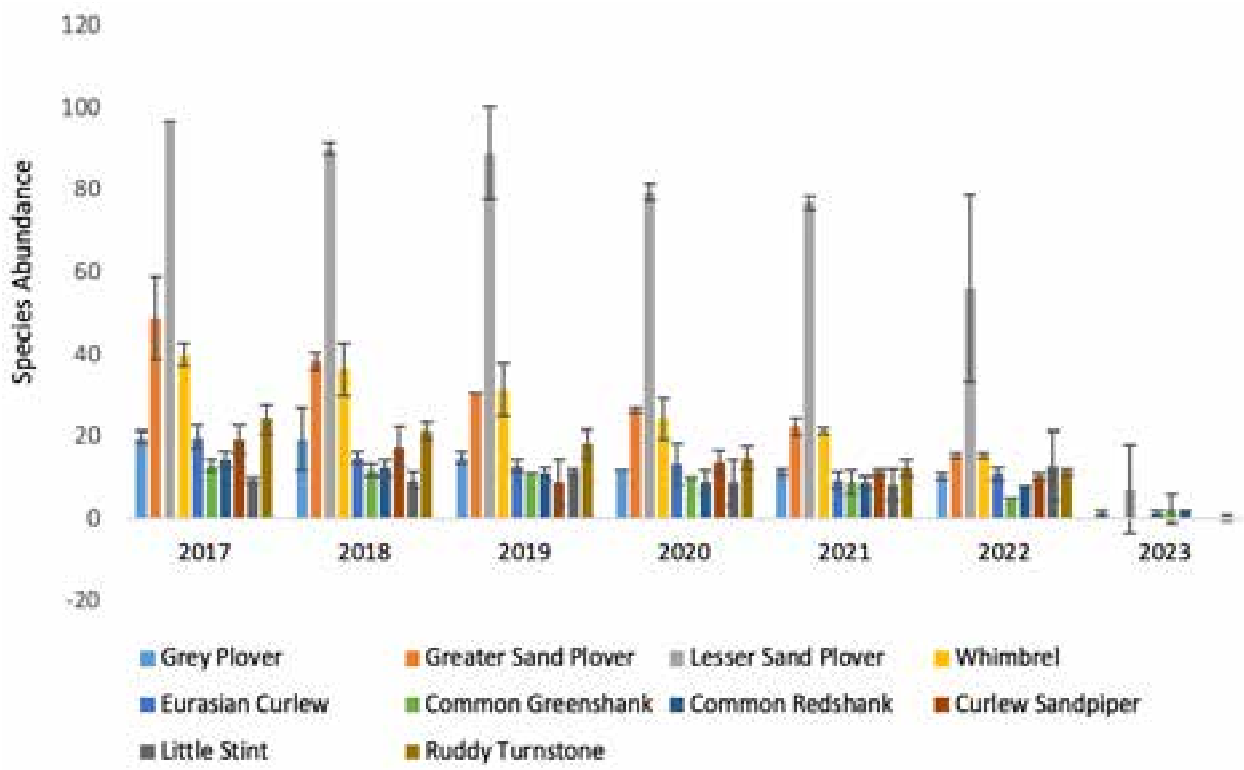

Figure 2. Abundance of over-summering shorebirds in Pillaimadam Lagoon.

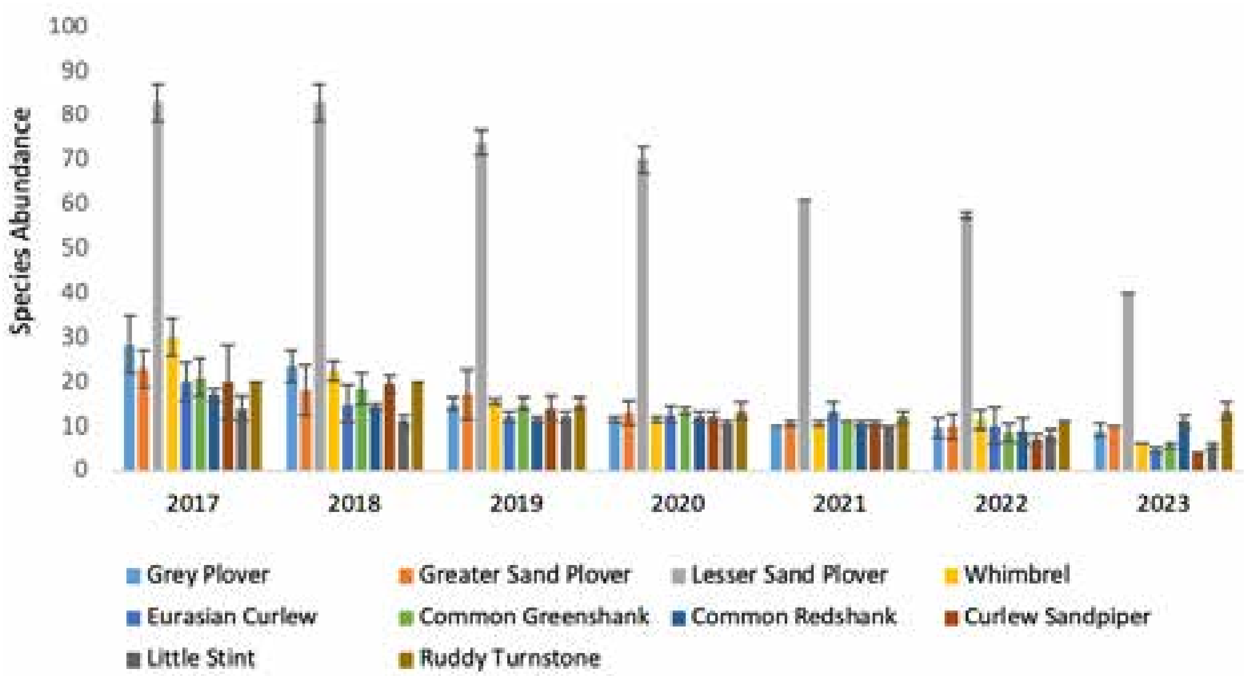

Figure 3. Abundance of over-summering shorebirds on Manoli Island.

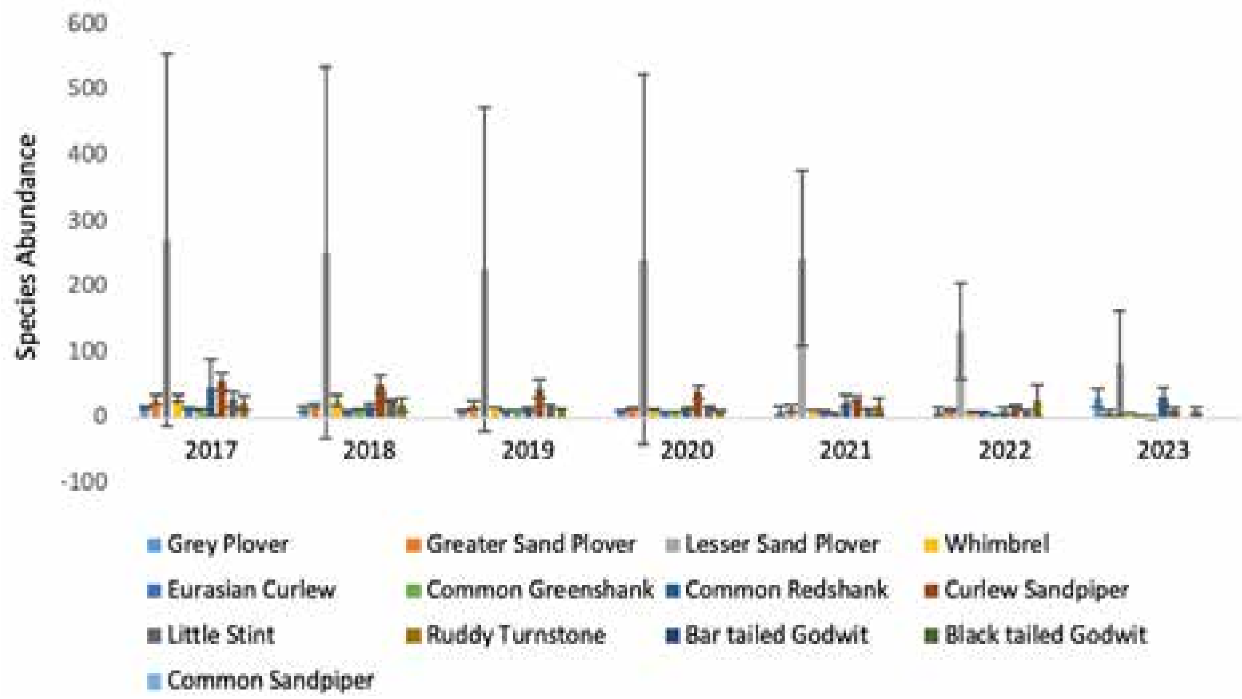

Figure 4. Abundance of over-summering shorebirds in Dhanushkodi Lagoon.

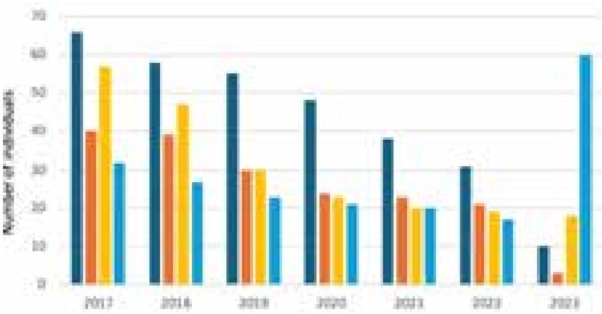

Figure 5. Abundance of over-summering Grey Plover in the study sites from 2017 to 2023.

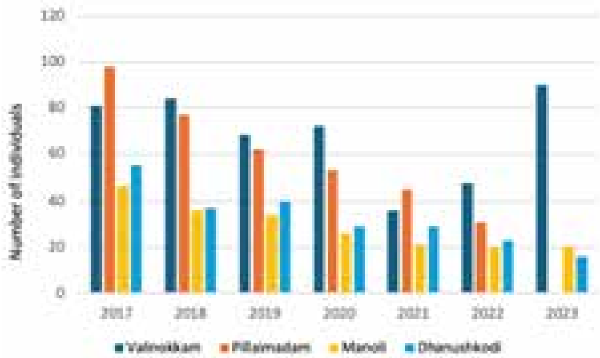

Figure 6. Abundance of over-summering Greater Sand Plover in the study sites from 2017 to 2023.

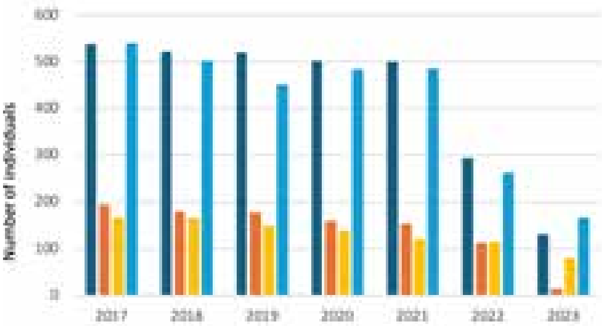

Figure 7. Abundance of over-summering Lesser Sand Plover in the study sites from 2017 to 2023.

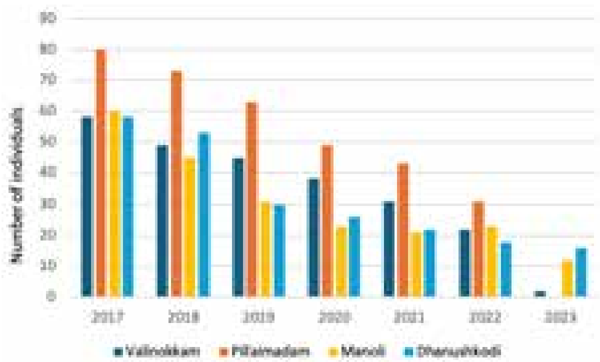

Figure 8. Abundance of over-summering Whimbrel in the study sites from 2017 to 2023.

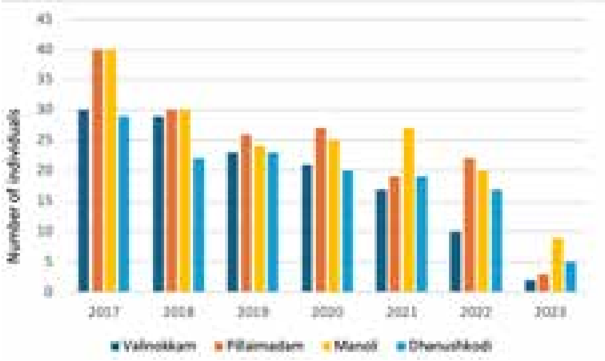

Figure 9. Abundance of over-summering Eurasian Curlew in the study sites from 2017 to 2023.

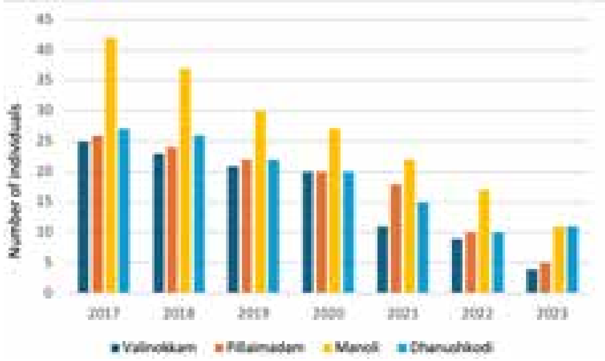

Figure 10. Abundance of over-summering Common Greenshank in the study sites from 2017 to 2023.

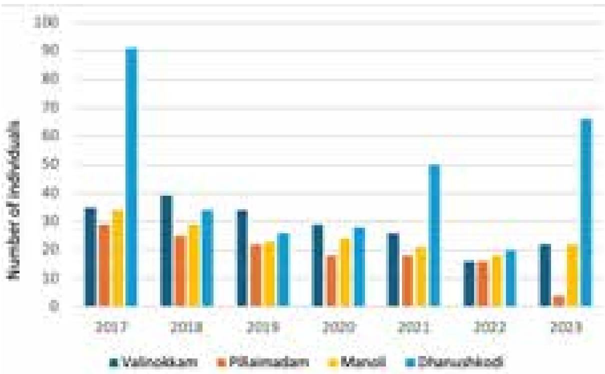

Figure 11. Abundance of over-summering Common Redshank in the study sites from 2017 to 2023.

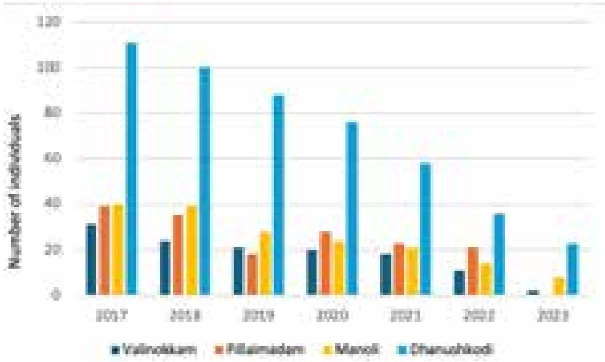

Figure 12. Abundance of over-summering Curlew Sandpiper in the study sites from 2017 to 2023.

two species were abundant in all sites. The occurrence of globally threatened species like Bar-tailed Godwit, Black-tailed Godwit, Curlew Sandpiper, and Eurasian Curlew during over-summering periods further reflects the importance of these study sites for the shorebirds of the CAF.

The present findings also indicate fluctuations in species diversity and richness of over-summering shorebirds, with notable increases in certain species – Grey Plover in Dhanushkodi, Little Stint & Greater Sand Plover in Pillaimadam. Additionally, three new species—Black-tailed Godwit, Bar-tailed Godwit and Common Sandpiper—were recorded in 2023, in the Dhanushkodi Lagoon. Similarly, previous studies from the eastern coast of India have documented five over-summering shorebird species in Chilika Lake, Odisha (Balachandran et al. 2009), 10 species in Point Calimere, Tamil Nadu (Balachandran & Thirunavakarasu 2009), and 12 species in GoM, Tamil Nadu (Daniel et al. 2007).

In Valinokkam, the decline of eight over-summering shorebird species over the study period suggests potential long-term negative impacts, such as habitat degradation or changes in prey availability. However, the marginal increase in Greater Sand Plover and Little Stint populations during the over-summering period could indicate localized changes in conditions. Since this is a man-made lagoon, one exclusively dependent on the seawater pumped for salt extraction, the local factors play a major role in species diversity and richness. Pillaimadam exhibited a concerning trend of drastic reductions in all over-summering shorebird species populations throughout the study period, emphasizing the need for targeted conservation efforts. The strategy of over-summering, where certain portions of the shorebird populations spend significant durations in areas that are largely undocumented and lacking proper protection, might contribute to this decline (Ntiamoa-Baidu 1991). This is similar to our two study sites, Valinokkam and Pillaimadam, as both are unprotected areas. Insufficient conservation efforts targeted at this specific phase of their life cycle could be a contributing factor to the observed trends in shorebird populations

The decline in over-summering shorebird abundance across all study sites (Tables 1–4) suggests an ongoing

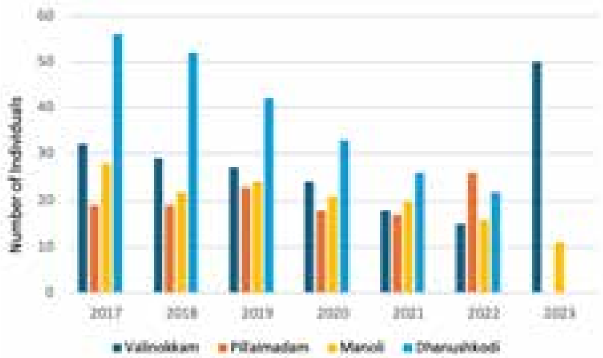

Figure 13. Abundance of over-summering Little Stint in the study sites from 2017 to 2023.

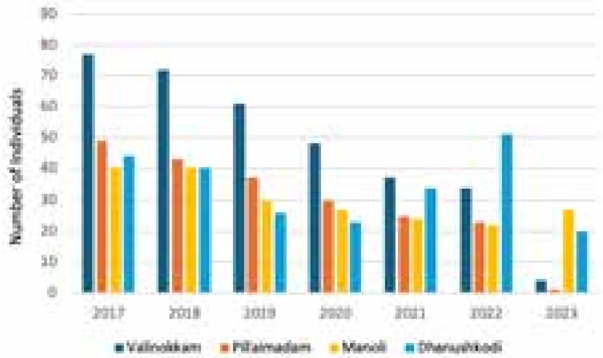

Figure 14. Abundance of over-summering Ruddy Turnstone in the study sites from 2017 to 2023.

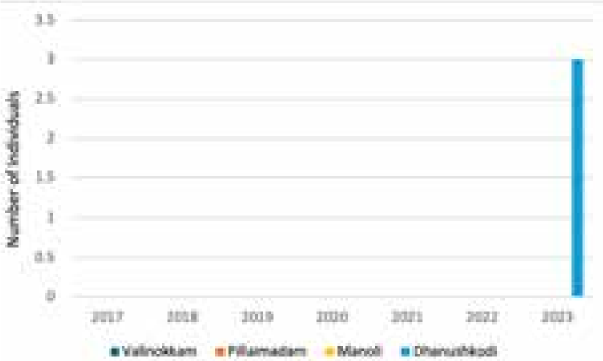

Figure 15. Abundance of over-summering Bar-tailed Godwit in the study sites from 2017 to 2023.

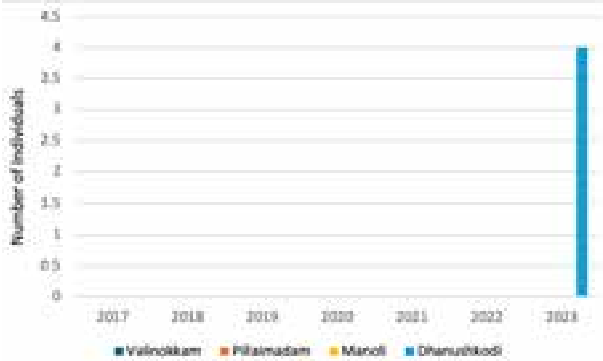

Figure 16. Abundance of over-summering Black-tailed Godwit in the study sites from 2017 to 2023.

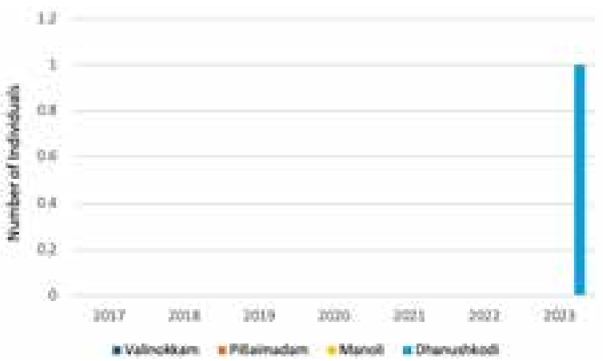

Figure 17. Abundance of over-summering Common Sandpiper in the study sites from 2017 to 2023.

habitat degradation issue, as reflected by the overall global decline in shorebird populations, particularly within the Central Asian flyway including regions like Dhanushkodi (Rashiba et al. 2023). The Shannon index values indicated fluctuations in species diversity over the study period, with a notable peak in 2023, particularly at Manoli Island (H = 2.25). The increase in over-summering shorebird diversity could be attributed to various factors including favourable environmental conditions and reduced anthropogenic pressures due to the lesser fishermen activities on this uninhabited island. Conversely, 2020 and 2021 marked low diversity of over-summering shorebirds across all sites, potentially due to disturbances such as habitat loss. Specifically, the substratum hardening and mangrove encroachments to the mudflats reduce the area of foraging in Manoli Island (Byju et al. 2023c) and the impact of infrastructure development including new roads in Dhanushkodi Lagoon witnessed a substantial decrease in overall shorebird abundance over a few decades.

This research provides valuable insights into the dynamics of over-summering shorebird populations along the southeastern coasts of Tamil Nadu. The decline observed, particularly in species with probing beaks, emphasizes the need for further conservation efforts. The variation in abundance among lagoons underscores the importance of site-specific conservation strategies to preserve these ecologically significant habitats including non-protected ones.

Image 2. Manoli Island. © H. Byju.

Image 3. Dhanushkodi Lagoon. © H. Byju.

Image 4. Valinokkam Lagoon. © N. Raveendran.

Image 5. Pillaimadam Lagoon. © H. Byju.

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ARTICLE

Seasonal changes in waterbird assemblages in Chambal River at Mukundra Hills National Park, Rajasthan, India

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Abstract: The seasonal pattern of species diversity and abundance of waterbirds of the Chambal River in the extent of Mukundra Hills National Park, Rajasthan, India was evaluated. The pre-monsoon (March–April 2021) and post-monsoon surveys (August–September 2021) were carried out using the direct count method with the help of a motorboat to monitor the population status of waterbirds. A total of 44 species of waterbirds belonging to 15 families and nine orders were identified, including 11 winter migratory species. Forty species of birds were recorded during pre-monsoon and 27 species during post-monsoon seasons. The species richness and relative abundance varied significantly between observed seasons (x^2 = 532.77, *df* = 43, p <0.05). Breeding activities of three species were recorded, namely, Grey Heron, Black-crowned Night Heron, and the 'Near Threatened' Woolly-necked Stork. The present study reveals the status of waterbirds in the protected area of Mukundra Hills National Park.

Keywords: Avifauna, Central Asian Flyway, Heronry, migratory birds, pre and post-monsoon, seasonal patterns, species richness.

Abbreviations: IUCN—International Union for Conservation of Nature | CAF—Central Asian Flyway.

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INTRODUCTION

The biodiversity assessment is a crucial component of conservation and is most often used to evaluate the importance of indigenous biodiversity values at one site compared with others (Usher 1986). The diversity of significant megafauna in a particular habitat is also widely used for assessing a riverine ecosystem. It includes major vertebrates like fishes, reptiles, waterbirds, and aquatic mammals. Freshwater fishes and waterbirds are by far the best-studied groups of freshwater habitats; sometimes, they are used as an indicator of ecosystem health (Revenga et al. 2005). Wetland ecosystems are generally considered to be one of the most productive as well as fragile ecosystems. The waterbirds are considered significant biological indicators of the health of these ecosystems. Globally, 871 species of waterbirds have been identified so far (Gopi & Hussain 2014).

Wetland biodiversity strongly depends on the quality, quantity, and local water cycle (van der Valk 2006). The hydroperiod may substantially impact species sorting and assemblage; thus, local variation in the hydrological pattern may constitute an important predictor of species composition (Urban 2004; Brönmark & Hansson 2005). The abundance and diversity of wetland birds show a strong relationship with seasons, the maximum turnover of bird density, diversity, and species richness observed in migratory seasons (Nagarajan & Thiyagesan 1996; Khan 2010; Pandiyan et al. 2010).

India covers a wide range of wetland habitats known to support the occurrence of over 240 species of waterbirds, except for 33 vagrant waterbirds (Gopi & Hussain 2014). Of the 243 species, 114 are migratory, and among them, two are summer visitors, four are local visitors, and 108 are winter visitors. Forty-four species of waterbirds are threatened as per the IUCN Red List 2014 (Gopi & Hussain 2014). Regarding Indian states, around 485 species of birds have been reported in Rajasthan (eBird 2021). Some of the studies on waterbirds in different parts of India are Kumar et al. (2007), Khan (2010), Mazumdar (2019), and Kar & Debata (2019). However, the information on seasonal variation in waterbird assemblage in riverine habitats is inadequate from wetlands of semi-arid regions. Systematic studies on the diversity and abundance of the waterbirds of the Chambal River in Mukundra Hills National Park are lacking. In order to evaluate one of the important rivers in a semi-arid region, the present study was undertaken to assess the seasonal status of waterbird assemblages in the Chambal River between Kota Barrage and Jawahar Sagar Dam, Rajasthan, India.

Study Area

The study area encompassed a total stretch of 30 km of the Chambal River upstream from Kota Barrage to Jawahar Sagar Dam, a part of Mukundra Hills National Park (25.176–25.037 ^{0}N and 75.825–75.678 ^{0}E; Figure 1). The most extended and only perennial river of Rajasthan state, the Chambal River originates from the southern slopes of Madhya Pradesh and flows through Rajasthan in the northeast direction covering a total distance of 960 km before joining to Yamuna River in Uttar Pradesh. Nearly 24% of the river course falls within Rajasthan and sprays over seven districts, mainly over southeastern districts embracing Kota, Baran, Jhalawar, and Bundi, called the 'Hadoti region'. The study site of Mukundra Hills National Park is an evenly topped and virtually parallel hill with a narrow central elevation. It has a subtropical climate with a wide array of temperatures (7–43°C) and rainfall (4–225 mm) throughout the year (IMD 2021). The vegetation consists of a ravine thorn forest, a subtype of the northern tropical forests (Champion & Seth 1968). The gorges of Chambal River, with an average width of 220 m and an elevation of about 850 m, are life ground to various bird species, including waterbirds, vultures, and other raptors.

MATERIALS AND METHODS

The study was carried out during the months of March–April and August–September 2021, largely classified into pre-monsoon and post-monsoon seasons, respectively. To understand the spatial status of waterbird assemblages, the total study stretch was divided into five equal segments of 5 km in length (Figure 1). Each segment was surveyed twice in a season and waterbird counts were made by direct count method with the help of a slow-moving motorboat (with an average speed of 5 kmph) (Weller 1999). During the survey, we observed birds on either side of the river banks/ riparian strips using binoculars (Hawke Nature Trek 8 × 42 mm & Nikon 8 × 40). To maximize the detection, surveys were conducted during the hours of peak activity of birds, i.e., 0630–1030 h and 1500–1730 h. Waterbirds were identified upto species level using standard field guides (Ali & Ripley 1987; Grimmett et al. 2016).

The residential/ migratory status of waterbirds was extracted from available literature (Ali & Ripley 1987; Grimmet et al. 2016). The checklist of Indian birds to obtain common and scientific names of waterbirds was followed (Praveen et al. 2021). We assigned the global conservation status of recorded waterbirds based

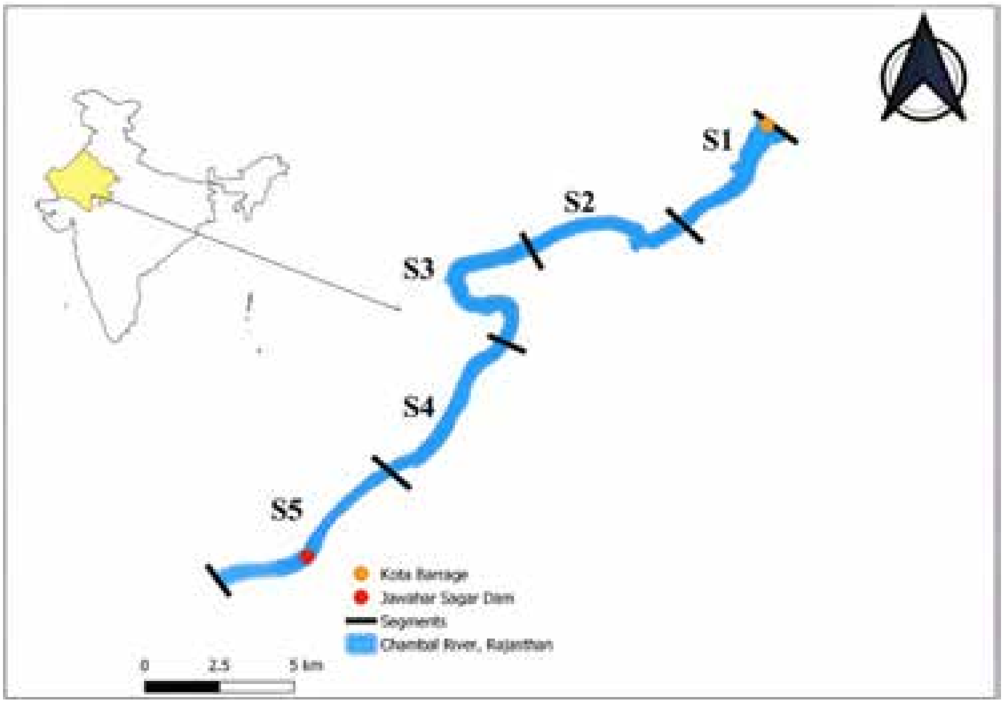

Figure 1. Study area of Chambal River between Kota barrage and Jawahar Sagar Dam, Rajasthan (S1 to S5-denotes the sampling segments one to five).

on the IUCN Red List assessments (IUCN 2021). The Shannon diversity index (H), dominance index (D), and evenness index were calculated to evaluate the diversity trend between studied seasons. We also performed a chi-square test (X^2) to evaluate species richness and abundance variances between the seasons. Based on the abundance of different species, a hierarchical clustering using a single linkage algorithm and Bray–Curtis similarity index was prepared to find the rescaled (dis)similarity in species richness between studied river segments. All statistical analyses were done using the software PAST version 4.03 (Hammer et al. 2001). Relative species abundance (RA) of families was calculated using the following formula as per Torre-Cuadros et al. (2007).

$$RA = Ni / Nt \times 100$$

Ni is the number of species in a family and Nt is the total number of species.

RESULTS

The present study recorded a total of 44 species of waterbirds belonging to 15 families and nine orders. The checklist of waterbirds recorded in the study area is presented in Table 1. Among the species, the order Pelecaniformes was well noticed and represented by two families and 14 species (Table 1). Similarly, the family Ardeidae belonging to the Pelicaniformes order was the most dominating family, with a maximum of twelve species. In each, only one species represented families like Anhingidae, Ciconidae, Podicipedidae, and Recurvirostridae.

The highest overall species richness was observed during the pre-monsoon season (S = 44), with a high number at river segment one (32 species). At the same time, low species richness was observed during the post-monsoon season, where only 27 species were recorded (Table 2). The species richness of waterbirds varied considerably between the seasons. Orders Pelecaniformes and Charadriiformes were encountered more in pre-monsoon with 12 and 10 species, respectively. The post-monsoon also shows the same trend with nine species in Pelecaniformes and six species in Charadriiformes (Figure 3). The total number of individuals of waterbirds observed in pre-monsoon (Number of Individuals N = 1233) was much higher than the post-monsoon (N = 336) (X^2 = 532.77, *df* = 43, *p* <0.05). The Shannon index was highest in segment one during post-monsoon (H = 2.44) and least in segment five (H = 1.62). The segment-wise information on waterbird assemblages covering pre-monsoon and post-monsoon seasons is given in Table 2.

In the pre-monsoon, segment-wise waterbird abundance ranged from 61 to 594 individuals (Table 2),

Table 1. Checklist of waterbirds recorded in Chambal River between Kota barrage and Jawahar Sagar Dam, Rajasthan.

Common name	Zoological name	IUCN Red List status	Residential status	Feeding guild	Relative abundance (%)		
					Pre-monsoon	Post-monsoon	Overall
Order:Coraciiformes							
Family: Alcedinidae							
Common Kingfisher	*Alcedo atthis* (Linnaeus, 1758)	LC	R	CA	1.54	-	1.21
Pied Kingfisher	*Ceryle rudis* (Linnaeus, 1758)	LC	R	CA	0.16	-	0.13
Stork-billed Kingfisher	*Pelargopsis capensis* (Linnaeus, 1766)	LC	R	CA	0.08	0.6	0.19
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	LC	R	CA	4.06	19.05	7.27
Order: Anseriformes							
Family: Anatidae							
Garganey	*Spatula querquedula* (Linnaeus, 1758)	LC	WM	OM	0.32	5.06	1.34
Lesser Whistling Duck	*Dendrocygna javanica* (Horsfield, 1821)	LC	R	HE	-	1.49	0.32
Ruddy Shelduck	*Tadorna ferruginea* (Pallas, 1764)	LC	WM	OM	0.16	-	0.13
Indian Spot-billed Duck	*Anas poecilorhyncha* (Forster, 1781)	LC	R	HE	0.16	-	0.13
Tufted Duck	*Aythya fuligula* (Linnaeus, 1758)	LC	WM	OM	0.08	-	0.06
Order: Suliformes							
Family: Anhingidae							
Oriental Darter	*Anhinga melanogaster* (Pennant, 1769)	NT	R	PI	0.32	0.3	0.32
Family: Phalacrocoracidae							
Great Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	LC	R	PI	0.65	-	0.51
Indian Cormorant	*Phalacrocorax fuscicollis* (Stephens, 1826)	LC	R	PI	22.3	0.89	17.72
Little Cormorant	*Microcarbo niger* (Vieillot, 1817)	LC	R	PI	23.28	6.85	19.76
Order: Pelecaniformes							
Family: Ardeidae							
Intermediate Egret	*Ardea intermedia* (Wagler, 1829)	LC	R	CA	0.08	-	0.06
Indian Pond Heron	*Ardeola grayii* (Sykes, 1832)	LC	R	CA	2.51	3.27	2.68
Black-crowned Night Heron	*Nycticorax nycticorax* (Linnaeus, 1758)	LC	R	CA	1.3	3.27	1.72
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	LC	R	CA	3	0.3	2.42
Great Egret	*Ardea alba* (Linnaeus, 1758)	LC	R	CA	1.05	0.6	0.96
Grey Heron	*Ardea cinerea* (Linnaeus, 1758)	LC	R	CA	8.19	11.9	8.99
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	LC	R	CA	1.22	-	0.96
Purple Heron	*Ardea purpurea* (Linnaeus, 1766)	LC	R	CA	1.62	2.38	1.78
Striated Heron	*Butorides striata* (Linnaeus, 1758)	LC	R	CA	0.32	-	0.25
Black Bittern	*Ixobrychus flavicollis* (Latham, 1790)	LC	R	CA	-	0.3	0.06
Cinnamon Bittern	*Ixobrychus cinnamomeus* (J.F. Gmelin, 1789)	LC	R	CA	-	0.3	0.06
Yellow Bittern	*Ixobrychus sinensis* (Gmelin, 1789)	LC	R	CA	0.16	0.3	0.19
Family: Threskiornithidae							
Black-headed Ibis	*Threskiornis melanocephalus* (Latham, 1790)	NT	R	CA	0.65	-	0.51
Red-naped Ibis	*Pseudibis papillosa* (Temminck, 1824)	LC	R	CA	0.08	-	0.06
Order: Charadriiformes							
Family: Charadriidae							
Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	LC	R	IN	12.08	3.87	10.33

Common name	Zoological name	IUCN Red List status	Residential status	Feeding guild	Relative abundance (%)		
					Pre-monsoon	Post-monsoon	Overall
Family: Jacanidae							
Bronze-winged Jacana	*Metopidius indicus* (Latham, 1790)	LC	R	HE	1.05	0.6	0.96
Family: Laridae							
River Tern	*Sterna aurantia* (Gray, 1831)	NT	R	PI	3.57	19.94	7.07
Whiskered Tern	*Chlidonias hybrida* (Pallas, 1811)	LC	R	CA	0.89	1.79	1.08
Lesser Black-backed Gull	*Larus fuscus* (Linnaeus, 1758)	LC	WM	CA	0.32	-	0.25
Pallas's Gull	*Ichthyaetus ichthyaetus* (Pallas, 1773)	LC	WM	PI	0.16	-	0.13
Family: Scolopacidae							
Common Sandpiper	*Actitis hypoleucos* (Linnaeus, 1758)	LC	WM	IN	0.08	2.68	0.64
Green Sandpiper	*Tringa ochropus* (Linnaeus, 1758)	LC	WM	IN	0.32	-	0.25
Wood Sandpiper	*Tringa glareola* (Linnaeus, 1758)	LC	WM	IN	0.32	-	0.25
Famil: Recurvirostridae							
Black-winged Stilt	*Himantopus himantopus* (Linnaeus, 1758)	LC	WM	CA	2.27	0.3	1.85
Order: Gruiformes							
Family: Rallidae							
Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	LC	R	OM	0.24	-	0.19
White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant, 1769)	LC	R	OM	3.81	3.87	3.82
Baillon's Crake	*Zapornia pusilla* (Pallas, 1776)	LC	WM	IN	0.16	-	0.13
Order: Passeriformes							
Family: Motacillidae							
Grey Wagtail	*Motacilla cinerea* (Tunstall, 1771)	LC	WM	IN	-	0.3	0.06
White-browed Wagtail	*Motacilla maderaspatensis* (Gmelin, 1789)	LC	R	IN	1.05	2.98	1.47
Order: Ciconiiformes							
Family: Ciconiidae							
Woolly-necked Stork	*Ciconia episcopus* (Boddaert, 1783)	VU	R	CA	0.24	6.55	1.59
Order: Podicipediformes							
Family: *Podicipedidae*							
Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	LC	R	IN	0.08	0.3	0.13

NT—Near Threatened | VU—Vulnerable | LC—Least Concern | R—Resident | WM—Winter Migrant | CA—Carnivore | IN—Insectivore | OM—Omnivore | PI—Piscivore | HE—Herbivore.

with an average of 246.6 ≤ 1.60 (≤ z value). In the case of post-monsoon, waterbird abundance was reduced to 336 individuals with an average of 67.2 ≤ 1.69 (≤ z value). Similarly, the bird species composition also varied between the seasons. Darters and Cormorants were most abundant during pre-monsoon and constituted about 50% of the total pre-monsoon population (Figure 2). Next, egrets, herons, and bitterns populations dominated in the waterbird assemblage; they occupied 22.87% of the population (N = 188). In the post-monsoon season, Egrets, Herons, Kingfishers, Terns and Gulls were almost equal in abundance (Figure 2). Little Cormorant *Microcarbo niger* and Indian Cormorant *Phalacrocorax fuscicollis* were dominant in overall abundance with 19.76% and 17.72%, respectively. Among the 44 species observed, 33 were residents, and 11 were winter migrants (Table 1). Most of the winter migrants belong to the order Charadriiformes, including species such as the Common Sandpiper *Actitis hypoleucos*, Green Sandpiper *Tringa ochropus*, Wood Sandpiper *Tringa glareola*, and Pallas's Gull *Ichthyaetus ichthyaetus*. Four out of the 44 species recorded in the study area are globally threatened (Table 1). Among these, three species are listed as Near-threatened (NT) and one

Table 2. Season wise diversity of waterbirds recorded in Chambal River between Kota barrage and Jawahar Sagar Dam, Rajasthan.

Segment	Season	Species richness (D)	Abundance (N)	Shannon index (H)	Dominance (D)	Evenness (J)
S1	Pre-monsoon	32	594	2.15	0.24	0.26
	Post-monsoon	19	100	2.44	0.12	0.60
S2	Pre-monsoon	16	237	2.02	0.20	0.47
	Post-monsoon	14	62	2.23	0.13	0.72
S3	Pre-monsoon	13	156	1.84	0.23	0.48
	Post-monsoon	11	56	1.96	0.18	0.64
S4	Pre-monsoon	11	185	1.85	0.18	0.58
	Post-monsoon	12	71	1.96	0.18	0.59
S5	Pre-monsoon	15	61	2.15	0.18	0.57
	Post-monsoon	9	46	1.62	0.28	0.56
Overall	Pre-monsoon	40	1233	2.52	0.13	0.31
	Post-monsoon	27	336	2.56	0.11	0.49

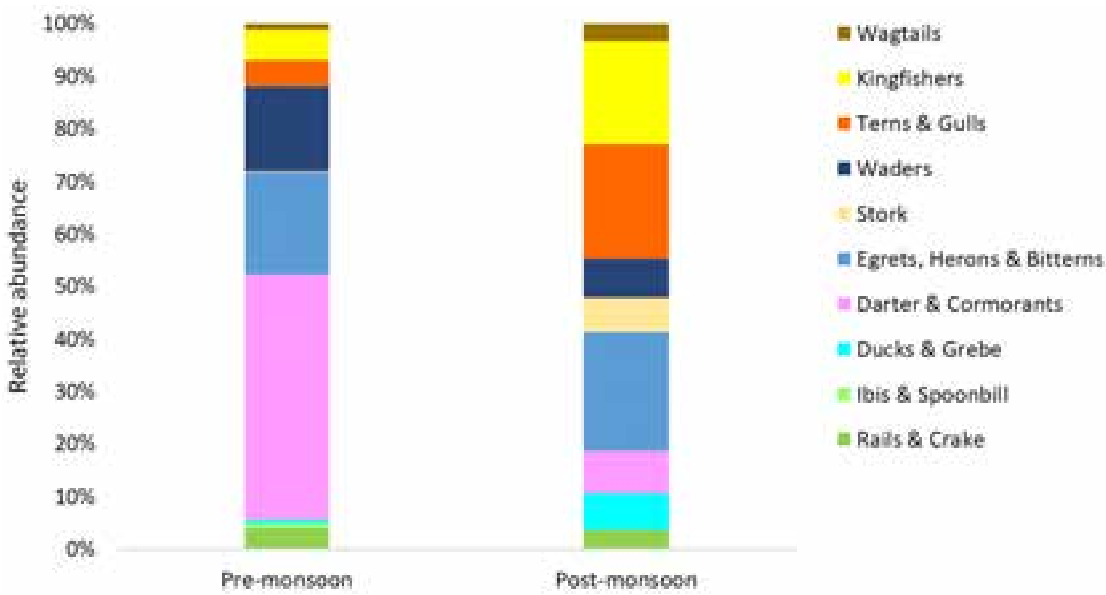

Figure 2. Seasonal variation in the composition of waterbirds in Chambal River between Kota barrage and Jawahar Sagar Dam, Rajasthan.

species as Vulnerable (VU) according to the IUCN Red List assessments (IUCN 2021).

The dendrogram analysis results showed differences in species composition between segments (Figure 4). The dendrogram produced three distinct clusters: one containing segment one, another containing segment five, and a third combining segments two, three, and four. There was a distinct variation in species composition between clusters one and two, indicating that segments two, three, and four had different species compositions. High dissimilarities in species assemblages between segments one and five led to their segregation into separate clusters. Segments three and four, showing the highest similarity in species composition, were grouped together in a single cluster (Figure 4).

DISCUSSION

It is a well-known fact that the Chambal River serves as one of the best over-wintering sites for migratory birds (Nair & Krishna 2013). Our surveys revealed that the Chambal River gorge provides a potential nesting site for three important waterbirds, including the

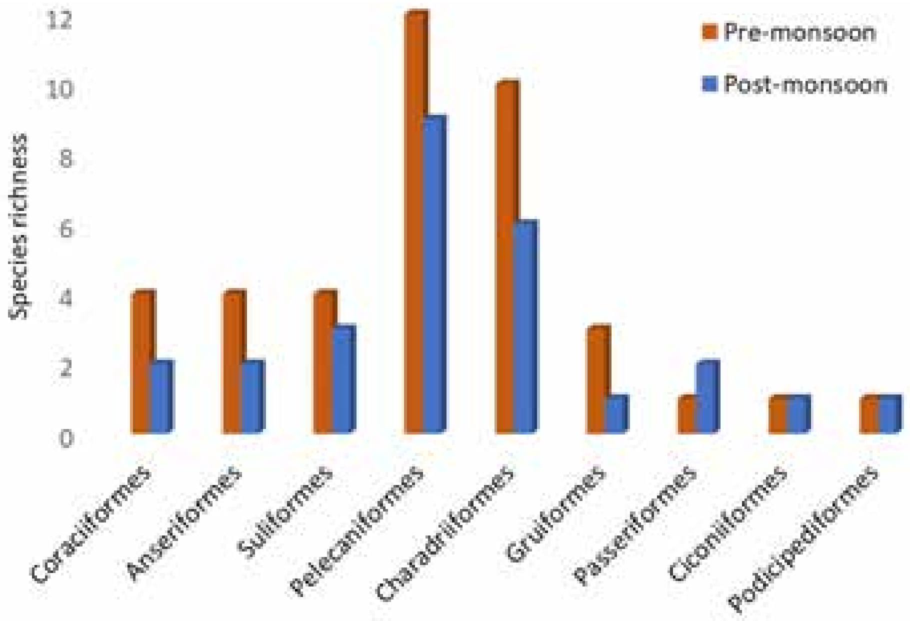

Figure 3. Occurrence of order-wise species richness of waterbirds in the study area.

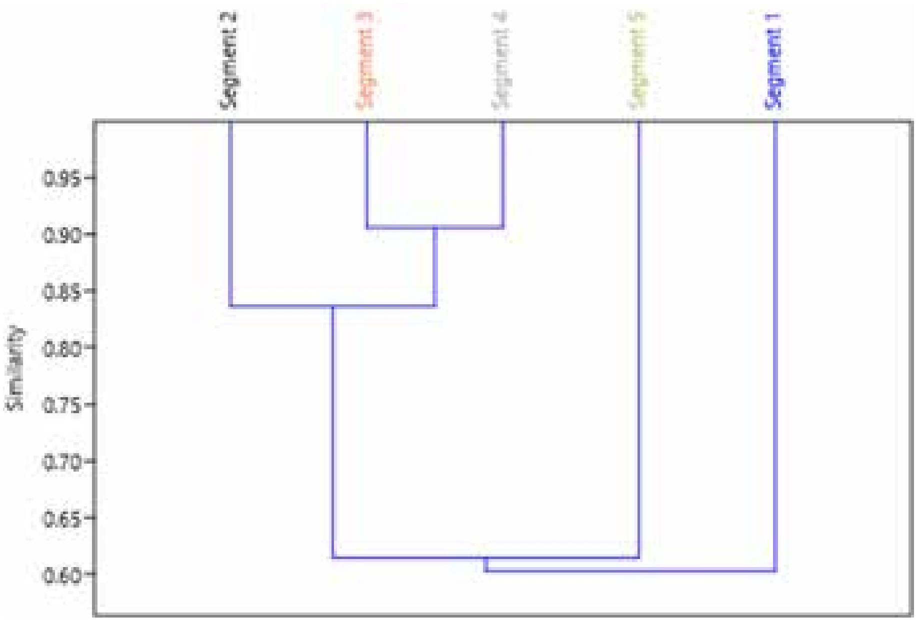

Figure 4: Dendrogram showing dissimilarity in waterbird species richness and composition between studied river segments in the Chambal River between Kota barrage and Jawagar Sagar Dam, Rajasthan.

threatened Woolly-necked Stork *Ciconia episcopus*. Grey Heron *Ardea cinerea* and Black-crowned Night Heron *Nycticorax nycticorax* are the other two species observed with the nests.

It was observed that resident species dominate the bird community, similar to that of earlier studies reported from different parts of India (Verma 2008; Nair & Krishna 2013; Kar & Debata 2019). In the present study, 33 resident waterbirds, constituting about 75% of the total recorded species from the study area were recorded. The remaining 25% were winter migrants. Generally, food availability, water levels, and habitat diversity are the essential factors determining the abundance and distribution of waterbirds (Saygili et

Image 1. Purple Heron. © Arun George.

Image 2. Baillon's Crake. © Arun George.

Image 3. Black-winged Stilt. © Arun George.

Image 4. River Tern. © Arun George.

Image 5. Great Cormorant. © Arun George.

Image 6. Common Moorhen. © Arun George.

al. 2011). Earlier studies have found that the Chambal River inhabits highly diverse fish fauna (Sivakumar & Choudhury 2008; Meshram 2010; Nair & Krishna 2013), which may be one of the reasons for the congregation of residents as well as wintering waterbirds.

The species richness, diversity, and abundance of waterbirds in the study area varied seasonally, and it may be due to the movement pattern of long-distance migrants during winter and local migrants during summer. The Central Asian Flyway (CAF) is one of nine global waterbird flyways, where India serves as a destination for nearly 71% of the CAF's migratory waterbirds (Kumar 2019). Maintaining the health of Indian wetlands is thus critical for the survival of waterbird populations along

Image 7. Bronze-winged Jacana. © Arun George.

Image 8. Grey Heron. © Arun George.

Image 9. Great Egret. © Arun George.

Image 10. Indian Cormorant. © Arun George.

Image 11. White-browed Wagtail. © Arun George.

Image 12. Little Egret. © Arun George.

the Flyway. In India, the arrival of waterbirds occurs in October, and departure takes place in March (Kar & Debata 2019). Thus, the high species richness and abundance of the waterbirds encountered during pre-monsoon account for migrant waterbirds in the study area. Though the survey season was at the temporal end of winter, few winter migratory species were observed during the surveys. Most wetlands usually dry during high temperatures, and resident waterbirds typically move to appropriate permanent water habitats (Balachandran et al. 2009). This might be the reason for the increase in the abundance of darters and cormorants in pre-monsoon.

Image 13. Lesser Whistling Duck. © Arun George.

Image 14. White-throated Kingfisher. © Arun George.

Image 15. Cinnamon Bittern. © Arun George.

Image 16. Red-wattled Lapwing. © Arun George.

Image 17. Black-crowned Night Heron. © Arun George.

Image 18. Indian Pond Heron. © Arun George.

The increase in local abundance of some resident birds, which possibly have migrated from nearby dried-up wetlands, was observed by Kar & Debata (2019). During the post-season, resident waterbirds are much more widely distributed due to the availability of wetland habitats and food resources (Kar & Debata 2019). Thus, this might be the reason for the lowest species richness encountered in the study area in post-monsoon.

About 65.58% of the total waterbird species in the present study, as reported in earlier studies were recorded. Previous long-term studies by Verma (2008) reported 61 species, from the entire Rajasthan state. Vyas

Image 19. Common Sandpiper. © Arun George.

Image 20. Red-naped Ibis. © Arun George.

Image 21. Little Cormorant. © Arun George.

Image 22. Striated Heron. © Arun George.

Image 23. Woolly-necked Stork. © Arun George.

Image 24. Black Bittern. © Arun George.

(2006) studied the heronries of the Kota district alone and recorded 829 nests. Cattle Egrets and Cormorants were the most abundant species in his heronry study. Apart from these, we also witnessed the breeding activities of Grey Heron *Ardea cinerea*, Black-crowned Night Heron *Nycticorax nycticorax,* and Woolly-necked Stork *Ciconia episcopus* in the study area. A total of 36 nests of Herons and five nests of Storks were observed in the Chambal River at Mukundra Hills National Park. Compared to an earlier study by Vyas (2006), the breeding activities of the Woolly-necked Stork, Grey Heron, and Night Heron are new additions to the heronries information of the Kota district, Rajasthan. A recent study by Koli et al. (2019) observed the nesting association of Black-headed Ibis with some other waterbirds, whereas it was observed that the nesting activity of Herons and Stork was independent of each other.

From the study, it can be inferred that the Chambal River stretch flowing through the Mukundra Hills National Park is a potential congregation site for resident waterbirds in pre-monsoon. Moreover, the area supported the breeding of some resident waterbirds, including the 'Near Threatened' Woolly-necked Stork *Ciconia episcopus*. In the present study, we also recorded some of the migratory waterbirds. Though the study area falls under the well-protected stretch of the Chambal River, some levels of human disturbance were observed in the study area, such as illegal fishing and noise pollution from residents, which may potentially disturb the residing and migrant waterbirds. In addition, abandoned fishing nets and lines threaten the Chambal River bird community, specifically diving waterbirds. Thus, sensitizing the local community towards conserving waterbirds and their habitat is essential for the long-term conservation of waterbirds in the Chambal River.

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ARTICLE

An updated checklist of the skippers (Lepidoptera: Hesperiidae) of Bhutan

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Abstract: The authors conducted a comprehensive review of Hesperiidae species in Bhutan, scrutinizing three existing checklists and 25 new records presented by Van der Poel et al. (2023). A thorough examination of all available documents and evidence confirmed 145 Hesperiidae species in Bhutan, with four additional species listed as tentative and one as "cf." (requiring further research). The updated checklist excludes 14 species that were listed in one or more of the three existing checklists and provides justifications for not including these species. Additionally, 11 unverifiable or wrongly identified species presented by non-peer-reviewed sources were not included in the checklist. Sixteen species with no verifiable records in the last 70 years were also identified. This review provides a comprehensive and authoritative checklist of Hesperiidae species in Bhutan.

Keywords: Butterflies, Himalaya, insect fauna, Papilionoidea, review, Rhopalocera, species.

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Author contributions: Karma initiated the checklist project and provided all information on records from Bhutan for the species concerned. Piet carried out the literature research for these species, did a first check of the identifications, wrote the text and prepared the table. Sajan checked the identifications, commented on the text, edited some parts and wrote the abstract and conclusions.

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INTRODUCTION

Butterflies of Bhutan did not receive much attention until the beginning of this century. Evans (1932) noted that lists of butterfly species for Nepal, Garhwal, and Bhutan would be interesting. Evans (1949) documented 43 species collected in Bhutan, with specimens held in the British Museum. Yazaki & Kanmuri (1985) reported on butterflies of western Bhutan and presented a list of 265 butterfly species for the whole country; the list included 25 Hesperiidae. Harada (1987a,b) listed 124 species with pictures, including six Hesperiidae, for western Bhutan, based on specimens collected in April–May of 1983. Van der Poel & Wangchuk (2007) published the first guidebook featuring pictures of 136 butterfly species of Bhutan, including eight Hesperiidae. Several other survey reports, guidebooks, and local checklists were published between 2012 and 2014, mostly relying on photographic evidence, although the pictures were often not included in the documents. Wangdi et al. (2012) reported 70 butterfly species, including 16 Hesperiidae, from Trashiyangtse, based on voucher specimens collected in 2011 during a joint Bhutanese-Japanese survey in northeastern Bhutan. Wangdi & Sherub (2014) published a guidebook on the Hesperiidae of Bhutan, listing and illustrating 92 species.

In 2012, Yazaki published a 268-page book on the butterflies of Bhutan in Japanese, which included 26 Hesperiidae but the authors were unable to consult the document as it was only distributed in Japan. Around 2013, Van Gasse posted an online PDF document on the butterflies of the Indian subcontinent. His Bhutan listings were primarily based on original descriptions, Evans (1932, 1949), and subsequent publications. An updated version of his annotated checklist of butterflies of the Indian subcontinent was published online five years later (Van Gasse 2018). It is presumed that Van Gasse (2018) considered species reported in recent documents as valid records if they were likely to occur in Bhutan. The first checklist of butterflies of Bhutan was compiled by Singh & Chib (2015), who listed 670 species based on all available documents on Bhutanese butterflies, generally assuming the correctness of species identifications in these documents but omitting some unlikely or misidentified species. In contrast, Sbordoni et al. (2015) reported 533 species, primarily relying on photographs with verified identifications. The main disparity between these lists was the number of Hesperiidae species: 73 in Sbordoni et al. (2015) versus 139 in Singh & Chib (2015).

Since 2015, local butterfly photographers and surveyors have added species to the known hesperiid fauna of Bhutan. We considered some of their identifications as doubtful if the pictures did not show the necessary distinguishing characteristics. Van der Poel et al. (2023) reviewed the evidence for these reported species; they checked published documents, grey literature, their own pictures, and pictures sent to them or found posted on the internet. For first records of a species and confirmation of a tentative species, they accepted records whose identifications they were 98–100% certain of. For recent records of species already reliably reported from Bhutan, they accepted records whose identifications they were 90% or more certain of. They officially reported 25 first records of Hesperiidae for Bhutan. This included species reported before in grey literature and on the internet, which are generally considered as not "officially" published. This also included species that were reported before, based on wrong or doubtful identifications, for which they found clear evidence. Furthermore, Van der Poel et al. (2023) provided pictorial evidence of another 25 species that were not reported with verifiable evidence in the last 70 years.

Some records from "Bhutan" in old documents from the time of the British Empire were reported from areas that are not within the present-day boundaries of Bhutan. For example:

1. *Celaenorrhinus flavocincta* was described by De Nicéville (1887) based on three specimens from the collections of Messrs. Knyvett and Möller, all obtained near "Buxa, Bhutan". However, Buxa is now located in Alipurduar District of West Bengal, India. Evans (1949) reported *Celaenorrhinus flavocincta* from "Bhutan", without specifying "Buxa". Subsequently, Singh & Chib (2015) and Van Gasse (2018) included the species in their checklists for Bhutan.

2. *Celaenorrhinus plagifera* was listed by De Nicéville (1889) with habitat: Sikkim, Bhutan. However, from the rest of the text of De Nicéville (1889), it appears that the Bhutan specimens came from the collection of Mr. Knyvett, known to have mainly collected near "Buxa Bhutan".

The Treaty of Sinchula in 1865 determined more or less the location of the present boundary between Bhutan and India. Many authors in the late 19th and early 20th century continued to refer to the area around Buxa in Alipurduar District of West Bengal as "Buxa, Bhutan". Some publications indicated as collection area "British Bhutan", which referred to the Kalimpong area of West Bengal, India.

METHODS

The authors first prepared a preliminary list of the Hesperiidae of Bhutan based on the checklists of Sbordoni et al. (2015), Singh & Chib (2015), and Van Gasse (2018). Singh & Chib (2015) listed the source documents for each species on which its listing was based. Other potential species were added to the preliminary list based on photographic evidence reported for Bhutan in recent documents, pictures posted on the internet, such as the Bhutan Biodiversity Portal (BBP) website, and pictures taken by or sent to the authors.

Species that were reported for Bhutan by Evans (1949) or Kehimkar (2008) were generally accepted as correct records. Evan's records for Bhutan were based on specimens in the British Museum (Natural History Museum, London). Isaac Kehimkar (pers. comm. 2023) reported that his 2008 listings for Bhutan were generally based on Evans (1932, 1949) or old documents in the library of the Bombay Natural History Society (BNHS). Thus, these species, which were based on old reports, were included in our checklist, unless the area from which the specimens were collected is certainly or most likely outside the present-day boundaries of Bhutan, e.g., in Buxa. Recent records for these species were accepted if the authors were at least 90% certain of their identification. This percentage is an estimate by the authors and is based on how well the characteristics of the photographed individual fit the characteristics of the species. It is especially useful for similar species with overlapping characteristics, such as *Potanthus* species. Websites such as observation.org give for automatically identified butterfly photographs the percentage chance that it is a particular species.

For all hesperiid species reported after 1949, the authors sought verifiable evidence in the form of pictures showing distinguishing characteristics of the species. Some of the species listed in the three checklists were based on only one or two source documents. Many source documents presented species without verifiable evidence. We considered some of the presented pictorial evidence insufficient for correct identification, e.g., when only the upperside or underside were shown and both sides were needed for identification. Several source documents listed misidentified species as the accompanying pictures were of different species. Thus, there was no guarantee that even species listed in all three checklists were reliably reported from Bhutan. Therefore, we checked for each species the reported sources to find the first record with correctly identified pictures or specimens for Bhutan. We also checked for the first correctly identified recent (since 2000) record. The pictorial evidence was verified by checking the identification with butterfly guidebooks, websites for SE Asia, original descriptions, and available recent literature. The consulted guidebooks included Evans (1949), Smith (1994, 2006, 2011, 2015), Kehimkar (2008, 2016), and Smetacek (2017). The websites included yutaka.it-n.jp, iNaturalist.org, and ifoundbutterflies.org. The authors discussed the identification of a number of individuals with several lepidopterists and naturalists. The consulted recent literature is mentioned in this document under the concerned species.

Species for which no verifiable evidence could be found and species for which the listing in the three checklists was entirely based on misidentifications in the source documents were not included in our Hesperiidae checklist for Bhutan. The reasons for not including these species are given later in this article for each of the species. Possible first records of species for which we considered the identification most probably (90-98% chance) correct were listed as tentative. This included species for which no study of the genitalia or DNA analysis was carried out, while this is required for confirmation of the identification. The authors assigned "cf." to records of individuals that differ from a known species and could potentially be a new species for Bhutan or a new form, subspecies, or species new to science. Tentative and "cf." species were listed, but not counted as species present in Bhutan. The updated checklist is arranged according to Zhang et al. (2023) for Hesperiinae and follows the same principles for other subfamilies. For the placement of *Apostictopterus fuliginosus* Leech, [1893] we followed Zhu et al. (2023).

RESULTS

1. Checklist of Hesperiidae of Bhutan (Table 1.): The updated checklist of the Hesperiidae of Bhutan lists 145 species and four tentative species. Tentative species are likely to occur in Bhutan, but the evidence presented until now was considered insufficient (i.e., the identification was considered to be 90–98% certain). One possible species, which requires additional research, is listed as "*Pedesta* cf. *gupta*", and is also not counted as a species of Bhutan. The updated checklist comprises more hesperiid species than the earlier lists (73 in Sbordoni et al. (2015), 139 in Singh & Chib (2015), and 142 in Van Gasse (2018)). Verification of the species' identification was given much more importance by the authors than in the three checklists cited above.

In addition, the checklist gives the first record from Bhutan, that the authors could find, for each species and the first recent record in this century. It also reports if species were first recorded or confirmed by Yazaki & Kanmuri (1985) or Harada (1987a). This allows any researcher, who may doubt the validity of a particular record, to check the reliability of the evidence presented for the species in the checklist.

To make it clear to other researchers which species were considered but not included in our checklist, we present these species in two lists. We also give reasons why these species were not included:

- Eleven species that were not listed in the three checklists but were reported in grey literature or online based on wrong or doubtful (less than 90% certain) identifications;

- Fourteen species that were listed in at least one of the three checklists but of which the identifications in the source documents were wrong or doubtful.

2. Species that were reported from Bhutan: In general publications, non-published reports, or on the internet, but were not included in any of the three mentioned checklists. We consider their identifications to be wrong or doubtful, or could not find any pictorial evidence. These include (with re-identification, using guidebooks and websites indicated in the methodology):

o ***Abaratha alida*** (de Nicéville, 1891) Alida Angle (no pictorial evidence);

o ***Celaenorrhinus patula*** de Nicéville, 1889 Large Spotted Flat (picture was *C. putra*);

o ***Celaenorrhinus pero*** de Nicéville, 1889 Mussoorie Spotted Flat (picture was *C. putra*);

o ***Celaenorrhinus sumitra*** (Moore, [1866]) Moore's Spotted Flat (de Nicéville (1889) reported it from "Rikisum, British Bhutan", which is now in Kalimpong, West Bengal);

o ***Pedesta (Thoressa) baileyi*** (South, 1914) reported on the Bhutan Biodiversity Portal (BBP) website. The picture was of *P. pandita.* The undersides of these two species can be quite similar. Fig. S1-32 of "*P. baileyi"* upperside in Li et al. (2019) was also of *P. pandita*;

o ***Satarupa gopala*** Moore, [1866] Large White Flat (picture was of *S. zulla*);

o ***Potanthus tibetana*** Huang, 2002 (picture ID uncertain, possibly *P. nesta* or *P. mara*. It has several characteristics different from the description of *P. tibetana* in Huang (2002);

o ***Idmon distanti*** (Shepard, 1937) Spotless Bob (picture was of *Baoris* spp.);

o ***Baoris pagana*** (de Nicéville, 1887) Figure of Eight Swift (picture was *Caltoris* sp.);

o ***Caltoris cormasa*** (Hewitson, 1876) Full-stop Swift (no pictorial evidence);

o ***Caltoris plebeia*** (de Nicéville, 1887) Tufted Swift (no pictorial evidence).

3. Species listed in the previous checklists, but not in the new Hesperiidae checklist of Bhutan: These species were listed in one or more of the three reviewed checklists. For these species, we judged the identifications to be certainly wrong or doubtful. We called an identification doubtful if we considered the chance that the original identification was correct between 0 and 89%.

Subfamily Tagiadinae, Tribe Celaenorrhini

Celaenorrhinus aurivittata (Moore, [1879]) Dark Yellow-banded Flat was reported for Bhutan by Wangdi & Sherub (2014, p.39) as *C. aurivittatus* [*sic*] from Punakha Dzongkhag. Based on Wangdi & Sherub (2014), *C. aurivittata* was listed in the checklists of Singh & Chib (2015) and Van Gasse (2018), but Shing & Chib (2014) also listed *C. aurivittatus*. Van der Poel et al. (2023) re-identified the picture of Wangdi & Sherub (2014, p.39) as *C. dhanada affinis* and indicated that *affinis* and *dhanada* are probably separate species, as their distribution areas overlap in Chiang Mai, Thailand (yutaka.it-n.jp website). These two "species" are probably also sympatric in Bhutan, where both have been reported from adjoining valleys in Mongar Dzongkhag.

Celaenorrhinus flavocincta (de Nicéville, 1887) Bhutan Flat was listed for Bhutan by Singh & Chib (2015) and Van Gasse (2018), because "Bhutan" was the type locality of the species or because it was mentioned by Evans (1949). De Nicéville (1887) described it from specimens obtained near Buxa, Bhutan, which is now in Alipurduar District of West Bengal. Thus, these specimens were most likely not collected from within Bhutan's present-day boundaries. Consequently, it was not included in our Hesperiidae checklist of Bhutan. It probably should be renamed "Buxa Flat", especially since even at the time of its description by De Nicéville (1887), Buxa was already part of British India.

Tribe Tagiadini

Capila lidderdali (Elwes, 1888) Lidderdale's Dawnfly. Elwes (1888) described it as "*Chaeticneme*? *lidderdali*". He inspected a single specimen in the British Museum of which he stated: "and though it may possibly have come from Buxa, is more probably a Sikkim insect". Elwes & Edwards (1897) indicated that it came from the collection of Dr. Lidderdale, who collected near Buxa and Darjeeling". Thus, with Buxa now being in West Bengal, it was not described from present-day Bhutan. Although Evans (1932) indicated only Bhutan as the collection area, in Evans (1949) this was changed to Sikkim or Bhutan, more in line with Elwes & Edwards (1897), although Darjeeling is not in Sikkim. Thus, the species was not included.

Coladenia hoenei Evans, 1939 was reported for Bhutan by Harada (1987a). It is now considered to be *Coladenia pinsbukana* (Shimonoya & Murayama, 1976). The two species are very similar. Huang (2021) stated that *C. hoenei* is restricted to the Chinese provinces of Shaanxi, Gansu, and Henan, and he reports *C. pinsbukana occidentalis* from Yunnan, Laos, Thailand, and Sikkim (India). Hence, *C. hoenei* was not included in our Hesperiidae checklist of Bhutan. For more detail on this rather confusing name change, see Van der Poel et al. (2023).

Seseria dohertyi (Watson, 1893) Himalayan White Flat was reported for Bhutan by Singh & Chib (2015) referring to Singh (2012) and Wangdi & Sherub (2014). *Seseria dohertyi* was also reported by Van Gasse (2018), very probably based on the same two reports. However, the picture in Singh (2012, image 52) is of *Gerosis phisara* and the picture in Wangdi & Sherub (2014, p.43) is of *Seseria sambara*, as it has a narrow spot in space 1b of the upper forewing which is notched outwardly; also, the white part of the upper hindwing and abdomen is sullied and not clear in the wet season form (Evans, 1949). Thus, *S. dohertyi* was not included in our checklist of Hesperiidae species of Bhutan.

Subfamily Heteropterinae

Carterocephalus silvicola (Meigen, 1829) Chequered Skipper was reported for Bhutan by Wangdi & Sherub (2014) from Thimphu, Paro, and Haa Dzongkhags and listed for western Bhutan by Van Gasse (2018), most probably based on Wangdi & Sherub (2014). The picture in Wangdi & Sherub (2014, p.79) was re-identified as *C. avanti* (de Nicéville, 1886). As there are no other reports of *C. silvicola,* it was not included in our checklist of Hesperiidae of Bhutan.

Subfamily Hesperiinae, Tribe Taractrocerini

Potanthus Scudder, 1872 **spp.** Many *Potanthus* species are very hard to identify and often analysis of the genitalia is the main way to identify them with certainty. The authors have accepted the five *Potanthus* species listed by Evans (1949) as correct. The other five species, listed by Singh & Chib (2015) and mostly also by Van Gasse (2018), have been scrutinized. *Potanthus dara* and *P. juno* were not included in our checklist and is explained later. Van der Poel et al. (2023) reported *P. pseudomaesa* as a species for Bhutan, *P. ganga* as a tentative species, and confirmed *P. trachala* as a species present in Bhutan. Thus, we have included seven *Potanthus* species in our checklist and one tentative *Potanthus* species.

Potanthus juno (Evans, 1932) Burmese Dart. *Potanthus juno* was listed by Van Gasse (2018) from Tsirang. Yazaki & Kanmuri (1986), A. Singh (2012), J. I. Singh (2014), and Singh & Chib (2014, 2016) reported on butterflies of Tsirang, but *P. juno* was not listed by any of them. Thus, the source of the listing by Van Gasse (2018) is not clear. The authors asked him about the source but did not receive a reply. Since there is no proof of the occurrence of *P. juno* in Bhutan, it was not included in our checklist, although it was reported as occurring in Assam by Varshney & Smetacek (2015).

Potanthus dara (Kollar, [1844]) Himalayan Dart was listed without a picture in Sbordoni et al. (2015) and in Singh & Chib (2015), the latter based it on the following three publications;

- Singh (2014), only listed the name, but did not present a picture;
- Nidup (2015), also only listed the name, *P. dara*;
- Wangdi & Sherub (2014, p.58) presented pictures 1 and 2. These do not show the conspicuous spot in space 6 of the hindwing of *P. dara*, while also the forewing spots in spaces 4 and 5 are not separate from the spots in 3 and 6; thus, these are congeners. Most likely, image 1 is *P. mara*, but it could also be *P. nesta*, and image 2 may be *P. pseudomaesa*.

Another picture reported to be of *P. dara,* possibly the picture on which the listing in Sbordoni et al. (2015) was based*,* also was not *P. dara*, since it had a conspicuous upper hindwing spot in space 7 rather than in 6. It was a typical example of *P. trachala* (see Van der Poel et al. 2023). Moreover, the authors are not aware of any reliable report confirming the presence of *P. dara* east of Central Nepal. *Potanthus dara* may well have been listed for Bhutan in other publications and on the internet, but the authors think that it is highly unlikely to occur in Bhutan. Hence, *P. dara* is not included in our Hesperiidae checklist.

Tribe Erionotini

Erionota thrax (Linnaeus, 1767), Palm Redeye, was listed for Bhutan by Singh & Chib (2015), apparently only based on Wangdi & Sherub (2014). However, we determined that the picture in Wangdi & Sherub (2014, p.69) was of *E. torus*, since the upper forewing termen and apex were rounded. It was not listed for Bhutan by Van Gasse (2018), who probably also realised that the picture was of *E. torus*. Consequently, *E. thrax* was not included in our checklist of Hesperiidae of Bhutan.

Matapa purpurascens Elwes & Edwards, 1897, Purple Redeye, was reported for Bhutan by Wangdi & Sherub (2014) from Zhemgang Dzongkhags and listed for Bhutan by Van Gasse (2018), most probably based on Wangdi & Sherub (2014). The picture in Wangdi & Sherub (2014, p.70) was re-identified as *Matapa druna*, and was listed as a first record for Bhutan in Van der Poel et al. (2023). As there appeared to be no other records of the species, *M. purpurascens* was not included in our checklist of Hesperiidae of Bhutan.

Pudicitia pholus (de Nicéville, 1889), Spotted Redeye, was described by De Nicéville (1889) as *Parnara pholus*. At least one and probably both of the two specimens were collected "near Buxa, Bhutan" in August. De Nicéville (1995) placed it in a new genus *Pudicitia*. Evans (1932) gave the distribution area for *P. pholus* as Bhutan to Naga Hills. This was probably the source of Van Gasse's (2018) listing. "Buxa, Bhutan" is presently in Alipurduar District of West Bengal, India. Evans (1949) did not list *P. pholus* for Bhutan, possibly because Buxa was no longer in Bhutan. Thus, there appears to be no proof of this species having been reported from within the present-day boundaries of Bhutan. Consequently, the species was not included in our Hesperiidae checklist of Bhutan.

Suastus minutus (Moore, 1877), Small Palm Bob, was listed by Singh & Chib (2015) and, probably based on that, by Van Gasse (2018). Yazaki & Kanmuri (1985) was listed as a source by Singh & Chib (2015), however, Yazaki & Kanmuri (1985) did not list *S. minutus* (and also not *S. gremius*). Thus, it is not clear on which document the listing of *S. minutus* was based. Consequently, this species was not included in our Hesperiidae checklist of Bhutan.

Tribe Baorini

Caltoris brunnea (Snellen, 1876), Dark-branded Swift, was reported for Bhutan by Wangdi & Sherub (2014) from Mongar Dzongkhags and listed for Bhutan by Van Gasse (2018), most probably based on the aforementioned publication. The picture in Wangdi & Sherub (2014, p.73) is almost certainly of *Pelopidas sinensis*. Thus, *C. brunnea* will be removed from the species checklist of butterflies of Bhutan. Image 3, taken by Karma Wangdi, was identified as possibly *C. brunnea* and not *C. tulsi, C. kumara* or *C. cahira*. The chance of it being *C. brunnea* was considered too low (<90%) to justify listing it as a tentative species.

Parnara ganga Evans, 1937, Continental Swift, was only reported for Bhutan by Wangdi & Sherub (2014) from Samdrup Jongkhar Dzongkhags and listed for W. Bhutan by Van Gasse (2018), most probably based on Wangdi & Sherub (2014). *Parnara bada* (Moore, 1878) was reported from Bhutan in several publications, including Wangdi et al. (2012). The individual in Image 4, copied from Wangdi & Sherub (2014, p.72), does not show the characteristics of *P. ganga* as indicated by Evans (1949): upperside forewing may have a lower cell spot. It also does not have the characteristics indicated by Evans (1949) for *P. bada*: the upper side forewing may have an upper cell spot and the underside hindwing may have a spot in 6. However, the hindwing spots of *P. bada* are generally smaller than those of *P. ganga*. Thus, the individual in image 4 is more likely to be *P. bada,* and its identification as *P. ganga* is doubtful, not warranting reporting it as a first record or tentative record for Bhutan. As there appeared to be no other records, *Parnara ganga* was not included in our checklist of Hesperiidae of Bhutan.

Pelopidas thrax (Hübner, [1821]), Desert Branded Swift, was reported for Bhutan by Sbordoni et al. (2015) and Van Gasse (2018). The picture on which Sbordoni et al. (2015) based their listing has not been found. The source of Van Gasse's (2018) listing of spp. *masta* may have been Sbordoni et al. (2015). Although it is likely to occur in Bhutan, no evidence for *P. thrax* has been found, and consequently, it was not included in our Hesperiidae checklist of Bhutan.

4. Species not recorded in the last 70 years (one species not since 1985):

Choaspes furcata Evans, 1932, Hooked Awlking, listed by Evans (1949, possibly based on Evans (1932)), no recent reports; often (FUNET, Varshney & Smetacek 2015, Van Gasse 2018) listed as *Choaspes furcatus*. The original description was *C. plateni furcata* and GBIF lists is as *Choaspes furcata*;

Hasora taminatus (Hübner, 1818), White-banded

Awl, was reported in old BNHM documents (Kehimkar 2008) and reported by Yazaki & Kanmuri (1985), no recent reports;

Celaenorrhinus badia (Hewitson, 1877), Scarce Banded Flat, listed by Evans (1949, source of listing unknown), no recent reports;

Celaenorrhinus pyrrha de Nicéville, 1889, Double-spotted Flat, was described from Bhutan by De Nicéville (1889) and listed by Evans (1949), no recent reports;

Capila zennara (Moore, 1866]), Pale Striped Dawnfly, listed by Evans (1949, source of listing unknown), no recent reports;

Gerosis bhagava (Moore, [1866]), Common Yellow-breast Flat, listed by Kehimkar (2008), based on old BNHM documents, recent listings had no evidence;

Pyrgus cashmirensis Moore, 1874, Kashmir Skipper, listed by Evans (1949, source of listing unknown), no recent reports.

Baracus vittatus (Felder, 1862), Hedge Hopper, listed by Evans (1949, source of listing unknown), no recent reports;

Creteus cyrina (Hewitson, 1876), Nonsuch Palmer, listed by Evans (1949) possibly based on De Nicéville (1895), no recent reports;

Potanthus confucius (C. & R. Felder, 1862), Chinese Dart, listed by Evans (1949, source of listing unknown). Recent listings and postings on BBP were wrongly identified or had no or insufficient evidence. One BBP posting was likely to be *P. confucius*, but some characteristics for a reliable confirmation were not visible;

Potanthus nesta (Evans, 1934), Brandless Dart, listed by Evans (1949, source of listing unknown), recent listings had no or insufficient evidence;

Potanthus palnia (Evans, 1914), Palni Dart, listed by Evans (1949, source of listing unknown), recent listings had no or insufficient evidence;

Potanthus rectifasciata (Elwes & Edwards, 1897), Branded Dart, listed by Evans (1949, source of listing unknown). It was described by Elwes & Edwards (1897) from Sikkim. No recent reports;

Koruthaialos butleri (de Nicéville, [1884]), Dark Velvet Bob, described from Bhutan, recent listings had no evidence or were not identifiable (too dark);

Caltoris tulsi (de Nicéville, [1884]), Purple Swift, listed by Evans (1949, source of listing unknown), recent listings had no evidence or were wrongly identified;

Pelopidas subochracea (Moore, 1878), Moore's Swift, listed by Kehimkar (2008), based on old BNHM documents, recent listings were wrongly identified or were listed without verifiable evidence.

DISCUSSION

The main difference between the present and the three previous checklists is that the previous ones seldom checked the reliability of the identifications in their source documents. It appeared that Singh & Chib (2015) often accepted the reported identifications in their source documents as correct if the species was reported by several sources regardless of the accuracy. They appeared more critical if a species was only reported by one source. Van Gasse (2018) generally accepted reported records of species that were likely to occur in Bhutan, apparently without critically checking the presented evidence. Sbordoni et al. (2015) looked more critically at the presented pictorial evidence but still accepted certain identifications that Van der Poel et al. (2023) considered to be misidentifications.

Sixteen of the species in the updated checklist have not been reported with verifiable evidence in the last 70 years. Many other species reported from nearby areas such as Sikkim and western Arunachal Pradesh are likely to be present in Bhutan. To increase the chance of finding these species regular, systematic butterfly surveys in a wide range of habitats across Bhutan are recommended.

Misidentification is not just a problem for beginning butterfly photographers. Earlier, the authors indicated that most probably all identifications of *P. dara* in Bhutan were wrong. This is what Evans (1949) wrote on misidentifications of *P. dara*:

"[*dara* is given in] Fig Lep Ind, pl. 816/3 ♂ as *nala*. Of the figures marked *dara*: Leech, pl. 40/14 is *pava*; Elwes & Edwards, pl. 25/69 genitalia are *flava*; Kershaw 1905, pl. 14/22 is *pseudomaesa clio*; Lep Ind, pl. 814/2 ♂ is *palnia* and ♀ *trachala tytleri*; Rhop Java, pl. 9/65 is *trachala*."

The authors urge all butterfly researchers and surveyors to double-check their identifications and have them verified by experts before publishing them, and to publish their findings only in peer-reviewed journals.

A persistent problem, especially on the Indian subcontinent, is the use of different scientific and common names of species by different organisations. In theory, there is only one correct scientific name for a species. However, scientists do not always agree on newly proposed names or on raising subspecies to species level. Moreover, with increased DNA sequencing, the placement and names of many species will change. Zhang et al. (2022) presented significant recent taxonomic changes based on genomic analysis. Hou et al. (2023) added additional taxonomic changes. Beginning butterfly surveyors often use the names as

Table 1. Checklist of Hesperiidae of Bhutan.

*—Source documents (see References for details): a+b=publication (a) that reported this species and publication (b) that presented the related evidence.

CTS18: Cheku et al. (2018); CBF23: Chiba et al. (2023); dNc**: De Nicéville (18**) ** = 83[84], 85, 86, 89, 90, 95; Drj14: Dorji (2014); Ev49: Evans (1949); Hr87: Harada (1887a); JSW14: JSWNP (2014); K08-old lit: Kehimkar (2008) based on old documents in BNHS library; Nd15: Nidup (2015); P&W07: Van der Poel & Wangchuk (2007); PWK23: Van der Poel et al. (2023); S&C16: Singh & Chib (2016); Sb15: Sbordoni et al. (2015); Si12: Singh (2012); Si14: Singh (2014); vG15: Van Gasse (2015); W&S14: Wangdi & Sherub (2014); Wea12: Wangdi et al. (2012); Wm&dN87: Wood-Mason & de Nicéville (1887); Y&K85: Yazaki & Kanmuri (1985).

	Species name	Authority, year	Subspecies (Authority, year)	Common name	Bht 1st record*	Bht recent record
Subfamily COELIADINAE						(no recent observt.)
1	*Badamia exclamationis*	(Fabricius, 1775)		Brown Awl	K08-old lit	W&S14
2	*Bibasis sena*	(Moore, [1866])	*sena* (Moore, [1866])	Orange-tailed Awlet	K08-old lit	W&S14
3	*Burara amara*	(Moore, [1866])		Small Green Awlet	Si12	← see 1st record
4	*Burara anadi*	(de Nicéville, [1884])	*anadi* (de Nicéville, [1884])	Plain Orange Awlet	PWK23	←
5	*Burara gomata*	(Moore, [1866])	*gomata* (Moore, [1866])	Pale Green Awlet	Sb15+ PWK23	←
6	*Burara harisa*	(Moore, [1866])	*harisa* (Moore, [1866])	Orange-striped Awlet	W&S14	←
7	*Burara jaina*	(Moore, [1866])	*jaina* (Moore, [1866])	Orange Awlet	K08-old lit	Si12
8	*Burara oedipodea*	(Swainson, 1820)	*belesis* (Mabille, 1876)	Branded Orange Awlet	Ev49	W&S14
9	*Burara vasutana*	(Moore, [1866])		Green Awlet	W&S14	←
10	*Choaspes benjaminii*	(Guérin-Méneville, 1843)	*japonica* (Murray, 1875)	Indian Awlking	Wea12	←
11	*Choaspes furcata*	Evans, 1932		Hooked Awlking	Ev49	
12	*Choaspes xanthopogon*	(Kollar, [1844])		Similar Awlking	PWK23	←
13	*Hasora anura*	de Nicéville, 1889	*anura* de Nicéville, 1889	Slate Awl	K08-old lit	PWK23
14	*Hasora badra*	(Moore, [1858])	*badra* (Moore, [1858])	Common Awl	W&S14	←
15	*Hasora chromus*	(Cramer, [1780])	*chromus* (Cramer, [1780])	Common Banded Awl	K08-old lit	W&S14
16	*Hasora taminatus*	(Hübner, 1818)	*bhavara* Fruhstorfer, 1911	White-banded Awl	K08-old lit	Y&K85/
17	*Hasora vitta*	(Butler, 1870)	*indica* Evans, 1932	Plain Banded Awl	W&S14	←
Subfamily EUDAMINAE						
18	*Lobocla liliana*	(Atkinson, 1871)	*liliana* (Atkinson, 1871)	Marbled Flat	K08-old lit	PWK23
Subfamily TAGIADINAE						
Tribe Celaenorrhini						
19	*Celaenorrhinus badia*	(Hewitson, 1877)		Scarce Banded Flat	Ev49	
20	*Celaenorrhinus dhanada*	(Moore, [1866])	*dhanada* (Moore, 1865)	Himalayan Yellow-banded Flat	Ev49	W&S14 + PWK23
			affinis (Elwes & Edwards, 1897)		PWK23	←
21	*Celaenorrhinus leucocera*	(Kollar, [1844])		Common Spotted Flat	dNc89	Wea12
22	*Celaenorrhinus munda*	(Moore, 1884)	*munda* (Moore, 1884)	Himalayan Spotted Flat	Y&K85	W&S14
			maculicornis (Elwes & Edwards, 1897)		W&S14	←
23	*Celaenorrhinus nigricans*	(de Nicéville, 1885)	*nigricans* (de Nicéville, 1885)	Small-banded Flat	Ev49 (mb outside Bht)	Sb15+ PWK23
Tentv	*Celaenorrhinus plagifera*	de Nicéville, 1889		De Nicéville's Spotted Flat	dNc89 (Knyvett collection)	
24	*Celaenorrhinus pulomaya*	(Moore, [1866])	*pulomaya* (Moore, [1866])	Multi-spotted Flat	dNc89	PWK23
25	*Celaenorrhinus putra*	(Moore, [1866])	*putra* (Moore, [1866])	Bengal Spotted Flat	Ev49	W&S14
26	*Celaenorrhinus pyrrha*	de Nicéville, 1889		Double-spotted Flat	dNc89	
27	*Celaenorrhinus ratna*	Fruhstorfer, 1909	*tytleri* Evans, 1926	Tytler's Multi-spotted Flat	Wea12	←
28	*Pseudocoladenia fabia*	(Evans, 1949)		Dented Pied Flat	Ev49	PWK23

	Species name	Authority, year	Subspecies (Authority, year)	Common name	Bht 1st record*	Bht recent record
29	*Pseudocoladenia fatua*	(Evans, 1949)		Sikkim Pied Flat	Ev49	PWK23
30	*Pseudocoladenia festa*	(Evans, 1949)		Naga Pied Flat	Ev49	Wea12
31	*Sarangesa dasahara*	(Moore, [1866])	*dasahara* (Moore, [1866])	Common Small Flat	Ev49	Y&K85/ W&S14
Tribe Tagiadini						
32	*Abaratha agama*	(Moore, [1858])	*agama* (Moore, [1858])	Spotted Angle	Ev49	W&S14
33	*Abaratha angulata*	(C. Felder, 1862)	*angulata* (C. Felder, 1862)	Chestnut Angle	Ev49	W&S14
34	*Capila jayadeva*	Moore, [1866]		Striped Dawnfly	K08-old lit	JSW14+ PWK23
35	*Capila pennicillatum*	(de Nicéville, [1893])	*pennicillatum* (de Nicéville, [1893])	Fringed Dawnfly	PWK23	←
36	*Capila zennara*	(Moore, [1866])		Pale Striped Dawnfly	Ev49	
37	*Coladenia agni*	(de Nicéville, [1884])	*agni* (de Nicéville, [1884])	Brown Pied Flat	PWK23	←
38	*Coladenia indrani*	(Moore, [1866])	*indrani* (Moore, [1866])	Tricolour Pied Flat	Ev49	Drj14
39	*Coladenia pinsbukana*	(Shimonoya & Murayama, 1976)	*occidentalis* Huang, 2021	Large-spot Pied Flat	Hr87	PWK23
40	*Darpa hanria*	Moore, [1866]		Hairy Angle	W&S14	←
41	*Gerosis bhagava*	(Moore, [1866])	*lebadea* (Hewitson, 1886)	Common Yellow-breast Flat	K08-old lit	
42	*Gerosis phisara*	(Moore, 1884)	*phisara* (Moore, 1884)	Dusky Yellow-breast Flat	K08-old lit	P&W07
43	*Gerosis sinica*	(C. & R. Felder, 1862)	*narada* (Moore, 1884)	White Yellow-breast Flat	Wea12	←
44	*Pintara tabrica*	(Hewitson, 1873)	*tabrica* (Hewitson, 1873)	Crenulate Orange Flat	CTS18	←
45	*Satarupa zulla*	Tytler, 1915	*zulla* Tytler, 1915	Tytler's White Flat	W&S14	←
46	*Seseria sambara*	(Moore, [1866])	*sambara* (Moore, [1866])	Sikkim White Flat	Ev49	PWK23
47	*Tagiades gana*	(Moore, [1866])	*athos* Plötz, 1884	Suffused Snow Flat	K08-old lit	W&S14
48	*Tagiades ravi*	(Moore, [1866])	*ravi* (Moore, [1866])	Common Snow Flat	K08-old lit	W&S14
49	*Tagiades litigiosa*	Möschler, 1878	*litigiosa* Möschler, 1878	Water Snow Flat	K08-old lit	W&S14
50	*Tagiades menaka*	(Moore, [1866])	*menaka* (Moore, [1866])	Spotted Snow Flat	Ev49	W&S14
51	*Tagiades parra*	Fruhstorfer, 1910	*gala* Evans, 1949	Large Snow Flat	Si12	←
52	*Mooreana trichoneura*	(C. & R. Felder, 1860)	*pralaya* (Moore, [1866])	Yellow Flat	W&S14	←
53	*Tapena vasava*	(Moore, [1866])	*vasava* (Moore, [1866])	Tawny Angle	W&S14	←
Subfamily PYRGINAE						
Tribe Carcharodini						
54	*Spialia galba*	(Fabricius, 1793)	*galba* (Fabricius, 1793)	Indian Skipper	W&S14	←
Tribe Pyrgini						
55	*Pyrgus cashmirensis*	Moore, 1874	*cashmirensis* Moore, 1874	Kashmir Skipper	Ev49	
Subfamily CHAMUNDINAE						
56	*Chamunda chamunda*	(Moore, [1866])		Olive Flat	S&C16	←
Subfamily HETEROPTERINAE						
57	*Carterocephalus avanti*	(de Nicéville, 1886)		Orange and Silver Hopper	Ev49	PWK23
58	*Carterocephalus houangty*	Oberthür, 1886	*bootia* Evans, 1949	Bhutan Mountain Hopper	Ev49	Hr87/ PWK23
Subfamily TRAPEZITINAE						
Tribe Barcini						
59	*Apostictopterus fuliginosus*	Leech, [1893]	*curiosa* (Swinhoe, 1917)	Giant Hopper	Wea12	←

	Species name	Authority, year	Subspecies (Authority, year)	Common name	Bht 1st record*	Bht recent record
Subfamily HESPERIINAE						
Tribe Aeromachini						
60	*Aeromachus kali*	(de Nicéville, 1885)		Blue-spotted Scrub Hopper	Y&K85	W&S14
61	*Aeromachus pygmaeus*	(Fabricius, 1775)		Pigmy Scrub Hopper	PWK23	←
62	*Aeromachus stigmata*	(Moore, 1878)	*stigmata* (Moore, 1878)	Veined Scrub Hopper	dNc90	Wea12
63	*Ampittia dioscorides*	(Fabricius, 1793)	*dioscorides* (Fabricius, 1793)	Bush Hopper	S&C16+PWK23	←
64	*Ampittia subvittatus*	(Moore, 1878)	*subradiatus* (Moore, 1878)	Tiger Hopper	Wdm& dNc87	PWK23
65	*Arnetta atkinsoni*	(Moore, 1878)		Atkinson's Bob	Si12	←
66	*Baracus vittatus*	(C. Felder, 1862)	*septentrionum* Wood-Mason & de Nicéville, [1887]	Hedge Hopper	Ev49	
67	*Creteus cyrina*	(Hewitson, 1876)	*cyrina* (Hewitson, 1876)	Nonsuch Palmer	dNc95	
68	*Halpe arcuata*	Evans, 1937		Overlapped Ace	W&S14	←
69	*Halpe aucma*	Swinhoe, 1893		Gold-spotted Ace	PWK23	←
70	*Halpe filda*	Evans, 1949		Elwes' Ace	Si14	←
71	*Halpe kumara*	de Nicéville, 1885		Plain Ace	deNcv85	Wea12
72	*Halpe molta*	Evans, 1949		Molta Ace	vG18 (listed as ssp.) + PWK23	←
73	*Halpe porus*	(Mabille, [1877])		Moore's Ace	K08-old lit	PWK23
74	*Halpe sikkima*	Moore, 1882		Sikkim Ace	W&S14	←
75	*Halpe zema*	(Hewitson, 1877)	*zema* (Hewitson, 1877)	Banded Ace	W&S14	←
76	*Pedesta aina*	(de Nicéville, 1889)		Garhwal Ace	W&S14	←
Tentv	*Pedesta fusca*	(Elwes, [1893])	*fusca* (Elwes, [1893])	Fuscous Ace	PWK23	←
77	*Pedesta gupta*	(de Nicéville, 1886)	*gupta* (de Nicéville, 1886)	Olive Ace	PWK23	←
cf.	*Pedesta* cf. *gupta*			(Yellow-spotted Olive Ace)	(PWK23)	←
78	*Pedesta hyrie*	(de Nicéville, 1891)	*hyrie* (de Nicéville, 1891)	Large-spot Plain Ace	Ev49	W&S14
79	*Pedesta masuriensis*	(Moore, 1878)	*masuriensis* (Moore, 1878)	Mussoorie Bush Bob	Y&K85	W&S14
80	*Pedesta pandita*	(de Nicéville, 1885)		Brown Bush Bob	Y&K85	Wea12
81	*Pedesta serena*	(Evans, 1937)		Serena Ace	P&KC23	←
82	*Pithauria murdava*	(Moore, [1866])		Dark Straw Ace	Wm&dNc87	PWK23
83	*Pithauria stramineipennis*	Wood-Mason & de Nicéville, [1887]	*stramineipennis* Wood-Mason & de Nicéville, [1887]	Light Straw Ace	Wm&dNc87	Si12
84	*Sebastonyma dolopia*	(Hewitson, 1868)		Tufted Ace	K08-old lit	PWK23
85	*Sovia grahami*	(Evans, 1926)	*grahami* (Evans, 1926)	Graham's Ace	PWK23	←
86	*Sovia lucasii*	(Mabille, 1876)	*magna* (Evans, 1932)	Lucas' Ace	W&S14	←
87	*Sovia separata*	(Moore, 1882)	*separata* (Moore, 1882)	Chequered Ace	Ev49	Wea12
88	*Thoressa cerata*	(Hewitson, 1876)		Northern Spotted Ace	W&S14	←
Tribe Astictopterini						
89	*Astictopterus jama*	C. & R. Felder, 1860	*olivascens* Moore, 1878	Forest Hopper	PWK23	←
90	*Cupitha purreea*	(Moore, 1877)		Wax Dart	Ev49 (dNc84 is probably Buxa)	PWK23
Tentv	*Zographetus ogygia*	(Hewitson, [1866])	*ogygia* (Hewitson, [1866])	Purple-spotted Flitter	PWK23	Tentative
91	*Zographetus satwa*	(de Nicéville, [1884])		Purple and Gold Flitter	W&S14	←
Tribe Taractrocerini						
92	*Cephrenes acalle*	(Hopffer, 1874)	*oceanica* (Mabille, 1904)	Plain Palm Dart	PWK23	←
93	*Oriens gola*	(Moore, 1877)	*pseudolus* (Mabille, 1883)	Common Dartlet	PWK23	←

	Species name	Authority, year	Subspecies (Authority, year)	Common name	Bht 1st record*	Bht recent record
94	*Oriens goloides*	(Moore, [1881])		Ceylon Dartlet	Ev49	H87/W&S14
95	*Potanthus confucius*	(C. & R. Felder, 1862)	*dushta* (Fruhstorfer, 1911)	Chinese Dart	Ev49	
Tentv	*Potanthus ganda*	(Fruhstorfer, 1911)	*ganda* (Fruhstorfer, 1911)	Sumatran Dart	Wea12	←
96	*Potanthus nesta*	(Evans, 1934)	*nesta* (Evans, 1934)	Brandless Dart	Ev49	
97	*Potanthus pallida*	(Evans, 1932)		Pale Dart	Ev49	W&S14
98	*Potanthus palnia*	(Evans, 1914)	*palnia* (Evans, 1914)	Palni Dart	Ev49	
99	*Potanthus pseudomaesa*	(Moore, [1881])	*clio* (Evans, 1932)	Indian Dart	PWK23	←
100	*Potanthus rectifasciata*	(Elwes & Edwards, 1897)		Branded Dart	Ev49	
101	*Potanthus trachala*	(Mabille, 1878)	*tytleri* (Evans, 1914)	Broad Bi-dent Dart	W&S14: Tentv	PWK23
102	*Taractrocera danna*	(Moore, 1865)		Himalayan Grass Dart	Ev49	Y&K85/ P&W07
103	*Taractrocera maevius*	(Fabricius, 1793)	*sagara* (Moore, [1866]	Common Grass Dart	K08-old lit	W&S14
104	*Telicota bambusae*	(Moore, 1878)	*bambusae* (Moore, 1878)	Dark Palm Dart	W&S14	←
105	*Telicota colon*	(Fabricius, 1775)	*colon* (Fabricius, 1775)	Common Palm Dart	K08-old lit	PWK23
Tribe Erionotini						
106	*Erionota torus*	Evans, 1941		Banana Skipper	vG18 (? re-ID of spp. in W&S'14) + PWK23	←
107	*Gangara lebadea*	(Hewitson, 1868)	*lebadea* (Hewitson, 1886)	Banded Redeye	PWK23	←
108	*Gangara thyrsis*	(Fabricius, 1775)	*thyrsis* (Fabricius, 1775)	Giant Redeye	PWK23	←
109	*Hyarotis adrastus*	(Stoll, [1780])	*praba* (Moore, [1866])	Tree Flitter	K08-old lit	W&S14
110	*Matapa aria*	(Moore, [1866])		Common Redeye	K08-old lit	PWK23
111	*Matapa cresta*	Evans, 1949		Fringed Redeye	PWK23	←
112	*Matapa druna*	(Moore, [1866])		Grey-brand Redeye	PWK23	←
113	*Matapa sasivarna*	(Moore, [1866])		Black-veined Redeye	Si12	←
114	*Pirdana hyela*	(Hewitson, 1867)	*major* Evans, 1932	Green-striped Palmer	PWK23	←
115	*Salanoemia noemi*	(de Nicéville, 1885)		Spotted Yellow Lancer	PWK23	←
116	*Scobura isota*	(Swinhoe, 1893)		Swinhoe's Forest Bob	PWK23	←
117	*Suastus gremius*	(Fabricius, 1798)	*gremius* (Fabricius, 1798)	Indian Palm Bob	K08-old lit	PWK23
118	*Unkana ambasa*	(Moore, [1858])	*attina* (Hewitson, [1866])	Hoary Palmer	PWK23	←
Tribe Notocryptini						
119	*Ancistroides nigrita*	(Latreille, [1824])	*diocles* (Moore, [1866])	Chocolate Demon	Ev49	W&S14
120	*Ancistroides curvifascia*	(C. & R. Felder, 1862)	*curvifascia* (C. & R. Felder, 1862)	Restricted Demon	dNc89	Y&K85/ P&W07
121	*Ancistroides feisthamelii*	(Boisduval, 1832)	*alysos* (Moore, [1866])	Spotted Demon	K08-old lit	(Y&K85)/ Wea12
122	*Ancistroides paralysos*	(Wood-Mason & de Nicéville, 1881)	*asawa* Fruhstorfer, 1911	Common Banded Demon	K08-old lit	W&S14
123	*Ancistroides folus*	(Cramer, [1775])		Grass Demon	Ev49	Y&K85/ W&S14
Tribe Ismini						
124	*Iambrix salsala*	(Moore, [1866])	*salsala* (Moore, [1866])	Chestnut Bob	W&S14	←
Tribe Psolosini						
125	*Koruthaialos butleri*	(de Nicéville, [1884])		Dark Velvet Bob	dNc86	
126	*Psolos fuligo*	(Mabille, 1876)	*subfasciatus* (Moore, 1878)	Coon	Nd15	←
Tribe Baorini						
127	*Baoris farri*	(Moore, 1878)	*farri* (Moore, 1878)	Paintbrush Swift	K08-old lit	W&S14 (1st pic)
128	*Borbo cinnara*	(Wallace, 1866)		Rice Swift	K08-old lit	W&S14
129	*Caltoris aurociliata*	(Elwes & Edwards, 1897)		Yellow-fringed Swift	PWK23	←

	Species name	Authority, year	Subspecies (Authority, year)	Common name	Bht 1st record*	Bht recent record
130	*Caltoris cahira*	(Moore, 1877)	*austeni* (Moore, [1884])	Colon Swift	(vG18-source?) PWK23	←
131	*Caltoris kumara*	(Moore, 1878)	*moorei* (Evans, 1926)	Blank Swift	PWK23	←
132	*Caltoris tulsi*	(de Nicéville, [1884])	*tulsi* (de Nicéville, [1884])	Purple Swift	Ev49	
133	*Iton semamora*	(Moore, [1866])	*semamora* (Moore, [1866])	Common Wight	PWK23	←
134	*Parnara bada*	(Moore, 1878)	*bada* (Moore, 1878)	Ceylon Swift	Wea12	←
135	*Parnara guttata*	(Bremer & Grey, [1852])	*guttata* (Bremer & Grey, [1852])	Straight Swift	K08-old lit	Y&K85/ W&S14 (pic1)
136	*Pelopidas agna*	(Moore, [1866])	*agna* (Moore, [1866])	Obscure-branded Swift	W&S14	←
137	*Pelopidas assamensis*	(de Nicéville, 1882)		Great Swift	K08-old lit	W&S14
138	*Pelopidas conjuncta*	(Herrich-Schäffer, 1869)	*conjuncta* (Herrich-Schäffer, 1869)	Conjoined Swift	K08-old lit	W&S14
139	*Pelopidas mathias*	(Fabricius, 1798)	*mathias* (Fabricius, 1798)	Small-branded Swift	K08-old lit	W&S14
140	*Pelopidas sinensis*	(Mabille, 1877)		Large-branded Swift	Wea12	←
141	*Pelopidas subochracea*	(Moore, 1878)	*subochracea* (Moore, 1878)	Moore's Swift	K08-old lit	
142	*Polytremis lubricans*	(Herrich-Schäffer, 1869)	lubricans (Herrich-Schäffer, 1869)	Contiguous Swift	K08-old lit	W&S14
143	*Pseudoborbo bevani*	(Moore, 1878)		Bevan's Swift	K08-old lit	P&W07
144	*Zenonoida eltola*	(Hewitson, 1869)	*eltola* (Hewitson, 1869)	Yellow-spot Swift	K08-old lit	Y&K85/ Wea12
Tribe Hesperiini						
145	*Ochlodes brahma*	(Moore, 1878)		Himalayan Darter	Y&K85	P&W07

indicated in the books they use to identify the species, but usually, these books have several outdated scientific names, which is inevitable. The situation has become more confusing on the Indian subcontinent since the website of the Indian Foundation of Butterflies (IFB) not only changed common names when considering the standard names "colonial leftovers", but also gave common names to subspecies. For the Hesperiidae checklist of Bhutan, the authors based their scientific and common names on scientific and historical evidence. Researchers and butterfly photographers in Bhutan are encouraged to use these names. Standardization of the common butterfly names across the Indian subcontinent is recommended. Moreover, to reduce confusion, common names should only be used for species and not for subspecies. Due to progress in DNA sequencing of the butterflies, there will be many taxonomic changes in the future. These changes are more likely to affect subspecies than species and thus this is an extra reason to not give common names to subspecies.

CONCLUSIONS

The authors present a comprehensive checklist of Hesperiidae in Bhutan, resulting from a thorough review of all available records. The updated checklist (Table 1) comprises 145 confirmed species, four tentative species, and one unidentified species, subspecies, or form (listed as "cf."). This revised checklist supersedes previous versions, offering enhanced accuracy and reliability. To ensure transparency, the authors also provide supplementary lists of excluded species, detailing the rationale for their omission. This rigorous approach ensures a trustworthy reference for future research and conservation efforts.

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Image 1. *Potanthus mara* or maybe *P. nesta*.

Image 2. *Potanthus* sp. (maybe *P. pseudomaesa*).

1Image 3. Possibly *Caltoris brunnea*.

Image 4. Probably *Parnara bada*.

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ARTICLE

Conservation imperatives for swallowtail butterflies (Lepidoptera: Papilionidae): a case study in the north bank landscape of river Brahmaputra, Bodoland Territorial Region, India

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Abstract: The decline of swallowtail butterflies in forest habitats, which was not a significant concern about two decades ago, has now garnered attention worldwide, leading to their designation as globally endangered by the International Union for Conservation of Nature. A recent study conducted in the north bank landscape (NBL) of river Brahmaputra, specifically under the Bodoland Territorial Region in India, has shed light on the remarkable diversity of swallowtail butterfly species in the area. The study documented a total of 35 species representing eight different genera. Notably, three species are endemic to northeastern India, and 12 enjoy federal protection. The findings suggest that the studied landscape plays a crucial role in supporting larval host plants and adult resources of swallowtail butterflies along with the other abiotic factors. These butterflies depend on 25 plant species from six families as essential food sources. Unfortunately, these host plants, valued for their traditional medicinal properties, are being overexploited. Urgent conservation measures are imperative to safeguard the habitats of swallowtail butterflies and other wildlife in the NBL under Bodoland Territorial Region, as they face significant threats from practices such as agriculture, illegal tree felling, forest fires, and cattle farming.

Keywords: *Aristolochia*, Bodoland, endangered, habitat, host plants, landscape, Papilionidae, protected, rare, wildlife.

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INTRODUCTION

Butterflies are closely associated with the landscape in various ways, and the characteristics of the surrounding environment can influence their presence, abundance, and diversity. They are excellent candidates for ecological studies in any landscape and serve as valuable indicators for evaluating biological conservation efforts (Nadeau et al. 2017). Within the vast diversity of insects, butterflies hold particular significance as they are well-suited for ecological research (Tomas & Mallorie 1985; Pollard & Yates 1993). Butterflies, in general, play a crucial role in a landscape because of their ecological contributions. Studies consistently show a positive relationship between butterfly diversity, specifically swallowtail butterflies, and environmental variables (Tomas & Mallorie 1985; Spitzer et al. 1997; Rossi & Halder 2010; Hill et al. 2021). Swallowtails, named for their swallow-like hindwing extensions, include both tailed & tailless species. While predominantly tropical, some extend into cooler temperate zones in both hemispheres (New et al. 1995). New (1991) reported that eastern and southeastern Asia's equatorial rainforests host a remarkable diversity of swallowtail butterflies. Collins (1987) documented India, Mexico, Taiwan, Malaysia, and Papua New Guinea as significant regions for swallowtails, collectively housing over two-thirds of global species, each with distinct geographic distributions.

The global count of swallowtail butterfly species stands at 573, inclusive of the Queen Alexandra's Birdwing *Ornithoptera alexandrae* Rothschild, 1907 found in Papua New Guinea's rainforests (Collins & Morris 1985). India hosts 77 swallowtail species, with only six being endemic (Collins & Morris 1985). Historically, northeastern India was noted for hosting 69 swallowtail species (Evans 1932), emphasizing its significance in swallowtail diversity. The International Union for Conservation of Nature and Natural Resources (IUCN) has designated northeastern India as a 'swallowtail-rich zone' under the Swallowtail Conservation Action Plan (MOEF 1990).

The study focused on evaluating species richness, distribution, and conservation status of swallowtail butterflies and their larval host plants in protected areas along the north bank landscape (NBL) of the Brahmaputra River in Bodoland Territorial Region (BTR), northeastern India. It also aimed to identify potential threats impacting populations of these globally threatened butterflies.

MATERIALS AND METHODS

Study Area

BTR, also previously known as Bodoland Territorial Council (BTC), is an autonomous council area unraveled from the northern part of western Assam under the sixth schedule of the constitution of India in 2003. It lies between 26.1200 N and 26.7972 E, covering an area of 8,970 km2, of which 40% is covered with forests. The river Pachnoi of Sonitpur district is the easternmost boundary and river Sankosh in the west, Bhutan in the north, and Dhubri, Bongaigaon, Barpeta, Nalbari, and Kamrup Districts in the south (Figure 1). The area of BTR extends over the NBL, is flat with some hills to the north, and is contiguous with the Royal Manas National Park (1,023 km^2) of Bhutan. This is at the confluence of Indo-Gangetic, Indo-Malayan, and Indo-Bhutan realms and a key conservational area of the Jigme Dorji Manas-Bumdeling conservation landscape in the eastern Himalayan eco-region (Wikramanayake et al. 2000). The NBL forests under BTR constitute major forest types such as the eastern Himalayan Bhabhar upper & lower Sal forest, eastern Terai Sal forest, eastern heavy alluvium plain Sal forest, eastern hill Sal forest, northern secondary moist mixed deciduous forest, evergreen forest, low alluvial savannah woodland, eastern wet alluvial grassland, riparian fringing forest, Khair-Sissoo forests, secondary bamboo brakes, and cane brakes (Champion & Seth 1968). The soil in this area is primarily dry sandy loam with a thin layer of humus and frequent surface stones. The temperature in the area can range from 7–34 ^{0}C. The site experiences fluctuating levels of rainfall throughout the year, with the winter season witnessing minimal precipitation of approximately 15 mm, while the wet season receives significantly higher rainfall, reaching up to 1,162 mm.

Sampling Methods

The butterfly population was surveyed using strip transects, following the slight modification of the method proposed by Pollard & Yates (1993). This involved counting individuals observed within a standardized 5 × 5 × 5 m in front of the observer. The observer maintained a consistent pace while walking through various habitats, including areas near water sources, damp patches within the forest, open sunny areas, and blooming flowers. Moreover, opportunistic searches were conducted within the catchment areas of streams and along their entire length, from top to bottom, to ensure a comprehensive record of the maximum number of species. The observed individuals were identified and

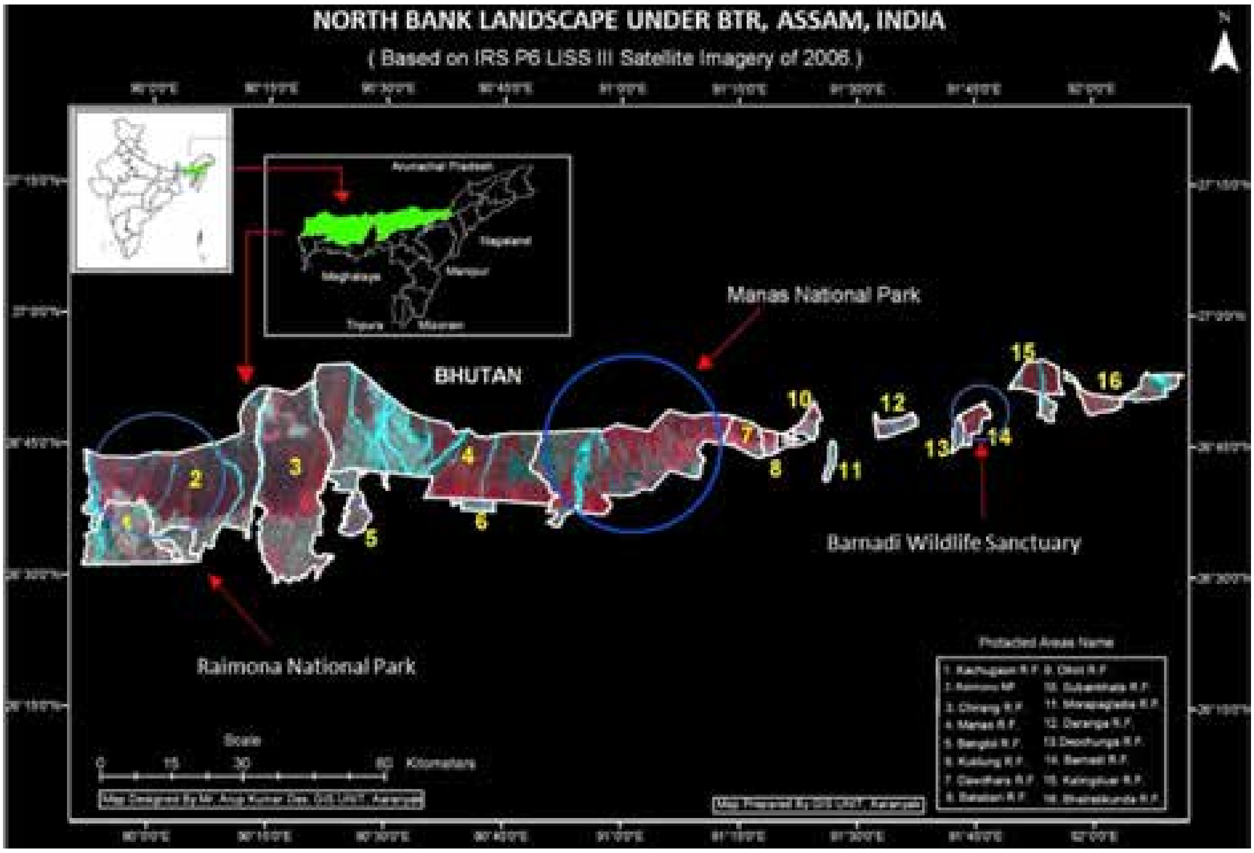

Figure 1. The study area with protected areas in the North Bank Landscape under Bodoland Territorial Region, Assam, India.

recorded. In cases where immediate identification was not possible, representative specimens were captured with the help of an insect net and photographed, then released without any injury for accurate identification.

The surveys were carried out during sunny conditions, specifically between 0900 h and 1600 h, as this is the time when butterflies are most active. The identification of butterflies was carried out with the help of identification keys available in the literature (Evans 1932; Wynter-Blyth 1957).

The basic technique for identifying larval host plants involves directly observing the egg-laying behaviors of female butterflies in the field, followed by a rigorous search for larvae on those plants. Subsequently, plant identification is accomplished using regional and local floras, including references such as Kanjilal et al. (1934–1940), and Borthakur et al. (2018).

RESULTS

In the study, 35 species of swallowtail butterflies from eight genera were recorded in the study area. These butterflies had a combined abundance of 4,267 individuals. Table 1 provides the recorded species' information, including their wing span, larval food plants, global distribution, local distribution, local status, and status in the Wild Life (Protection) Amendment Act, 2022.

Among the recorded species, eight belonged to the 'red-bodied' group, which encompassed three genera: *Atrophaneura* Reakirt (consisting of four species), *Pachliopta* Boisduval (with one species), and *Triodes* (with two species). The group characterized by 'black-bodied' species, including the genera *Papilio* Linnaeus and *Graphium* Scopoli, displayed the highest species richness, with each genus containing 11 species. Additionally, the genera *Chilasa* Moore were represented by four species, while the genera *Lamproptera* Gray, *Pachliopta* Boisduval, and *Meandrusa* Moore had the lowest species count, with only one species each (Figure 2). Within the documented species, one particular

Table 1. List of swallowtail butterflies recorded in the North Bank Landscape (NBL), under Bodoland Territorial Region (BTR), Assam, India along with their common name, scientific name, wing span, global distribution, larval host plants, local distribution, local conservation status, and status in the Wild Life (Protection) Amendment Act, 2022.

	Common name	Scientific name	Wing span (mm)	Geographical range	Larval food plants	Local distribution	Local status	WL (P) Act
1	Lesser Batwing	*Atrophaneura aidoneus* Doubleday, 1845	120–162	India (Uttaranchal to Arunachal Pradesh, Meghalaya), Nepal, Bhutan, and Myanmar	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Bhairabkunda RF, Chirang RF, Barnadi WS, and Khungring RF	Rare	
2	Common Batwing	*Atrophaneura varunaastorion* West Wood, 1842	88–136	India (Uttaranchal to Arunachal Pradesh, Meghalaya), Nepal, Bhutan, Myanmar, and Bangladesh	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Chirang RF, Barnadi WS, and Khungring RF.	Rare	
3	Great Windmill	*Atrophaneura dasaradadasarada* Moore, 1857	100–140	India (Jammu & Kashmir to Arunachal Pradesh), Nepal, Bhutan, Myanmar, and Bangladesh	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Chirang RF, BarnadiWS, and Khungring RF.	Very Rare	
4.	Common Windmill	*Atrophaneura philoxenuspolyeuctus* Doubleday, 1842	110–140	India (J&K to north-east), Nepal, Bhutan, Myanmar, and Pakistan.	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Chirang RF, and Khungring RF.	Occasional	
5	Tailed Jay	*Graphium agamemnon agamemnon* Linn, 1758	85–110	India, Nepal, Bhutan, Bangladesh, Sri Lanka, and Myanmar	*Michelia champaca* *Polythia longifolia* *Annona squamosa*	Chirang RF, Barnadi WS, and Khungring RF	Frequent	
6	Common Jay	*Graphium dosonaxion* C & R Felder, 1864	70–80	India, Sri Lanka, Nepal Bhutan, and Myanmar.	*Polyalthia simiarum* *Polylthia longifolia* *Michelia champaca* *Magnolia grandiflora* *Cinnamomum* spp.	Chirang RF, Barnadi WS, and Khungring RF.	Frequent	
7	Great Jay	*Graphium eurypylus* Linn, 1758	75–100	India (Sikkim-Arunachal, north-east, West Bengal (northern hills), Andaman), Bhutan, Bangladesh, and Myanmar	*Magnolia grandiflora* *Polyalthia longifolia*	Chirang RF, Barnadi WS, and Khungring RF.	Frequent	Sch-II
8	Common Blue Bottle	*Graphium sarpedon sarpedon* Linn, 1758	80–95	India, Sri Lanka, Nepal, Bhutan, and Bangladesh.	*Polyalthia longifolia* *Cinnamomum tamala* *Saraca indica* *Cinnamomum zeylanicum* *Litsea chinensis* *Annona squamosa*	Chirang RF, Barnadi WS, and Khungring RF.	Frequent	Sch-II
9	Fivebar Swordtail	*Graphium antiphates pompilus* Fabricius, 1787	80–95	India, Nepal, Bhutan, Bangladesh, and Myanmar.	*Michelia champaca* *Annona squamosa* *Desmos dunalii*	Chirang RF, BarnadiWS, and Khungring RF.	Frequent	
10	Spot Swordtail	*Graphium nomius nomius* Esper, 1785-98	75–90	India, Nepal, Bhutan, Sri Lanka, Bangladesh, and Myanmar	*Annona squamosa* *Polyalthia longifolia*	Chirang RF, Barnadi WS, and Khungring RF.	Rare	
11	Fourbar Swordtail	*Graphium agetes agetes* Westwood, 1843	75–90	India, Nepal, Bhutan, Bangladesh, and Myanmar.	*Annona squamosa* *Michleia* spp.	Barnadi WS, and Khungring RF.	Rare	Sch-II
12	Chain Swordtail	*Graphium aristeus anticrates* Doubleday, 1846	70–80	India (Sikkim to Assam), and Myanmar.	*Annona squamosa* *Michleia* spp.	Chirang RF.	Rare	Sch-II
13	Great Zebra	*Graphium xenocles xenocles* Doubleday, 1842	85–120	India (Uttaranchal to north-east), Nepal, Bhutan, Bangladesh, and Myanmar.	*Annona squamosa* *Michelia* spp.	Chirang RF, and Barnadi WS.	Rare.	
14	Glassy Bluebottle	*Graphium cloanthus* Westwood, 1841	85–95	India (J&K to north-east), Nepal, Bhutan, Myanmar, and Pakistan.	*Michelia* spp.	BarnadiWS, and Khungring RF.	Rare	Sch-II
15	Lesser Zebra	*Graphium macareus lioneli* Fruh, 1902	80–100	India (Uttaranchal to northeastern India), Nepal, Bhutan, Bangladesh, and Myanmar.	*Annona squamosa* *Michelia* sp.	Chirang RF, Barnadi WS, Raimona NP, Chirang RF, Manas NP, and Kuklung RF.	Very Rare	
16	Common Birdwing	*Troides helena cerberus* C. & R. Felder, 1865	140–170	India (Orissa, Sikkim to Arunachal Pradesh and Andaman & Nicobar Islands), Nepal, Bhutan Bangladesh, and Myanmar.	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, and Deochunga RF.	Occasional	

	Common name	Scientific name	Wing span (mm)	Geographical range	Larval food plants	Local distribution	Local status	WL (P) Act
17	Golden Birdwing	*Troides aeacusaeacus* C. & R. Felder, 1860	119–188	India (Uttaranchal to Arunachal Pradesh and Andaman & Nicobar Islands), Nepal, Bhutan Bangladesh, and Myanmar.	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, and Daranga RF.	Rare	Sch-II
18	Red Helen	*Papili ohelenus helenus* Linn, 1758	110–130	India, Nepal, Bhutan, Bangladesh, Myanmar, and Sri Lanka.	*Toddalia asiatica* *Zanthoxylum* spp. *Paramignya griffithii* *Aegle marmelos* *Citrus* spp.	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Frequent	
19	Yellow Helen	*Papilio nepheluschaon* Westwood, 1845	115–130	Odisha, northeastern India, Nepal, Bhutan, Bangladesh, and northern Myanmar.	*Aegle marmelos* *Toddalia asiatica* *Zanthoxylum* sp. *Citrus* spp. *Paramignya griffithii* *Murraya koenigii*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata RF.	Frequent	
20	Common Raven	*Papilio castor polas* Jordan, 1909	80–120	Northeastern India, Bhutan, Bangladesh, and northern Myanmar.	*Toddalia asiatica* *Glycosmis pentaphyla* *Zanthoxylum* sp. *Citrus* sp.	Chirang RF, Kachugaon RF, Khungring RF, and Barnadi WS.	Occasional	
21	Great Mormon	*Papilio memnonagenor* Linn, 1758	120–150	India (Sikkim to north-east, West Bengal, Andaman & Nicobar Island), Nepal, Bhutan, Myanmar, and Bangladesh.	*Paramignya griffithii* *Murraya koenigii* *Citrus medica* *Citrus* spp. *Glycosmis entaphylla* *Evodiameliaefolia* *Zanthoxylum* spp.	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Frequent	
22	Common Mormon	*Papilio polytes romulus* Cramer, 1775	90–100	India, Nepal, Bhutan, Sri Lanka, Myanmar, Bangladesh, and Pakistan.	*Aegle marmelos* *Citrus* spp. *Murraya koenigii* *Glycosmis entaphylla* *Evodiameliaefolia* *Zanthoxylum nitdum* *Citrus medica* *Citrus aurantfolia* *Citrus sinensis* *Correa* sp. *Glycosmis* sp. *Triphasia* sp. *Zanthoxylum* sp.	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, BarnadiWS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Frequent	
23	Spangle	*Papilio protenor euprotenor* Fruhstorfer, 1908	100–130	Northern Pakistan, Jammu & Kashmir, Garhwal Himalaya, Sikkim, Assam, Bangladesh, Burma, southern China (including Hainan), northern Vietnam, northern Laos, Taiwan, North Korea, South Korea, and Japan.	*Zanthoxylum* sp. *Citrus* sp. *Zanthoxylum nitdum* *Citrus medica* *Zanthoxylum alatum*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Barnadi WS, Kalingduar RF, Daranga RF, and Subankhata.	Rare	
24	Yellow Crested Spangle	*Papilio elephenor elephenor* Doubleday, 1886	110–130	Northeastern India (Assam).	Data deficient	Raimona NP	Vary Rare	Sch-I

	Common name	Scientific name	Wing span (mm)	Geographical range	Larval food plants	Local distribution	Local status	WL (P) Act
25	Paris Peacock	*Papilioparisparis* Linn, 1758	90–140	The Himalaya from Kumaon to Sikkim, Nepal and Bhutan; the hills of Assam, Burma and Tenasserim, extending to China, Siam, and the Malay Peninsula.	*Citrus* spp.	Raimona NP, Chirang RF, Manas NP, and Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Occasional	
26	Common Peacock	*Papilio polyctor ganesa* Doubleday, 1832	90–130	India (J&K to north-east) Nepal, Bhutan, Myanmar, Afghanistan, and Pakistan	*Zanthoxylum* spp. *Citrus* spp. *Clausena* spp. *Zanthoxylum oxyphyllum* *Zanthoxylum hamiltonianum*	Khungring RF.	Rare	
27	Redbreast	*Papilio alcmenor* C. & R. Felder, 1864	110–130	India (Uttaranchal to north-east), Nepal, Bhutan, Bangladesh, and Myanmar.	Data deficient	Chirang RF and Khungring RF.	Rare	
28	Lime Butterfly	*Papilio demoleus demoleus* Linn, 1758	80–100	India, Nepal, Bhutan, Bangladesh, Pakistan, Sri Lanka, Afghanistan, and Myanmar.	*Solanum nigram* *Aegle marmelos* *Citrus* spp. *Murraya koenigii* *Glycosmis pentaphyla*	Chirang RF, Kachugaon RF, Barnadi WS, and Khungring RF.	Frequent	
29	Common Mime	*Chilasa clytia clytia* Linn, 1758	90–120	India, Nepal, Bhutan, Pakistan, Bangladesh, Sri Lanka, and Myanmar.	*Cinnamomum tamala* *Litsea chinensis* *Alseodaphne semecarpifolia,* *Cinnamomum verum* *Litsea glutnosa,* *Persea gamblei,* *Ocotea lancifolia* *Sarcosperma arboreum*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Occasional	Sch-II
30	Lesser Mime	*Chilasa epicydes epicydes* Hewitson, 1862	70–90	Northeastern India, Myanmar.	*Cinnamomum* sp.	Barnadi WS.	Rare	Sch-II
31	Blue-Striped Mime	*Chilasa slateri slateri*, Hewitson, 1857	80–100	Northeastern India, Nepal, Bhutan, Bangladesh, and Myanmar.	*Cinnamomum* sp.	Chirang RF.	Very Rare	Sch-II
32	Great Blue Mime	*Chilasa paradoxa telearchus*Hewitson, 1852	120–150	India (Assam to Arunachal Pradesh), Nepal, Bangladesh, and Myanmar.	Data deficient	Chirang RF.	Very Rare	Sch-II
33	White Dragontail	*Lemproptera curius curius* Fabricus, 1787	40–45	India (Assam, Arunachal Pradesh), Bangladesh, and Myanmar.	*Lligera cordata*	Barnadi WS.	Rare	
34	Common Rose	*Pachliopta aristolochiae aristolochiae* Fabricius, 1775	90–110	India, Sri Lanka, Pakistan, Nepal, Bhutan, Myanmar, and Bangladesh.	*Aristolochia bracteolata* *Aristolochia indica* *Aristolochia tagala*	Raimona NP, Chirang RF, Manas NP, Kuklung RF, Dawdhara RF, Barnadi WS, Kalingduar RF, Bhairabkunda RF, Deochunga RF, Daranga RF, and Subankhata.	Frequent	
35	Yellow Gorgon	*Meandrus apayeni* Boisduval, 1836	11–130	India (Sikkim-Assam), Bhutan, southern Burma, northern Thailand, northern Vietnam, Laos, China, Malaysia, Indonesia, and Myanmar.	Data Deficient	Dawdhara RF.	Very Rare	

WL (P) Act—Wild Life (Protection) Amendment Act, 2022.

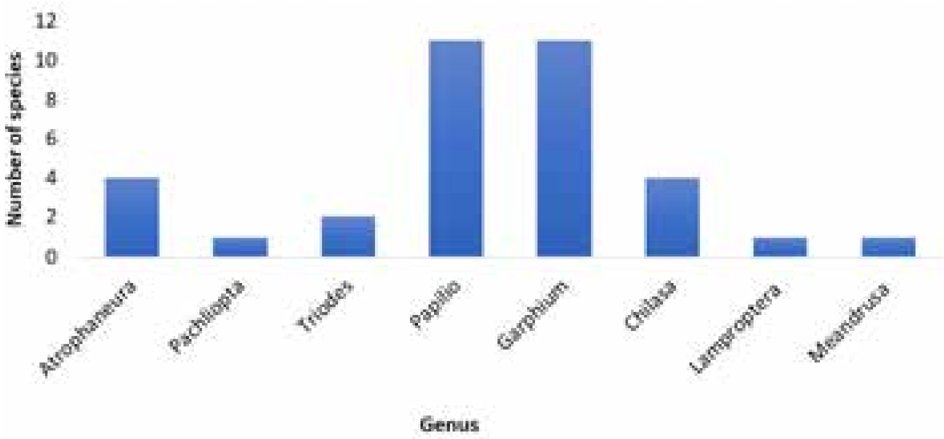

Figure 2. Dominant genera of swallowtail butterflies in the North Bank Landscape under Bodoland Territorial Region, Assam, India.

swallowtail butterfly species has been accorded the highest level of protection as Schedule I under the Wild Life (Protection) Amendment Act, 2022. Additionally, 11 other species have been recorded and designated as Schedule II under the same Act (Table 1, Image 1).

When assessing the abundance of swallowtail butterflies in the study area, the following scale was used: "Very rare" refers to a sighting or occurrence of 1–3 instances; "Rare" signifies a slightly higher occurrence, ranging 4–10 instances; "Occasional" represents a moderate frequency, encompassing 10–50 instances; and "Frequent" indicates a high frequency of occurrence, starting from 21 instances or more, indicating a significant presence of swallowtail butterflies (Table 1).

The larval host plants recorded in the study belonged to six different families of plant species. The family Rutaceae had the highest number of host plant species, with 12 species identified. Following Rutaceae, the family Lauraceae had four species, while the families Aristolochiaceae and Annonaceae each had three species. Magnoliaceae and Fabaceae had two species and one species, respectively (Figure 3).

DISCUSSION

The study documented a total of 35 species, which accounts for 45% of the total species reported in India by Evans (1932) and Talbot (1939). Out of the five endemic species found in the eastern Himalaya, according to Evans (1932) and Talbot (1939), three species were recorded during the study: Yellow-crested Spangle *Papilio elephenor elephenor* Doubleday, 1886, Lesser Zebra *Graphium macareus lioneli* Fruh, 1902, and Great Zebra *Graphium xenocles xenocles* Doubleday, 1842. Choudhury (2010) recorded Yellow-crested Spangle after several decades from Phipsu (presently Raimona National Park). This species is listed as endangered recently under the Wild Life (Protection) Amendment Act, 2022. There is minimal knowledge about its population dynamics because of its elusiveness. The Lesser Zebra *Graphium macareus lioneli* Fruh, 1902 was recorded in the forest trails of Barnadi WS, Chirang RF, and Raimona NP during June and July. A single individual of the Great Zebra was found alongside the Saralpara-Sarpang road under the Chirang Reserve Forest. Despite its typical occurrence at higher elevations between 1,000 m and 2,200 m, three individuals of the Lesser Mime *Chilasa epycides* Hewitson, 1862 was recorded in February near Saralpara under the Chirang RF, at 125 m. It is conceivable that these species may have migrated from Bhutan to seek refuge from the harsh winter temperatures, as the hills of Bhutan are contiguous with this particular land.

The Blue-striped Mime *Chilasa slateri slateri* Hewitson, 1857 was observed near the Kalanadi Forest Camp of Barnadi Wildlife Sanctuary, while the remaining species were found across all the reserves. Notably, the survey did not record any species from the *Teinopalpus* Hope and *Bhutanitis* Atkinson genera. This is significant as the Bhutan Glory *Bhutanitis lidderdalei* Atkinson, 1873 and Kaiser-I-Hind *Teinopalpus imperialis*, Hope 1843, already rare in the Assam region during the early 20th century, have not been observed for several years. Many researchers (Pollard 1979: Pollard 1988; Roy & Sparks 2000; Barua et al. 2010) stated that heavy showering and closed canopy are the two critical abiotic factors for the richness of swallowtail butterflies. Arguably, the seasonality of tropical insects is predominantly

Image 1. Swallowtail butterflies protected by the Wild Life (Protection) Amendment Act, 2022 in India: A—*Papilio elephenor* | B—*Graphium macareus* | C—*Chilasa epicydes* | D—*Chilasa slateri* | E—*Graphium aristeus* | F—*Graphium agetes* | G—*Graphium xenocles* | H—*Chilasa clytia* | I—*Graphium cloanthus* | J—*Graphium eurypylus* | K—*Chilasa paradoxa* | L—*Triodes aeacus.* © Kushal Choudhury.

influenced by changes in rainfall patterns (Wolda 1989; Hill et al. 2003). According to Jain et al. (2012), there is evidence of a gradual decrease in rainfall across the entire northeastern region of India over several years, potentially contributing to the decline of swallowtail butterflies. Furthermore, the detrimental impacts of activities such as illegal tree felling, uncontrolled forest fires, tea gardening near protected areas, pesticide usage (Steffan-Dewenter et al. 2005), and the persisting issue of illegal cattle farming within these protected areas may be crucial factors contributing to the decline of these butterflies (Harrisson et al. 2012) (Image2).

The availability of host plants is one of the most critical factors for the survival of butterflies. The black-bodied species belonging to *Papilio* (including mormons, peacock, and helens) and *Graphium* (comprising jays and bluebottles) were observed to feed on six distinct plant families. The dominant plant families among these were Rutaceae, Lauraceae, and Magnoliaceae. Figure 3 shows varying levels of species richness among the different plant families, with Rutaceae being the most diverse one. According to Hajra et al. (1997), the study area is situated in the "Citrus belt of the world" and supports a diverse range of citrus species, including 17 species, 52 varieties, and six potential hybrid citrus species (Bhattacharya & Dutta 1956). This abundance of citrus plants may be linked to the richness of the *Papilio* genus, as these butterflies predominantly rely on citrus plants for their larval development. However, the population of citrus species, primarily found in the wild or semi-wild habitats, is declining due to the shrinkage of forested lands and overexploitation. As a result, these citrus species are now mainly confined to home gardens or backyard settings. This decline in the wild population of citrus species may be a possible reason for the disappearance of these butterfly species.

The butterfly genera *Atrophaneura* (Corbet & Pendlebury 1992), *Pachliopta* (Venkataramana et al. 2004), and *Triodes* (Parsons 1996, 1999) have a specialized diet, exclusively feeding on plants from the Aristolochiaceae family. Three species of the genus *Aristolochia* (*A. bracteolate*, *A. indica*, and *A. tagala*) were recorded within the study area. Due to their significant traditional medicinal value, these plants were extensively harvested from the wild, resulting in a sharp decline in their density (Mebs & Schneider 2002;

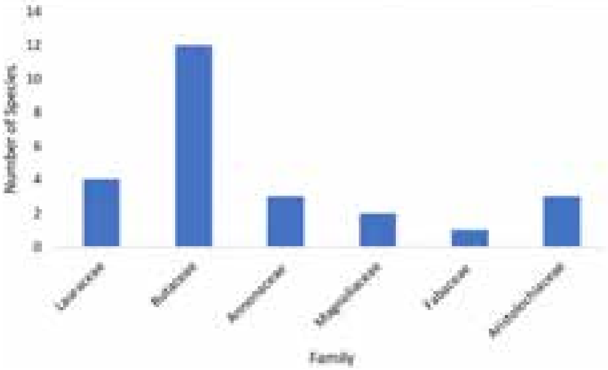

Figure 3. Dominant genera of larval host plants for swallowtail butterflies in the North Bank Landscape under Bodoland Territorial Region, Assam, India.

Heinrich et al. 2009; Michl et al. 2013). This decline directly affects the population of *Aristolochia* feeding swallowtail butterflies. In the family Magnoliaceae, which comprises 24 species from northeastern India, only two species, *Magnolia champaca* and *Magnolia grandiflora*, were recorded from the study area. Their density is declining daily, despite their great economic value, as they provide helpful wood for making boxes and musical instruments and yield excellent commercial timber known as 'white wood' or 'yellow poplar' (Pandey & Misra 2009). *Polyalthia simiarum*, *Annona squamosa*, and *P. longifolia* are representative species of the Annonaceae family. *Polyalthia longifolia* is commonly planted in urban areas as an ornamental plant. *P. longifolia* and *P. simiarum* hold tremendous medicinal value (Rashid et al. 1996; Kabir et al. 2013).

Lauraceae includes *Cinnamomum camphora*, *C. verum*, *C. zeylanicum*, *C. tamala*, and *Litsea chinensis*. Ahmad et al. (2022) reported the traditional use of *Cinnamomum camphora,* while *C. tamala* has been found to have beneficial effects on digestion and appetite stimulation (Hamidpour et al. 2013; Mehta et al. 2014). Pathak & Sharma (2021) emphasized the medicinal benefits of *Cinnamomum verum* and *C. zeylanicum*.

In the study, *Lamproptera* species were the only recorded monophagous specialists, relying on a single host plant, *Ligustrum cordatum,* under the family Oleaceae. In traditional medicine, certain parts of *Ligustrum cordatum* are believed to possess medicinal properties. On the other hand, the polyphagous *Graphium* species fed on plants from the Lauraceae and Magnoliaceae families. Koh et al. (2004) observed that host-specific butterflies are especially susceptible to localized fragmentation of their resources. The comparable environmental conditions in the study area might have played a role in the reduced or limited numbers of *Lamproptera* species observed within protected regions.

Unfortunately, our study did not reveal any identified host plants associated with Yellow-crested Spangle *Papilio elephenor* Doubleday, 1886*,* Redbreast *Papilio alcmenor* C. & R. Felder, 1864*,* Great Blue Mime *Chilasa paradoxa* Hewitson, 1852*,* and Yellow Gorgon *Meandrusa payeni* Boisduval, 1836 from the study area. The lack of related host plant resources for these

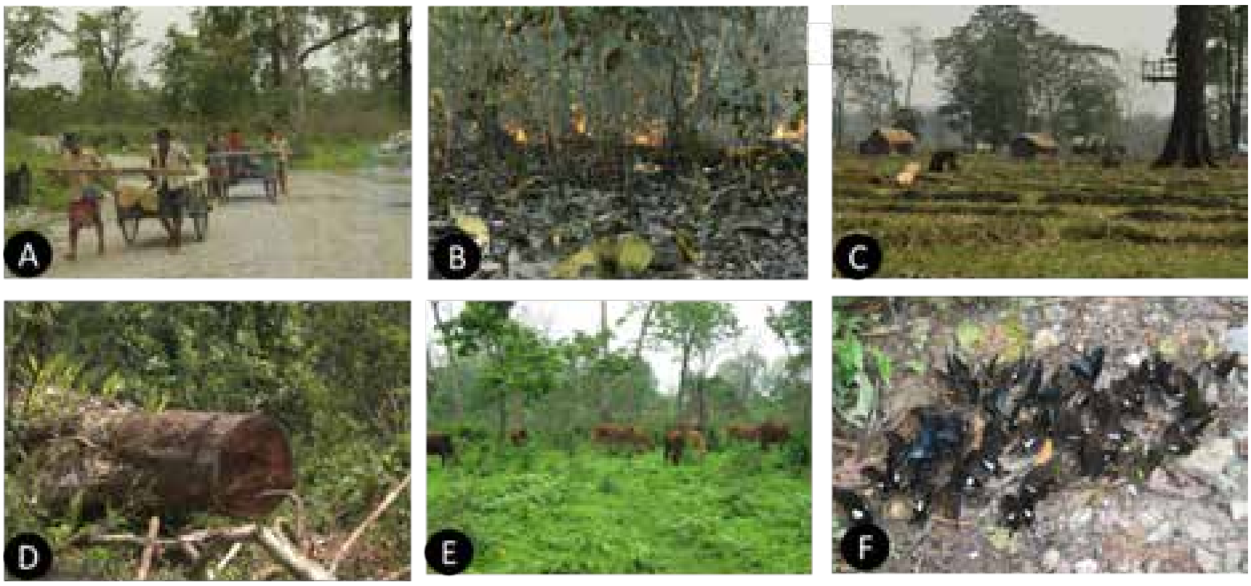

Image 2. Threats of swallowtail butterflies in the study area: A—collection of timber | B—unscientific forest fire | C—encroachment and agricultural practice | D—tree felling | E—cattle farming | F—puddling of swallowtail butterflies. © Kushal Choudhury.

species raises concerns about their long-term survival and ecological well-being. Host plants are fundamental to the lifecycle of many species, playing an essential role in their reproduction and sustenance.

While the study primarily focused on identifying essential plant families as larval food resources for swallowtail butterflies, the study area exhibited a diverse range of plant species that serve as good nectar sources. It is essential to mention that adult butterflies exhibit less specificity and more excellent opportunism in their feeding behaviors compared to their larval stages, as observed by Gilbert & Singer (1975). Prior research confirms that butterfly diversity and abundance are significantly influenced by floral and larval resources and climate's impact on plant phenology. Moreover, the local abundance and timing of nectar and host-plant resources can substantially affect butterfly populations more than their mere presence (Simonson et al. 2001).

The study findings have brought to light the importance of both global environmental changes (Swaay et al. 2010) and local factors in the decline of these threatened butterfly species. In order to revive their populations, it is crucial to focus on conserving their preferred microhabitats and the medicinal plants they rely heavily on. We can create a conducive environment for their recovery by preserving these plants and their habitats. Additionally, for critically endangered species that have dwindling numbers in the wild, implementing captive breeding programs can play a vital role in boosting their populations. Conducting an extensive survey is crucial for comprehending the present state of larval host plants, encompassing their abundance, distribution, and conservation status, which lays the groundwork for effective conservation strategies, and species preservation. Furthermore, micropropagation techniques facilitate the swift propagation of larval host plants, thereby supporting the conservation and expansion of rare populations.

CONCLUSION AND RECOMMENDATION

Habitat restoration and protection are crucial components of any conservation strategy. Initiatives should be undertaken to enhance the quality and availability of larval host plants, nectar sources, and breeding grounds. This includes reforestation efforts, native plant restoration, and reducing harmful activities such as illegal logging & forest fires. Collaboration with experts and institutions specializing in butterfly breeding is essential to establish successful breeding protocols and release strategies, providing a safety net against extinctions. The protection of medicinal plants serving as larval host plants should also be a priority, emphasizing promoting sustainable harvesting practices in collaboration with local communities and traditional medicine practitioners. Micropropagation techniques should be explored to ensure a sustainable supply of larval host plants, contributing to the conservation of rare plant species and the butterflies that depend on them. Education and awareness campaigns targeting local communities, schools, and the general public are critical to promote understanding of the ecological importance of swallowtail butterflies, their threats, and individual actions that can support their conservation. A long-term conservation plan with clear goals, milestones, and funding mechanisms is essential to ensure the sustainability of swallowtail butterfly conservation efforts, capable of adapting to changing circumstances.

Engaging local communities through capacity-building workshops, training programs, and employment opportunities related to butterfly conservation is vital for garnering their support and participation. By implementing these measures, we can significantly contribute to safeguarding swallowtail butterflies and preserving their ecological importance for current and future generations. These recommendations must be implemented promptly to reverse the decline of these beautiful and ecologically significant butterflies.

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ARTICLE

OPEN ACCESS

The present state of leech fauna (Annelida: Hirudinea) in Dal Lake, Jammu & Kashmir, India

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Abstract: Dal Lake supports a diverse group of fauna, including fishes, aquatic birds, zooplankton, and macrobenthic invertebrates. This study is the first taxonomic documentation of the leech fauna of Dal Lake. A total of nine leech taxa belonging to four families were identified and described: Glossiphoniidae – *Alboglossiphonia weberi*, *A. heteroclita*, *Glossiphonia complanata*, *Helobdella stagnalis*, *Hemiclepsis marginata asiatica*, and *Theromyzon* sp.; Erpobdellidae – *Erpobdella octoculata*; Hirudinidae – *Poecilobdella granulosa*; and Haemopidae – *Haemopis indicus*. Leeches play key roles in prey-predator dynamics and host-parasite relationships in freshwater ecosystems and as bioindicators of water pollution. This study provides essential data for taxonomic accounts and the diversity of leech fauna in Dal Lake.

Keywords: Freshwater ecosystem, annelid diversity, Himalaya, taxonomy, distribution, Glossiphoniidae, Erpobdellidae, Hirudinidae, Haemopidae.

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Author contributions: Conceptualization—Yahya Bakhtiyar, Niyaz Ali Khan. Methodology—Niyaz Ali Khan, Zahoor Ahmad Mir. Identification—Niyaz Ali Khan, Yahya Bakhtiyar, Zahoor Ahmad Mir. Writing—original draft preparation—Niyaz Ali Khan, Yahya Bakhtiyar. Review and editing— Yahya Bakhtiyar, Niyaz Ali Khan, Zahoor Ahmad Mir. Supervision—Yahya Bakhtiyar.

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INTRODUCTION

Leeches are annelids that coexist in freshwater ecosystems with molluscs, oligochaetes, and insect larvae and are found on every continent and in every ocean, except for terrestrial Antarctica (Sket & Trontelj 2008). Leeches prefer diverse environments and exhibit tolerance to extreme conditions such as variation in temperature, moisture, salinity, pressure, light, and pollution. They can be found in some wet soil on land and bottom substrates of freshwater, estuarine, and marine ecosystems (Phillips et al. 2020). Leeches are regarded as one of the most significant ecological indicators in freshwater ecosystems. Several aquatic species of leeches are important components in the aquatic food web at different trophic levels and also play a role in prey-predator and parasite-host relationships. Additionally, they are good bioindicators of water pollution, making them highly relevant from a scientific perspective (Bezmaternykh 2007; Romanova & Klimina 2010; Kaygorodova et al. 2014). Leeches serve as intermediary hosts for some larval stages of trematodes and are essential components of prey-predator and parasite-host relationships in aquatic environments (Pyrka et al. 2021). Around one-third of the total leech species have feeding mode as predators, while majority of leech species consume the blood of other invertebrates and vertebrates for their nutrition (Atkauskien & Rutkauskaitė-Sucilien 2022). Considering the taxonomic accounts, leeches have a circumoral and a posterior ventral sucker for attachment to substratum as well as a fixed number of segments (Wetzel 1992). They also lack setae but have a genital orifice and analogue jaws as diagnostic characters. One of the species, *Hirudo medicinalis*, of the class Hirudinea was traditionally used to treat people suffering from a variety of illnesses and medical ailments (Sig et al. 2017). In India, numerous new species of terrestrial and freshwater leeches have been documented over time beginning with the works of (Harding 1924; Baugh 1960 a,b; Soota & Ghosh 1977; Chandra 1982; Nesemann et al. 2004; Mandal 2004, 2013, 2015; Mandal et al. 2020a,b, 2022; Uttam & Langer 2021). There is a significant lack of comprehensive data regarding the distribution, biology, and ecology of many Indian leech species (Bhatia 1930, 1940; Baugh 1960 a,b; Ray 1980; Raut & Nandi 1985; Raut 1986; Raut & Saha 1987; Mandal et al. 2022). The existing literature regarding the leech fauna in the Kashmir valley's water bodies is mostly fragmented. Moreover, there are very few old records about the species composition of leeches from the waterbodies of Kashmir. In the 20th century, Moore (1924); Bhatia (1930, 1934, 1939, 1940), and Soota (1956) conducted studies on the leech fauna in Kashmir. Therefore, the literature reveals the need for fresh surveys and redescription of species regarding the leech fauna in freshwater bodies of the Kashmir valley. Considering the taxonomic concerns and lack of data available regarding the leech fauna, the present study has been conducted to explore the current leech fauna of Dal Lake.

MATERIALS AND METHODS

Study area

Dal Lake, one of the most cherished water bodies, in the Kashmir Himalaya, is situated in the urban area, providing numerous ecosystem services to the local population and boosting the urban economy. The lake is located between geographic coordinates 34.067–34.183 °N & 74.800–74.880 °E (Figure 1) covering a total catchment area of approximately 337 km^2. The lake has a surface area of 24 km^2, with 10.5 km^2 available as open water (Rashid et al. 2017). It is divided into four distinct basins: Hazratbal, Lokut Dal, Nigeen, and Gagribal (Amin et al. 2014). Dal Lake functions as an open drainage system, receiving water input from various streams and springs. Telbal Nallah and Botkol serve as the two main inflow channels, while smaller streams such as Meerakshah Nallah along with multiple springs originating from the lake bed and nearby mountains contribute to its water sources (Qadri & Yousuf 1980). The lake has two primary outlets, namely Nallah Amir Khan and Dalgate (Kumar et al. 2022). In the present study, the samples were collected from different locations within Dal Lake.

Methods applied for sampling, processing, and identification

Freshwater leeches were collected with standard bottom samplers (EU-WFD) used in different zones of Dal Lake, during the research work from January 2021 to December 2022. An Ekman's dredge was used to collect the mud samples in the deep water (limnetic zone) while the kick method was applied in shallow water (littoral zone) to collect samples from macrophytes, leaf packs, submerged logs, stones, concrete banks, and debris. Leech samples were carefully separated from extraneous material by handpicking tools and delivered as live samples in water- filled plastic jars (1l) to the Fish Biology and Limnology Research Laboratory, Department of Zoology, University of Kashmir. The

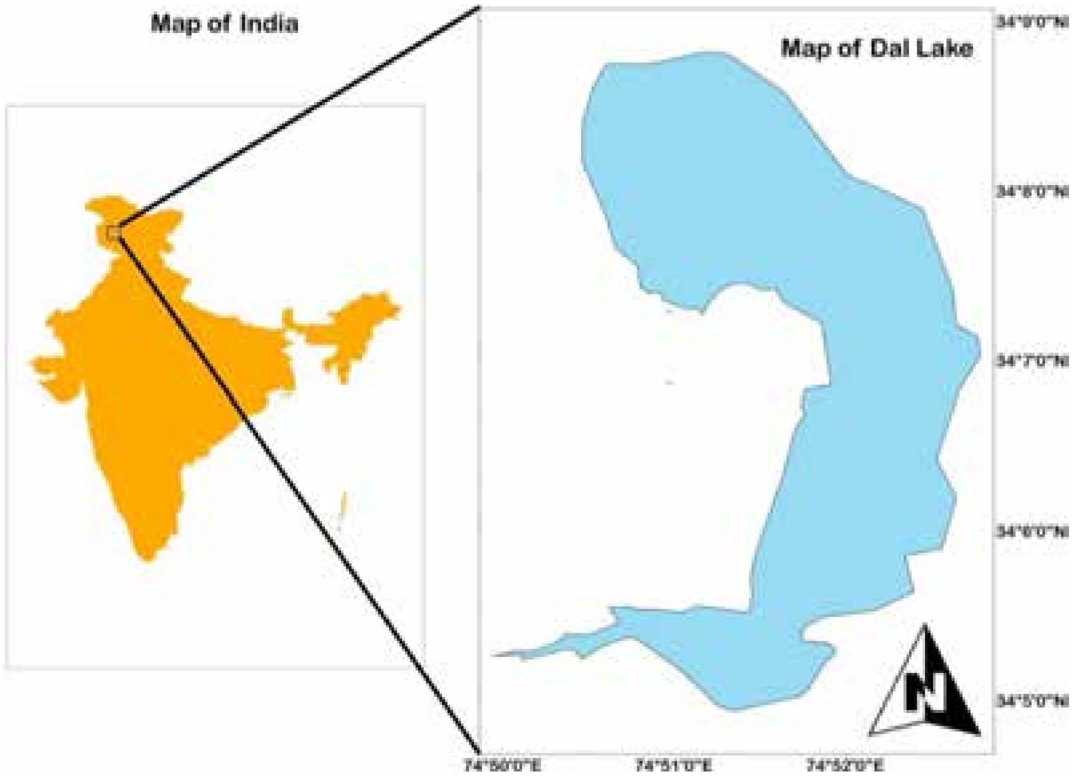

Figure 1. Geographical representation of Dal Lake from Kashmir Himalaya.

specimens were first narcotized using a gradient of low ethanol solutions and then preserved in 80% ethanol following the standard protocol of Kaygorodova & Bolbat (2020). Morphological analysis and photography were carried out using stereo zoom microscopes (Magnus MS 24 and LEICA S98) with a digital microscope camera (Magcam DC 10). Identification of species was done by using existing standard taxonomic keys of leeches (Klemm 1985; Chandra 1991; Nesemann et al. 2004; Mandal 2013).

RESULTS AND DISCUSSION

Family: Glossiphoniidae

***Alboglossiphonia weberi* (Linnaeus, 1761)**

Location: Telbal, 34.140°N & 74.863°E, 29.viii.2021, 13.ix.2022, coll. Niyaz Ali Khan.

Material examined: Image 1A–C; number of specimens observed = 15.

Diagnosis: The body is translucent ovate 10 mm in length; the dorsal surface is roughened by the presence of numerous tubercles (Image 1A); colour of the live specimen is somewhat yellowish-brown and on preservation in alcohol it becomes greenish white; it possesses a radial stripe of the same dark pigment which occurs upon the body (Image 1A); Presence of three pair of eyes one each on sixth, seventh and eighth ring (Image 1C); crop with six pairs of lateral diverticula**.**

Habitat: *Alboglossiphonia weberi* occurs in ponds, tanks, pools, lakes, slow-moving streams, and rivers. This species is found attached to the smooth surfaces of cobbles and pebbles in streams, and rivers.

Distribution: Widely distributed throughout India while outside India occurs in Pakistan, Nepal, Myanmar, and Sumatra (Chandra 1991).

***Glossiphonia complanata* (Linnaeus, 1758)**

Location: Telbal, 34.140°N & 74.863°E, 27.viii.2021, 15.iii.2022, coll. Niyaz Ali Khan; Nigeen, 34.123°N & 74.827°E, 27.viii.2021, coll. Niyaz Ali Khan; Ashai bagh, 34.114°N & 74.836°E, 27.viii.2021, 15.iii.2022, coll. Niyaz Ali Khan.

Material examined: Image 1D–H; n = 23.

Diagnosis: Body flat, leaf- shaped, dark brown and greenish in colour; the length is 14–25 mm; dorsal surface of the body is covered with six rows of papillae; dorsal surface has two paramedial dark lines interrupted by papilla which extends up to the middle portion of the body (Image 1D,G); two strips are also prominent on the

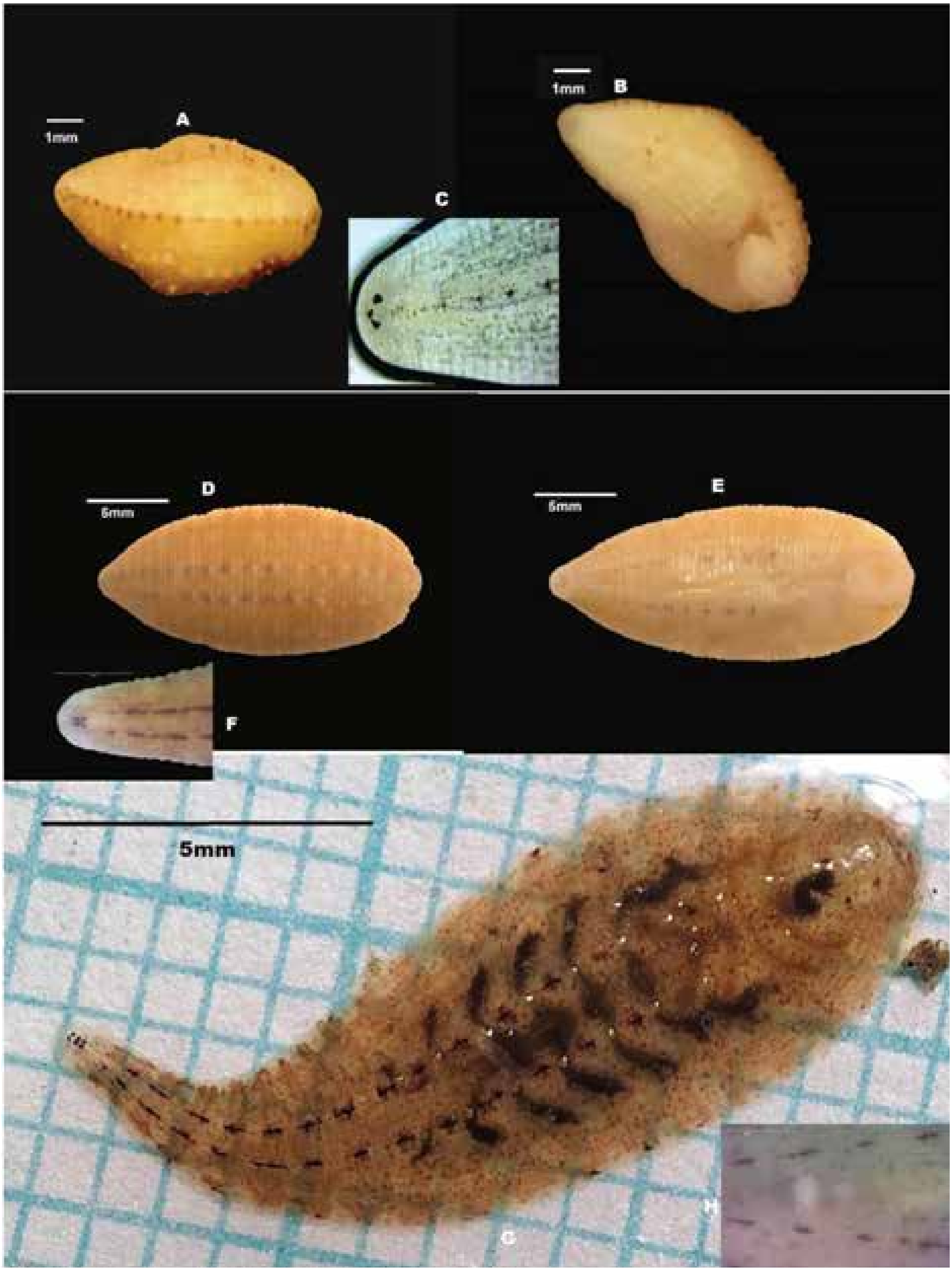

Image 1. Leech fauna of Dal Lake: A—dorsal view of *Alboglossiphonia weberi* | B—ventral side | C—anterior part showing the eyes pattern | D—dorsal side of *Glossiphonia complanata* | E—ventral side | F—anterior part of the body showing eye position | G—whole body of the live specimen | H—male and female gonopores. © Niyaz Ali Khan.

ventral side (Image 1E); three pair of eye spots located on the anterior somite's (Image 1F); posterior sucker is disk- like while the anterior sucker is triangular; six pair of crop caeca can be seen in freshly collected live specimens.

Habitat: *Glossiphonia complanata* was commonly found in stagnant water bodies and slow-flowing rivers characterized by plentiful vegetation and molluscs. Typically, this species was observed under submerged wood or stones.

Distribution: The species is widely distributed in India such as Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Karnataka, Madhya Pradesh, Bihar, West Bengal, Meghalaya, Manipur, and Odisha while outside India it has been reported from Pakistan, Nepal, Myanmar, Indonesia, Japan, U.S.A, and Europe (Chandra 1991; Mir et al. 2024).

***Alboglossiphonia heteroclita* (Linnaeus, 1761)**

Location: Telbal, 34.140°N & 74.863°E, 29.iii.2021, coll. Niyaz Ali Khan; Nigeen, 34.123°N & 74.827°E, 10.viii.2021, coll. Niyaz Ali Khan.

Material examined: Image 2A–C; n = 23.

Diagnosis: Small, flat, and ovate leeches are generally yellowish translucent in live specimens; the head region is bulbous consisting of three pair of eyes of which the first pair of eyes lie close to each other and are the smallest ones as compared to the other two pairs (Image 2C); second and third pair of eyes are widely separated but the components lie near together giving approximately a triangular shape (Image 2C); three pair of eyes generally lie in rings five , seven and eight respectively; one median line of dark black spots on every third annulus and numerous small spots on the dorsal surface (Image 2A); dorsal and ventral surface of the body is smooth and without papillae (Image 2A,B).

Habitat: *Alboglossiphonia heteroclita* is found in lakes and ponds attached to submerged articles and are parasitic mainly on molluscs (Chandra 1991).

Distribution: *Alboglossiphonia heteroclita* is a species with a Holarctic distribution, found in central and western Europe (Nesemann & Neubert 1999; Bielecki et al. 2011). It has also been recorded in Lithuania while in India, the species occur in Rajasthan and Bihar (Chandra 1991).

***Helobdella stagnalis* (Linnaeus, 1758)**

Location: Telbal, 34.140°N & 74.863°E, 2.iv.2021, 22.x.2022, coll. Niyaz Ali Khan.

Material examined: Image 3A–C; n = 7.

Diagnosis: Small flat, leaf- shaped ceramic white when alive and pale white on preservation with numerous tiny spots on the dorsal surface; an anterior region with a single pair of eyespots and a chitinous scute (nuchal plate) is visible on the dorsum (Image 3A,C); smooth body surface without any papillae.

Habitat: *Helobdella stagnalis* is found in stagnant water bodies in association with molluscs. Adults show parental care where young ones are attached to the ventral side of the body (Image 3B).

Distribution: In India, the species occur in Himachal Pradesh and Jammu & Kashmir (Mir et al. 2024) while outside India it has been reported from the USA, Lithuania (Zettler & Daunys 2007), Canada, and Paraguay (Chandra 1991).

***Theromyzon* sp. Philippi, 1867**

Location: Telbal, 34.140°N & 74.863°E, 22.x.2021, coll. Niyaz Ali Khan.

Material examined: Image 3D– J; n = 33.

Diagnosis: Large dorsoventrally flattened olive green or brownish in colour (Image 3G); preserved specimens are brownish due to decolouration (Image 3D); six rows of yellow spots on the dorsal side of the body; ventral side possesses a large number of small papillae; suckers are small and weak in comparisons to the body size; four pair of eyespots arranged straight in head region; first pair of eyespots lie close to each other and second, third and fourth pair of eyes widely separated in ascending order (Image 3J); four annuli between male and female gonopore (Image 3F); young ones appear green in colour and are found attached to the ventral side of the parent body (Image 3H).

Habitat: *Theromyzon* sp. was found mainly in the stagnant water with the presence of aquatic birds. They are found attached to the submerged articles, under stones and wood. Adult shows parental care where around 100 young ones are attached to the ventral side of the body (Image 3H).

Distribution: *Theromyzon* sp. has been reported in many states of India (Chandra 1982) while outside India, the species occurs in European, American, and African countries (Davies et al. 2008).

***Hemiclepsis marginata asiatica* (Moore, 1924)**

Location: Telbal, 34.140°N & 74.863°E, 27.viii. 2021, coll. Niyaz Ali Khan.

Material examined: Image 4A–D; n = 11.

Diagnosis: The leech is commonly known as the disproportioned- eyed leech; two pairs of eyes are present, with the anterior pair being extremely small (Image 4C); the first pair of eyes are closely positioned

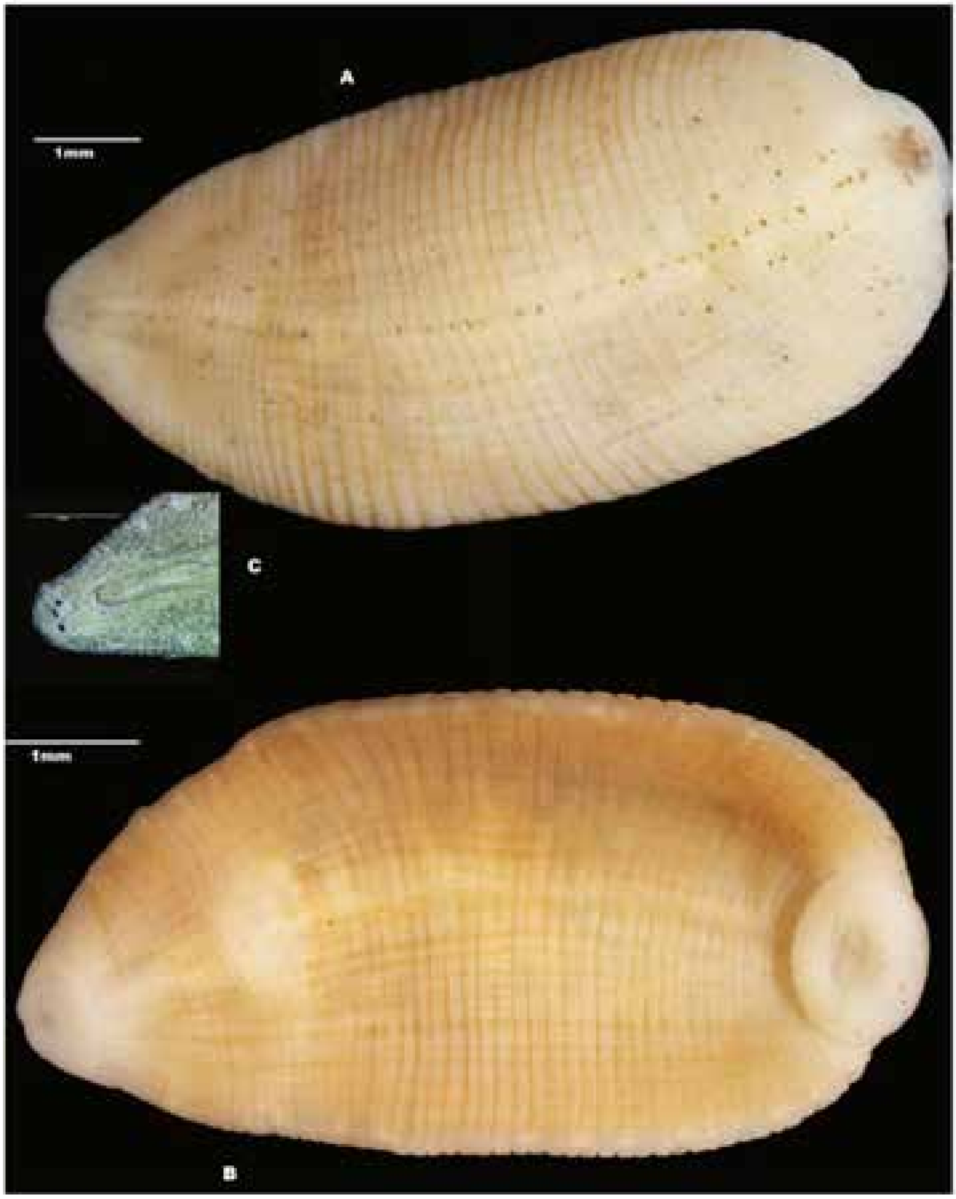

Image 2. Leech fauna of Dal Lake: A—dorsal view of *Alboglossiphonia heteroclita* | B—ventral side | C—anterior part showing the eyes pattern. © Niyaz Ali Khan.

and very tiny (Image 4C); eyes are typically located just ahead of the more noticeable and widely spaced posterior pair of eyes; leech is translucent in appearance; size is approximately 16 mm in length and 6 mm in width; the head region is enlarged and differentiated from the rest of the body; leech exhibits a reddish-brown colour in natural environment and whitish on preservation; dorsal surface with broken transverse stripes in a pale-yellow (Image 4A); crop region contains 11 pairs of lateral diverticula.

Habitat: *Hemiclepsis marginata asiatica* is common in shallow margins of lakes and ponds overgrown by vegetation. Found attached to submerged articles, plants, stones, and wood as microhabitats.

Distribution: Mostly occurs in Jammu & Kashmir and Himachal Pradesh states of India (Chandra 1991; Mir et al. 2024).

Family: Erpobdellidae

***Erpobdella octoculata* (Linnaeus, 1758)**

Location: Telbal, 34.140°N & 74.863°E, 2.i.2021, coll. Niyaz Ali Khan; Nigeen, 34.123°N & 74.827°E, 2.i.2021, coll. Niyaz Ali Khan; Ashai bagh, 34.114°N & 74.836°E, 17.viii.2021, 27.viii.2022, coll. Niyaz Ali Khan.

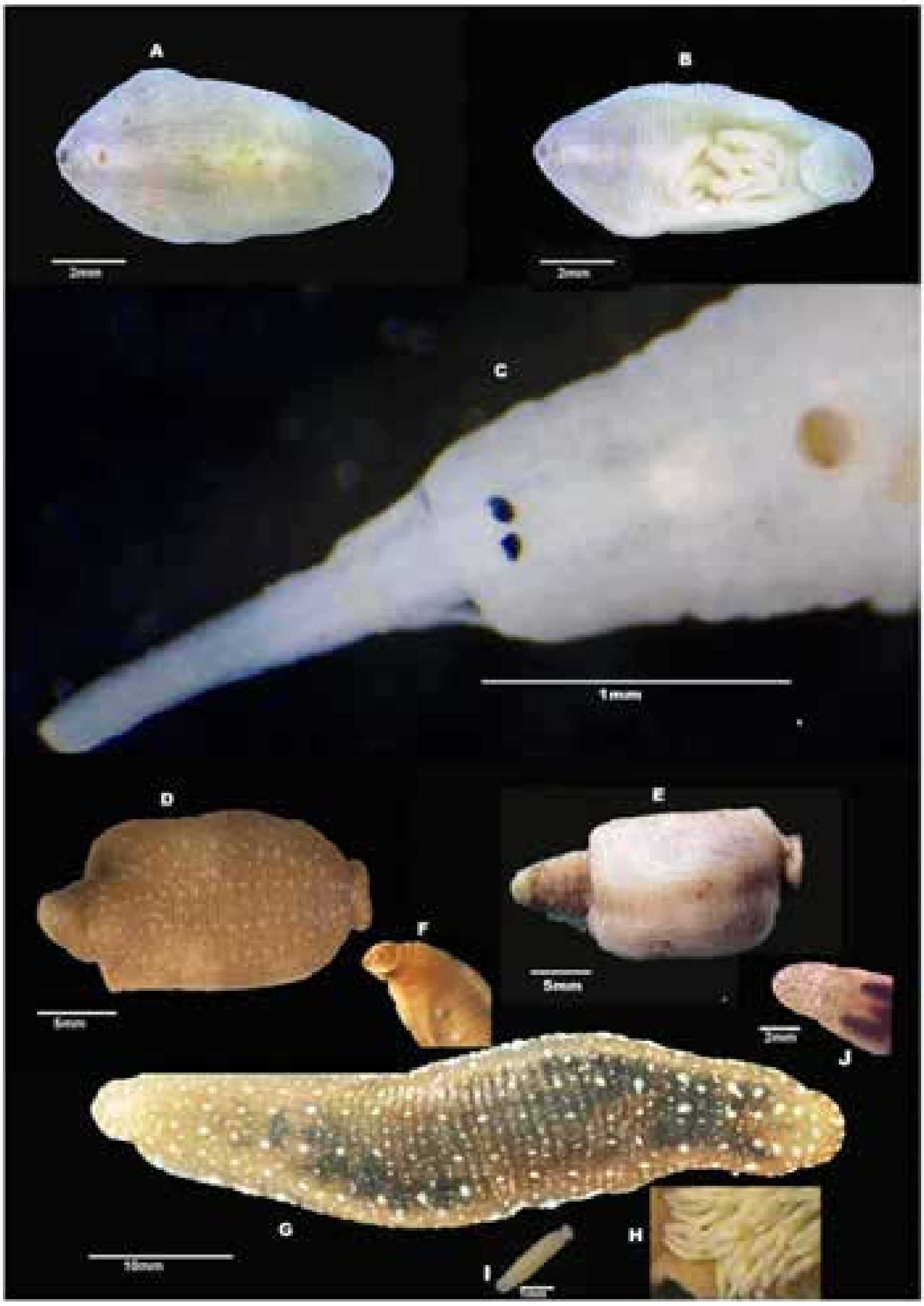

Image 3. Leech fauna of Dal Lake: A—dorsal view of *Helobdella stagnalis* | B—young ones attached to the ventral side | C—anterior part showing the single pair of eyes and nuchal scute | (D)—dorsal side of the preserved specimen *Theromyzon* sp. | E—ventral side of preserved specimen | F—position of male and female gonopores| G— full body of live specimen | H— young ones attached to the ventral side of adult body | I—juvenile | J—anterior part showing the four pairs of eyes. © Niyaz Ali Khan.

Material examined: Image 4E–H; n = 43.

Diagnosis: These leeches vary in size, ranging from medium to large, and also exhibit a variety of colours; possess a relatively robust body form compared to other species in the same family, with a nearly uniform shape that tapers anteriorly to the clitellum; head is relatively small in proportion (Image 4E); typically, they have four pairs of eyes; first pair located on segment II; second pair at the furrow between segments II and III; third and fourth pairs situated on the sides of the buccal ring on segment IV (Image 4F); breeding individuals display a well-defined clitellum; gonopores are separated by approximately two and a half annuli (Image 4H).

Habitat: Most common leech species found in

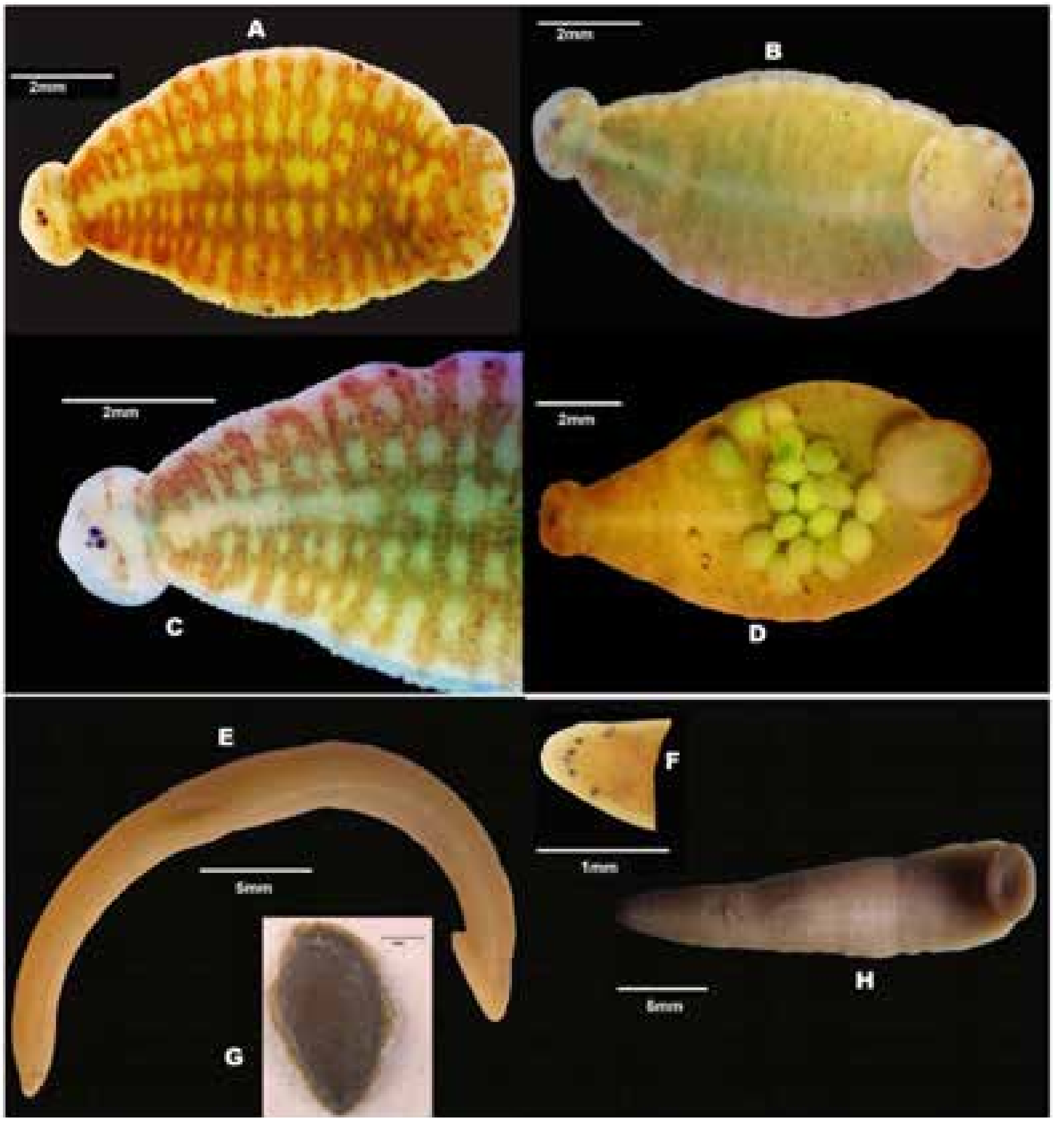

Image 4. Leech fauna of Dal Lake: A—dorsal view of *Hemiclepsis marginata asiatica* | B—ventral side | C—anterior part showing the eyes | D—eggs attached to the ventral side of adult | E—dorsolateral view of *Erpobdella octoculata* | F—anterior part showing the four pair of eyespots | G—cocoon | H—ventral side. © Niyaz Ali Khan.

both lentic and lotic water bodies attached to stones, submerged articles, and leaves of aquatic plants.

Distribution: In India, occurs mostly in Jammu and Kashmir (Mir et al. 2024) while outside India, it occurs in Lahore (Pakistan), Palestine, and Europe (Chandra 1991).

Family: Hirudinidae

***Poecilobdella granulosa* (Savigny, 1826)**

Location: Nigeen, 34.123°N & 74.827°E, 10.ix.2021, coll. Niyaz Ali Khan.

Material examined: Image 5(A–D); n = 10.

Diagnosis: The average adult body is about 70 mm long; dark greenish-brown in colour, and has a dorsal surface covered in geometrically structured black patterns and squares (Image 5A); the median line is always dark; the body is solid and has a very rough surface with the abundance of big papillae; typical five sets of eyes present (Image 5C).

Habitat: *Poecilobdella granulosa* was found in stagnant water or nearly stagnant water bodies with muddy bottoms, vegetation, and water with organic-rich material.

Distribution: In India, occurs in Punjab, Himachal Pradesh, Uttar Pradesh, Gujrat, Maharashtra, Madhya Pradesh, Tamil Nadu (Chandra 1983), Jammu & Kashmir, Kerala, Manipur, Odisha, Rajasthan, Sikkim, Uttarakhand, and West Bengal (Ahmed 2021) while outside India, occurs in Sri Lanka, Nepal, and Myanmar.

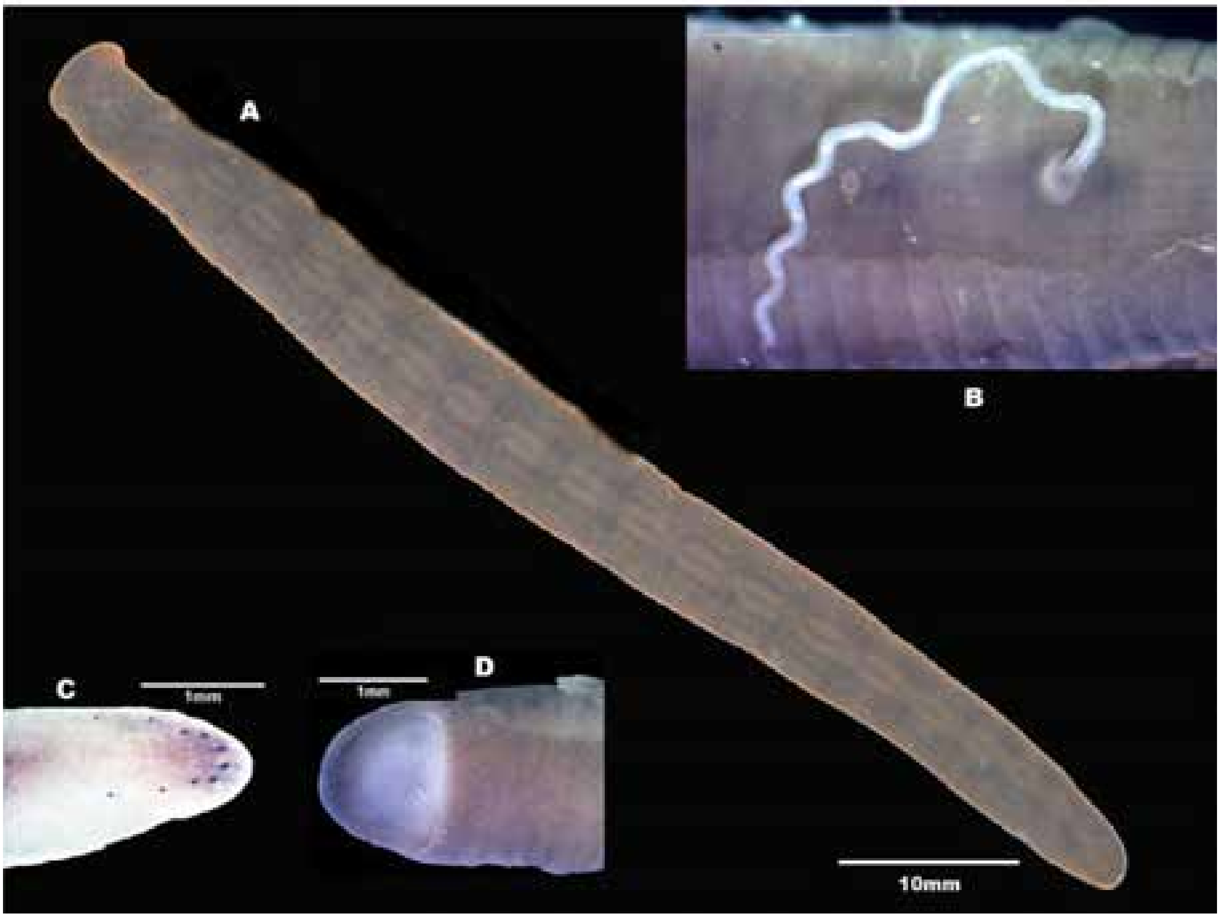

Image 5. Leech fauna of Dal Lake: A—dorsal view of *Poecilobdella granulosa* | B—position of male and female gonopores | C—anterior part showing five pair of eyespots | D—mouth position. © Niyaz Ali Khan.

Table 1. The systematic list of leech species collected from Dal Lake.

Phylum	Class	Order	Family	Genus/Species	Authority	Common Name
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Alboglossiphonia weberi*	(Blanchard, 1897)	Proboscis-bearing Leech
				Glossiphonia complanata	(Linnaeus, 1758)	Proboscis-bearing Leech
				Helobdella stagnalis	(Linnaeus, 1758)	Proboscis-bearing Leech
				Theromyzon sp.	Philippi, 1867	Duck Leech
				Alboglossiphonia hetroclita	(Linnaeus, 1761)	Small Snail Leech
				Hemiclepsis marginata asiatica	(Moore, 1924)	Disproportioned-eyed leech
		Archynchobdellida	Erpobdellidae	*Erpobdella octoculata*	(Linnaeus, 1758)	Worm Leech
			Hirudinidae	*Poecilobdella granulosa*	(Savigny, 1826)	Cattle Leech
			Haemopidae	*Haemopis indicus*	(Bhatia, 1940)	Blood-sucking Leech

Family: Haemopidae

***Haemopis indicus* Bhatia, 1940**

Location: Ashai Bagh, 34.114°N & 74.836°E, 3.iii.2022, coll. Niyaz Ali Khan.

Material examined: Image 6A–C; n = 6.

Diagnosis: The body of the leech is characterized by its remarkably soft and flabby texture; it appears thick for the majority of its length; gradually tapering towards both ends; the ventral surface is relatively flat; the dorsal surface is broadly arched; the posterior sucker is small and lacks strength; leech displays a dark colouration without any distinct markings (Image 6A);

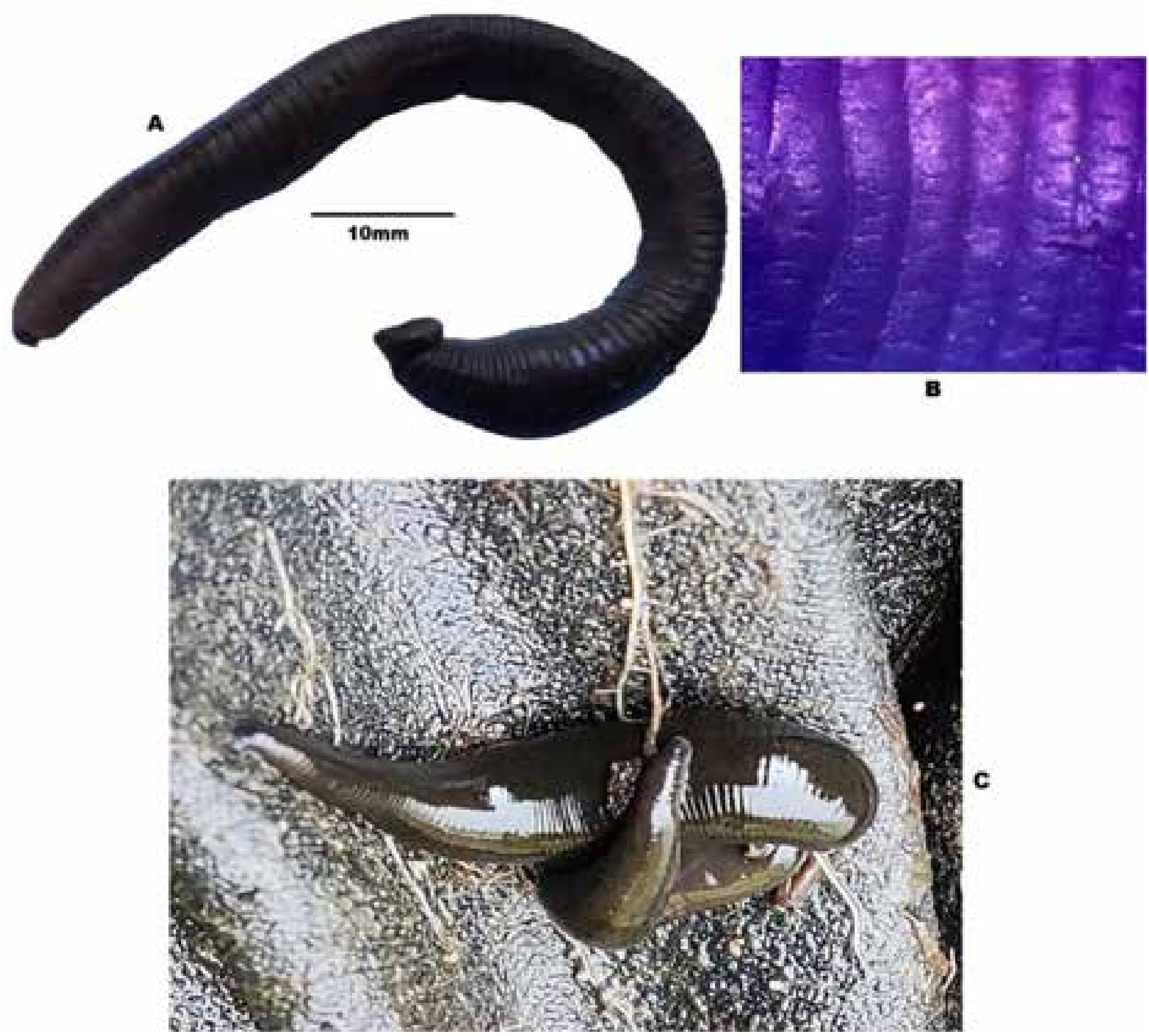

Image 6. Leech fauna of Dal Lake: A—dorsolateral view of *Haemopis indicus* | B—position of male and female gonopores | C—dorsal view of live specimens. © Niyaz Ali Khan.

the arrangement of the five pairs of eyes follows the typical pattern; fourth eye separated from the third by a single annulus; fifth eye separated from the fourth by two annuli; gonopores are separated by approximately five and a half annuli (Image 6B).

Habitat: *Haemopis indicus* also known as barrowing leech was mainly found attached to submerged articles in stagnant water bodies or nearly stagnant water rich in organic matter and vegetation.

Distribution: The species has been mostly reported in Jammu and Kashmir, India (Chandra 1991; Mir et al. 2024).

During the present study, a total of nine taxa belonging to the class Hirudinea were identified on the basis of morphological characteristics like colour, size and shape, number and position of eyes, papillation, number of annulations, and position of male and female gonopores (Table 1). The taxa identified were *Alboglossiphonia weberi*, *A. heteroclita*, *Glossiphonia complanata*, *Helobdella stagnalis*, *Hemiclepsis marginata asiatica*, *Theromyzon* sp., *Erpobdella octoculata*, *Poecilobdella granulosa*, and *Haemopis indicus*. As per earlier record, Bhatia (1939) described and reported *Theromyzon mathai* from Kashmir which is morphologically similar to *Theromyzon* sp. collected during the current study except the latter possesses four annuli between male and female gonopore instead of three annuli. The collected specimen resembles more to the European species *Theromyzon tessulatum* but it still needs confirmation based on the comparative studies with the closer species of *Theromyzon* sp. The paper presents the first photographic documentation of aquatic leeches occurring in Dal Lake. This study redescribed the leech species that were previously recorded in the valley. In contrast to the previous species found in the valley, most of the species are found in Dal Lake and many other species have no records. Based on existing records, there have been a total of 32 known leech species documented in Jammu and Kashmir (Mandal et al. 2022). To verify the species richness and specifically identify any new species, it is necessary to conduct proper surveys in the water bodies of the valley to overcome the fragmented and scanty record of the previous two decades. The current knowledge of leech diversity in Kashmir is far from being a comprehensive study and needs detailed surveys for complete documentation.

CONCLUSION

The present study provides knowledge about the taxonomic description, habitat, and distribution of freshwater leech fauna from the Kashmir Himalaya. A total of nine species belonging to four families of class Hirudinea were recorded and documented. Six species were reported from the family Glossiphonidae while single species were reported each from the families Hirudinidae, Erpodellidae, and Haemopidae. As per the literature and present status, the habitat of leech fauna has been disturbed due to growing poor water quality and shrinkage of freshwater water bodies. The present study has been conducted to address the taxonomic record of leech fauna in Dal Lake of Kashmir Himalaya.

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ARTICLE

First report of five monogonont rotifers from Jammu, J&K UT, India, with remarks on their distribution

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Abstract: Rotifers are microscopic metazoans which are generally predominant in freshwater ecosystems both in terms of species richness and species abundance. Despite their small size, they are crucial in maintaining ecological balance. In the present investigation, plankton samples collected during February 2019–January 2021 from two lentic water sources of Jammu region of Jammu & Kashmir revealed 58 species of rotifers belonging to 16 families, among which five species of monogonont rotifers from three genera were recorded to be the first reports from this region. These include three species from family Lecanidae: *Lecane arcula, L. inermis, L.* (*Monostyla*) *unguitata*; one species from family Brachionidae: *Anuraeopsis coelata*; and species *Pompholyx sulcata* of family Testudinellidae. Among these five monogonont species, *Anuraeopsis coelata* shows pantropical distribution, *Lecane unguitata* is a palaeotropical species, while other three are cosmopolitan in occurrence. Furthermore, comments are made on the diagnosis, seasonality, biogeographical, and ecological distribution of these species.

Keywords: Abundance, first reports, freshwater invertebrates, Jammu and Kashmir, Lecanidae, morphology, physico-chemical parameters, rotifers, seasonal distribution, Zooplankton.

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Author contributions: Nidhi Sharma—carried out the fieldwork, sampling, species identification, data collection, analysis & interpretation and manuscript writing. Sarbjeet Kour—study design, supervision and guidance in sample collection, careful examination and confirmation of identified species, thorough checking, and final approval to the manuscript. Aayushi Dogra—data analysis, intellectual input, review and Editing

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INTRODUCTION

Rotifera are unsegmented, bilaterally symmetrical invertebrates commonly known as 'wheel animalcules' which form an important constituent of freshwater zooplankton and an integral link of aquatic food chain (Sharma 1998). They can be planktonic, semi-planktonic or sessile, and are identified by the presence of an anterior ciliary apparatus, the corona, and a specialized muscular pharynx or mastax containing complex jaws, the trophi (Shiel 1995). Nearly 2,500 species of this phylum have been described from all over the world. Earlier, the taxon was divided into two classes, Monogononta and Digononta (Pennak 1978). Wallace et al. (2019) described two classes Pararotatoria and Eurotatoria under this phylum which are further divided into subclasses Seisonoidea (Pararotatoria) and Bdelloidea & Monogononta (Eurotatoria), respectively. Monogononta include rotifer genera which are mostly free living, but few are also parasitic and as the name suggests, all possess a single gonad. It is the largest group of rotifers composed of more than 1,500 species, spread over 30 families and more than 100 genera globally. Since Anderson's initial taxonomic survey in 1889, Rotifera have been documented from a variety of locations in India. Based on the current evaluation of rotifer biodiversity of India, 434 Rotifera species (~24% of global record), representing 25 families and 68 taxa, considered to be known from the country, among which 396 species of monogonont rotifers belonging to 22 families and 61 genera have been validly described.

The Jammu & Kashmir UT, located in the Himalayan biodiversity hotspot, is blessed with various water bodies including Ramsar sites, floodplain wetlands, lakes, and ponds that provide excellent opportunities to study the biodiversity of aquatic metazoans, particularly that of rotifers. Sharma & Sharma (2018) have given a systematic list of 173 rotifer species (40% Indian record) from J&K and 140 species from Kashmir valley in particular, among which they recorded 25 first reports from northwestern India. Jammu region of J&K lies at the foothills of Shivalik range of Himalaya which is to its north, while northern plains lie to its south. It has a humid subtropical climate and is an abode to many freshwater lotic & lentic sources like rivers, lakes, and ponds. Among these aquatic ecosystems, the small ponds are significant by being large repository of microfaunal biodiversity.

Investigations on rotifer diversity from different regions of Jammu division have been contributed by Jyoti & Sehgal (1979), Kumar et al. (1991), Kour (2006), Shvetambri (2007), Slathia & Dutta (2008), Sharma et al. (2013). However, the water bodies of Jammu plains have not been fully explored due to which regional data on this important fauna is insufficient. Thus, the present communication, a part of a study to document Eurotatoria diversity from two lentic sources of Jammu plains, provides first record of five monogonont rotifer species from Jammu region and it incorporates brief taxonomic description, illustration, seasonality, biogeography, and ecological distribution of the examined species. Present study extends the distribution range of these monogonont rotifer species to this region of northwestern India and this data on regional diversity will further make addition to the freshwater biodiversity of Jammu & Kashmir.

MATERIAL AND METHODS

Study Area

The present study is a part of limnological investigation of two small lentic water bodies; Kanjak di Chhapadi (Station I) and Bhatyari pond (Station II), located in Bishnah region (32.6108 ^{0}N, 74.8595 ^{0}E) of Jammu, J&K (Figure 1; Image 1) . The former is a sacred pond located in the vicinity of a temple of Hindu deity named as 'Kanjak Darwaar'. This is a subtropical and perennial pond situated amidst the agricultural fields. This pond is roughly rectangular in shape with concrete embankment and it is spread over an area of 2,583.38 m^2. This pond is inhabited by fish *Puntius sophore* and it is believed to have great religious and therapeutic significance (Image 1a). Bhatyari pond is a roadside natural pond, surrounded by human habitation on one side and agricultural fields on the other sides. It is spread over an area of about 3,843.36 m^2 and is a roughly rectangular pond having soft, muddy embankment surrounded by weeds. The weed *Alternantheria* sp. can be seen growing here. People use its water for irrigation (Image 1b).

Methods

Sampling was done for a period of two years (February 2019–January 2021) on a monthly basis. Water samples were collected in clean polyethylene bottles to analyse their physico-chemical parameters as per standard methods specified in Adoni (1985) and APHA (1992). Sixteen abiotic parameters were measured, viz., air temperature, water temperature, pH, transparency, free carbon dioxide (FCO_2), dissolved oxygen (DO), chlorides, calcium, magnesium, carbonates, bicarbonates, total hardness, biological oxygen demand (BOD), sulphates, nitrates, and phosphates. Plankton samples were collected by filtering 50l of water sample through plankton

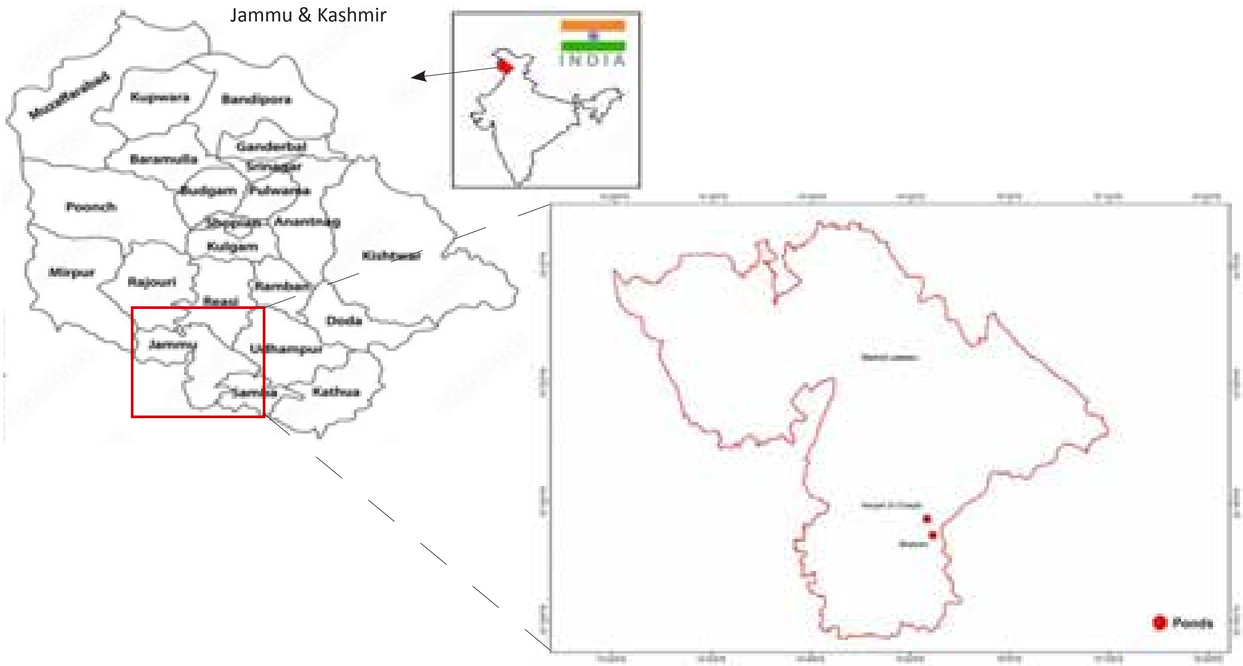

Figure 1. Map of sampling sites.

Image 1a. Station I (Kanjak di Chhapadi). © Nidhi Sharma.

Image 1b. Station II (Bhatyari pond). © Nidhi Sharma.

net (mesh size 40 µm) made of bolting silk (no. 25). The filtered sample was concentrated to 20 ml volume and preserved with 4% formalin. The preserved samples were examined under an Olympus compound light microscope (model CH20i). Measurements were taken with the help of an ocular micrometer and drawings were made with the help of glass type camera Lucida & Rotring Germany 1928 pens. The rotifer taxa were identified by following standard identification keys provided by Edmondson & Winberg (1971), Pennak (1978), Battish (1992), Segers (1995, 2012), and Sharma (1998).

RESULTS AND DISCUSSION

Group Rotifera was represented by 25 genera and 58 species (33.52% of total record from J&K) belonging to 16 families. Presently, highest number of rotifer taxa were reported at station II, i.e., 49 species. Station I, however, was characterized by the presence of 35 rotifer species during the study period (2019–2021). Of the total 16 families reported, family Brachionidae contributed the maximum species, i.e., 16 species followed by family Lecanidae with 15 species. According to Dumont (1983), dominance of Lecanidae and Brachionidae families is typical of tropical environment. Genera *Lecane* outnumbered the genus *Brachionus* in terms of species richness by contributing 15 species to the total rotifer fauna, whereas genus *Brachionus* was represented by eight species. The species rich status of genus *Lecane* in tropical waters has also been postulated by Arora & Mehra (2003). *Keratella tropica* and *Brachionus calyciflorus* had the maximum annual count at station I, whereas *B. rubens* and *B. falcatus* were the largest contributors to population abundance at station II.

In this study, we identified three lecanid species and two planktonic genera each from families Brachionidae and Testudinellidae which were previously unrecorded from the region under study. Lecanids are of major biogeographical interest and they particularly thrive in littoral habitats of varying environments like freshwater & saline water (Segers 1996; Khaleqsefat et al. 2011). The genus *Anuraeopsis* is one of the seven genera belonging to family Brachionidae which form an important component of planktonic rotifers. Genera *Pompholyx*, one of the two genera belonging to family Testudinellidae also includes pelagic species.

Systematic list of first records from Jammu waters
Phylum: Rotifera Cuvier, 1817
Class: Eurotatoria De Ridder, 1957
Subclass: Monogononta Plate, 1889
Order: Ploima Hudson & Gosse, 1886
Family: Brachionidae Ehrenberg, 1838
Genus: *Anuraeopsis* Lauterborn, 1900
1. *Anuraeopsis coelata* (De Beauchamp, 1932)

Family: Lecanidae Remane, 1933
Genus: *Lecane* Nitzsch, 1827
2. *Lecane arcula* (Harring, 1914)
3. *Lecane inermis* (Bryce, 1892)
4. *Lecane unguitata* (Fadeev, 1925)

Family: Testudinellidae Harring, 1913
Genus: *Pompholyx* Gosse, 1851
5. *Pompholyx sulcata* (Hudson, 1885)

Short description of first reports

1. *Anuraeopsis coelata* (De Beauchamp, 1932)

Lorica ellipsoidal elongated. Two longitudinal ridges run parallel to each other on the dorsal plate that get united at the posterior end forming a U shape. Anterior dorsal margin with a broad median sinus and is without any spines or serrations. Three marginal facets present at the posterior end that continue in long lateral facets on each side (Image 2A&B)

Differential diagnosis: The present specimens differ from those of West Bengal (Sharma 1998) with respect to the distal end of dorsal surface in which the longitudinal ridges terminate into a single short ridge forming a Y shaped structure, whereas in the present specimens, U shaped structure ends into a terminal plate.

2. *Lecane arcula* (Harring, 1914)

Lorica little longer than broad; external angles of ventral plate raised into two small antero-lateral spines. Clear surface markings on dorsal plate. Ventral plate oval and slightly narrower than dorsal plate. Posterior segment is small and rounded. Toes with small, slightly out curved claws (Image 3A&B).

Differential diagnosis: It is distinguished from very similar species *Lecane aculeata* by its relatively shorter lorica and antero-lateral spines.

3. *Lecane inermis* (Bryce, 1892)

Lorica is soft, flexible, and elongated with indistinguishable dorsal and ventral plates. Anterior margins nearly straight, without any spines at anterior external angles. Toes are small and these terminate into long and pointed claws (Image 4A&B).

Differential Diagnosis: *L. inermis* is one of the 14 illoricated *Lecane* species among which it shows close similarity to *L. elegans* and *L. margalefi* (Yang & Min 2021). It may be recognized from these two congeners, by its toes with comparatively long claws (Segers 1995).

4. *Lecane unguitata* (Fadeev, 1925)

Lorica almost circular with relatively small anterior opening. Anterior margin of dorsal plate is straight; antero-ventral margin with a distinct median sinus and rounded external corners. Dorsal plate truncate posteriorly and smaller than ventral plate. Single toe having two pointed and long pseudoclaws (Image 5A&B).

Differential diagnosis: *Lecane unguitata* can be misidentified with *Lecane stephensae*, but the latter has short toe and pseudoclaws (Segers 1995; 1996).

5. *Pompholyx sulcata* (Hudson, 1885)

Lorica oval/egg shaped, not dorso-ventrally flattened; four longitudinal grooves divide it into four lobes in cross-section. Anterior end produced into a lobe-like projection dorsally; a shallow median sinus on ventral margin is flanked by two lateral elevations. Eggs attached on retractile threads passing through the cloacal aperture at the posterior end (Image 6A&B).

Differential diagnosis: *Pompholyx sulcata* can be distinguished from *Pompholyx complanata* by its egg

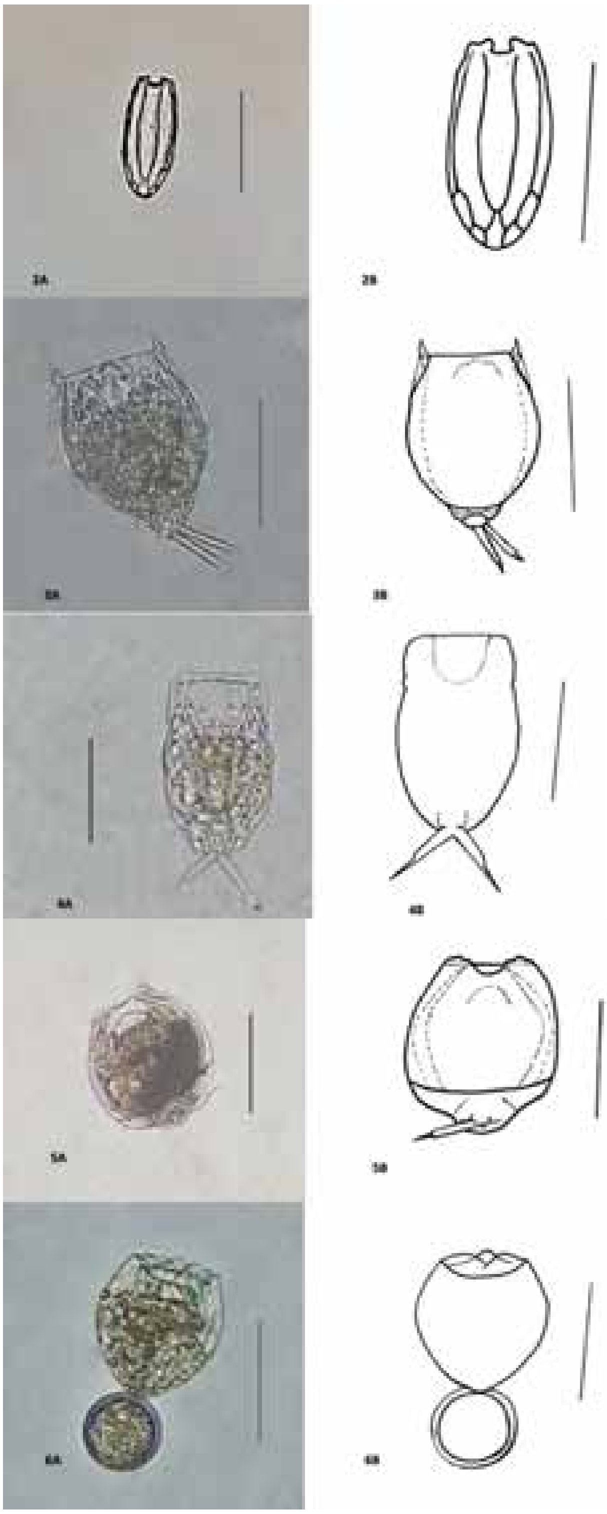

Image 2–6. 2—Illustrations of *Anuraeopsis coelata* (De Beauchamp, 1932): A—Image, B—Line drawing | 3—Illustrations of *Lecane arcula* (Harring, 1914): A—Image, B—Line drawing | 4. Illustrations of *Lecane inermis* (Bryce, 1892): A—Image, B—Line drawing | 5—Illustrations of *Lecane unguitata* (Fadeev, 1925): A—Image, B—Line drawing | 6—Illustrations of *Pompholyx sulcata* (Hudson, 1885): A—Image, B—Line drawing. Scale Bar: 50 µ.

shaped lorica, while the latter has a circular body.

Seasonal and spatial distribution

Tables 1 and 2 highlight the mean & standard deviation and range of values of 16 abiotic parameters of sampling stations. The water bodies had air temperature ranging from 6.5–35 ˚C, water temperature 8–34 ˚C, pH ranging 6.1–9.5 and a dissolved oxygen value ranging 2.88–11.2 mg/l throughout the study period. *Anuraeopsis coelata* showed restricted distribution only to station I. The occurrence of *Lecane unguitata* and *L. arcula* was restricted to station II; while *Pompholyx sulcata* and *L. inermis* were observed at both the stations. Seasonally, *Anuraeopsis coelata* was observed in summer, monsoon, and post-monsoon (25–29 ˚C) with maximum density during monsoon season. *Pompholyx sulcata* was observed during summer (25–28 ˚C) and winter months (9–11.5 ˚C) with no appearance of species in intermediate seasons. All the *Lecane* species were represented by few numbers of individuals (Table 3) at each station. *Lecane unguitata* showed its presence in summer and post-monsoon, *Lecane inermis* was present during summer to post-monsoon period, while *Lecane arcula* showed rare occurrence, and was observed only once in post-monsoon period (18˚C).

Biogeographical distribution

Many of the presently recorded species of rotifers are cosmopolitan in distribution. But among the species reported for the first time, *Anuraeopsis coelata is* a pantropical species and from India, it has been reported from Assam, West Bengal, Odisha, and Gujarat. This species has not been listed in inventory of Sharma & Sharma (2018) which marks its first ever record from entire J&K UT. *Lecane arcula* is tropicopolitan in distribution; it has been earlier recorded from Haryana, Andhra Pradesh, West Bengal, Kashmir, and Mizoram.

Both *Pompholyx sulcata* and *Lecane inermis are* cosmopolitan species. Indian records of *Pompholyx sulcata* include those from West Bengal, Assam, Odisha, Karnataka, Punjab, Kashmir, Ladakh, and Nagaland. *Lecane inermis* has been reported from Asian countries like Cambodia, China, India, Thailand, and Laos. From India, it has shown its records from Kashmir, West Bengal, and Meghalaya. *Lecane unguitata*, according to Segers (1996), is a biogeographically interesting paleotropical species common in tropical and subtropical environment of Eastern Hemisphere. This species is widely distributed in India and has been earlier reported from the states of West Bengal, Assam, Meghalaya, Tamil Nadu, and Gujarat.

Table 1. Annual mean values and ranges of various physicochemical parameters at the two stations from February 2019 to January 2020.

	Parameter	Station I		Station II	
		Range	Mean ± SD	Range	Mean ± SD
1	Air temperature (˚C)	6.5–35	16.95 ± 9.65	7–34	23.66 ± 8.24
2	Water temperature (˚C)	8–34	17.16 ± 8.20	9–33	23.23 ± 7.46
3	pH	7.5–9.3	8.3 ± 0.44	6.8–8.7	7.86 ± 0.56
4	Transparency (cms.)	19–48.5	30.72 ± 10.84	9–33	21.66 ± 9.27
5	Dissolved Oxygen (mg/l)	3.2–9.6	5.11 ± 1.87	2.88–10.24	5.82 ± 2.34
6	Free Carbon Dioxide (mg/l)	0–14.96	8.88 ± 4.69	0–9.12	6.85 ± 1.66
7	Carbonate (mg/l)	0–18	11.37 ± 5.79	0–13.2	9.2 ± 4.99
8	Bicarbonate (mg/l)	92.72–244	171.20 ± 41.47	158.6–280.6	216.04 ± 37.12
9	Chloride (mg/l)	18.01–39.04	24.85 ± 7.81	56.06–82.09	65.98 ± 8.15
10	Calcium (mg/l)	8.41–31.95	19.63 ± 8.16	8.41–44.57	29.36 ± 12.67
11	Magnesium (mg/l)	2.55–16.81	10.47 ± 4.09	6.97–23.20	15.40 ± 5.74
12	Total Hardness (mg/l)	42–128	92.2 ± 27.30	52–194	136.75 ± 53.85
13	BOD (mg/l)	1.06–5.41	2.34 ± 1.89	0.32–2.18	1.17 ± 0.55
14	Sulphate (mg/l)	2.59– 20.38	9.83 ± 5.82	5.73–15.59	9.52 ± 3.03
15	Phosphate (mg/l)	0.019–0.207	0.087 ± 0.05	0.010–0.256	0.08 ± 0.06
16	Nitrate (mg/l)	0.59–2.54	1.39 ± 0.75	0.051–1.88	0.78 ± 0.65

Table 2. Annual mean values and ranges of various physicochemical parameters at the two stations from February 2020 to January 2021.

	Parameter	Station I		Station II	
		Range	Mean ± SD	Range	Mean ± SD
1	Air temperature (˚C)	11.5–34	22.79 ± 7.34	10–35	22.33 ± 7.69
2	Water temperature (˚C)	10–29	20.83 ± 6.78	10–30	21.62 ± 6.91
3	pH	7.1–9.2	8.20 ± 0.58	6.1–9.5	7.68 ± 1.05
4	Transparency	24.5–54	40.20 ± 9.61	13.5– 30.5	22.33 ± 5.64
5	Dissolved Oxygen (mg/l)	2.88–10.56	5.35 ± 2.17	3.20– 11.2	5.19 ± 2.25
6	Free Carbon Dioxide (mg/l)	0–26.4	8.51 ± 9.83	0–28.16	14.29 ± 7.94
7	Carbonate (mg/l)	0–22.8	16.9 ± 5.09	0– 35.16	20.54 ± 10.10
8	Bicarbonate (mg/l)	138–221.3	170.97 ± 22.52	150.2– 239.45	192.03 ± 28.53
9	Chloride (mg/l)	18.52–31.03	24.69 ± 3.61	49.05– 87.03	62.55 ± 15.28
10	Calcium (mg/l)	16.39–37.84	27.13 ± 6.95	10.09– 32.79	21.52 ± 6.18
11	Magnesium (mg/l)	8.16–19.31	13.81 ± 3.04	9.13– 20.42	14.72 ± 4.23
12	Total Hardness (mg/l)	84–154	124.61 ± 22.55	66– 146	114.38 ± 24.50
13	BOD (mg/l)	0.22–3.14	1.20 ± 0.89	0.81– 3.97	1.99 ± 1.03
14	Sulphate (mg/l)	9.03–21.68	15.58 ± 3.79	11.46– 24.04	17.52 ± 3.66
15	Phosphate (mg/l)	0.022– 0.212	0.08 ± 0.05	0.025– 0.264	0.08 ± 0.06
16	Nitrate (mg/l)	0.49–2.42	1.10 ± 0.60	0.011– 1.93	0.67 ± 0.64

Ecological distribution

Anuraeopsis and *Pompholyx* are two planktonic-bacterivorous genera. *Anuraeopsis coelata* occured only during warmer months at a temperature above 25˚C and at alkaline pH above 7.9. Segers (2007) suggested that all *Anuraeopsis* species are warm water inhabitants. It is considered to be a eutrophic indicator (Nogrady 1983) and presently, it was found coexisting with other

Table 3. Monthly quantitative abundance of rotifers (Organism/litre) during the study period.

Rotifer species	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Mean
Station I (2019–2020)													
Anuraeopsis coelata	-	-	-	7.28	-	-	9.84	-	0.64	-	-	-	**5.92**
Pompholyx sulcata	-	-	-	1.28	-	-	-	-	-	-	-	-	**1.28**
Station I (2020–2021)													
Anuraeopsis coelata	-	-	6.34		0.06	0.72	0.72	-	-	-	-	-	**1.96**
Lecane inermis	-	-	-	-	-	0.24	-	-	-	-	-	-	**0.24**
Station II (2019–2020)													
Lecane unguitata	-	-	-	-	-	0.32	-	-	0.72	0.16	-	-	**0.4**
Pompholyx sulcata	-	-	-	10.32	-	-	-	-	-	-	7.52	0.88	**6.24**
Station II (2020–2021)													
Lecane inermis	-	-	-	-	-	0.48	0.16	0.08	0.67	1.76	-	-	**0.63**
Lecane arcula	-	-	-	-	-	-	-	-	-	0.24	-	-	**0.24**
Lecane unguitata	-	-	-	0.16	-	-	-	-	-	-	-	-	**0.16**

eutrophy indicator rotifers like *Brachionus calyciflorus*, *B. angularis*, *Filinia longiseta*, *Keratella cochlearis*, *F. tecta*, and Cladocera species *Chydorus sphaericus. Pompholyx sulcata* is a detritivorous species (Ejsmont-Karabin et al. 2020; Gilbert 2022). This confirms its high abundance at station rich in vegetation which after decaying provided them with lot of detritus and periphyton. It is a planktonic species which most commonly inhabits meso-eutrophic and alkaline eutrophic waters. The association of bacterivorous species like *Anuraeopsis fissa* and *Pompholyx sulcata* with eutrophication has been suggested earlier by Gannon & Stemberger (1978) and Pejler (1983). Ejsmont-Karabin et al. (2020) considered it a warm stenothermic species owing to its common occurrence in summer. In the present study, it was equally abundant during both summer (10.32 ind./l in May 2020) & winter (7.52 ind./l in December) and showed its abundance during extremes of environmental parameters like temperature (9–28 ˚C), pH (6.1–8.5), transparency (10.5–33 cm), and dissolved oxygen (3.20–8.64 mg/l); which also indicates its wide tolerance to variable environmental conditions. It co-occurred with rotifer *Platyias patulus*, Cladocera species *Diaphanosoma senegal*, *Ceriodaphnia cornuta,* and copepods *Phylodiaptomus blanci* & *Cryptocyclops bicolor* in the present investigation.

Lecanids are non-planktonic rotifers that prefer littoral-periphytic zone. They are usually not restricted to any specific macrophyte but are found to be euryecious in periphytic environment. The genus *Lecane* Nitzsch, 1827 of family Lecanidae is one of the largest and most species rich genera within the subclass Monogononta comprising nearly 200 species (Jersabek & Leitner 2013; Yang & Min 2021). Scarcity in the population of *Lecane* species observed in the present study might be attributed to insufficiency of periphytic collections. *Lecane arcula*, an oligotrophy indicator species (Yin et al. 2018) was observed to be a rare species that occurred only once at station II with a very low population density of 0.24 ind./l in our collection. Present investigation revealed higher nitrate concentration at station I than station II. Being an oligotrophy indicator (Yin et al. 2018), presence of *L. arcula* only at station II can be attributed to comparatively low nitrate concentration of this station than station I. But very low population count of this species can be due to the relatively high nutrient status of this pond which might not be tolerable & favorable for its growth and reproduction. Segers (1995) categorized it as a warm stenotherm species. *Lecane inermis,* a eurythermal species, was recorded between a slightly acidic to alkaline pH range of 6.8–8.8 and a temperature ranging from 18–30 ˚C. It co-existed with *Lecane curvicornis* at one of the stations while it was present together with *L. arcula* and *L. bulla* at other station. Donner (1970) suggested that it can tolerate wide range of temperature as well as salinity as he detected it in extreme environments of thermal springs and at geyser temperature of 62.5˚C. Glime (2017) suggested its general preferred pH to be 7.3 while Sharma (1987) also recorded it in acidic waters (5.6–6.5). Report of *Lecane arcula* and *L. inermis* from Kashmir Himalayan floodplains (Sharma & Sharma 2018) formed their first ever record from northwestern India. *L. unguitata* exhibited preference for warm weather and was accompanied by other congeneric species such as *L. bulla*, *L. curvicornis*, *L. ludwigi,* and *L. luna*.

CONCLUSION

The results obtained during the present investigation demonstrated high rotifer richness in two lentic water bodies of Jammu with a record of 58 species in which cosmopolitan species formed the major component. Family Brachionidae was the most species rich followed by Lecanidae. Of the total species recorded, five monogonont species representing families Lecanidae, Brachionidae, and Testudinellidae formed the first record from the region; out of which two species are cosmopolitan, one palaeotropical, one pantropical, and one species is tropicopolitan. Seasonally, all these species were present during post-monsoon season except *Pompholyx sulcata*, which showed its presence in summer and winter. The three *Lecane* species recorded in the present study were noticed to be low in abundance. Furthermore, ecological distribution highlighted *Anuraeopsis coelata* and *Pompholyx sulcata* as eutrophic indicator species.

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ARTICLE

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Diversity of vascular epiphytes on preferred shade trees in tea gardens of sub-Himalayan tracts in West Bengal, India

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Abstract: Tea gardens are the main economic backbone of the Terai & Dooars region and intermingle with forest areas of northern Bengal in India. The study aims to explore the vascular epiphytic diversity and their zone-wise assemblage pattern on 10 dominant shade trees in the tea gardens. Four years (March 2018–September 2022) of surveys recorded a total of 6,704 individuals that belong to 74 species of 20 families of vascular epiphytes. Considering life forms, the majority of them are holoepiphytes (62.16%), followed by hemiepiphytes (20.27%), accidental epiphytes (13.51%), and facultative epiphytes (2.7%). The predominantly recorded families are Orchidaceae (21 spp.), Araceae (11 spp.), Apocyanaceae with six species, and Piperaceae & Pteridaceae with three species each. *Albizia lebbeck* (L.) Benth. hosts a maximum of 737 vascular epiphytic assemblages (VEAs), whereas, *Gmelina arborea* Roxb. has a minimum of 450 VEAs. Vascular epiphytes were also studied for their host specificity using interpolation and extrapolation analyses. The findings of the study show that vascular epiphytic assemblage upon the shade trees of the tea garden has a remarkably high potential to contribute toward epiphytic diversity of this region other than forest and contribute significant ecological impacts.

Keywords: Diameter at breast height, Orchidaceae, Shannon-Weiner index, vascular epiphytic assemblages, vertical distribution, zonation pattern.

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Author contributions: RC—contributed to data collection, field visits, sampling, data analysis, map making, and manuscript preparation. MC—contributed to data analysis, taking photographs, graph making, and study site explorations

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INTRODUCTION

Vascular epiphytes are a conspicuous and highly diverse group in nature (Benzing 1987). Epiphytes are found to grow at the base of tree trunks up to as high as 50 m or even higher favouring the discussion of canopy access, ecological role, ecophysiology, and conservation of epiphytes. The major groups with epiphytic genus are ferns, gymnosperms, monocots (especially orchids, bromeliads, and aroids), and dicots. Epiphytes are not restricted to living hosts only, instead, they can also grow on the non-living substrate with adequate moisture content and favourable environmental conditions (Madison 1977). They are a significant component of tropical and subtropical forests, not just because of their diverse species, but also for their huge biomass accumulation (Gentry & Dodson 1987; Benzing 1990; Nadkarni 1994; Isaza et al. 2004). In relation to their habitat, they are not only part of forest flora but also an inevitable part of the urban localities, and tea gardens of this region. The tropical climate of the West Bengal supports more than 300 tea gardens (Terai, Dooars, and Darjeeling) according to the Tea Board of India mainly due to appropriate rainfall, soil character (clay to sandy loam in texture), and high humidity present in this region (https://www.teaboard.gov.in/ as retrieved on 30 July 2023). The tea-growing areas of this region range 90–1,750 m with annual rainfall of around 350 cm. These tea gardens play a significant role in the economy of this region and also support enriching the green coverage of the area. The trees adjacent to the tea gardens show immense epiphytic diversity and are an important part of increasing tea productivity under favourable environmental conditions by conserving soil from erosion during heavy rainfall (Rahman et al. 2020). The tree also enriches soil fertility and organic matter content through leaf litter and supports diverse flora and fauna (Visser 1961; Hadfield 1974, Mohotti 2004). A total of 45 species of preferred shade trees representing 34 genera of 15 families were recorded from the tea gardens of Terai and Dooars out of which Fabaceae shows the highest number of preferred shade trees (Chowdhury et al. 2016). The major shade trees of this region are *Albizia odoratissima* (L.f.) Benth., *Albizia chinensis* (Osbeck) Merr., *Albizia lebbeck* (L.) Benth., *Albizia procera* (Roxb.) Benth., *Dalbergia sissoo Roxb.* ex DC., *Erythrina variegata* L., and *Melia azedarach* L. (Barua 2007). Therefore, the present study attempts to analyse and record the vascular epiphytic diversity in the tea gardens of the study area to understand the present ecosystem for future conservation.

MATERIAL AND METHODS

Study area

The present study was conducted in the tea gardens of Terai & Dooars of West Bengal, which are spreading through the districts of Jalpaiguri, Alipurduar, some parts of Coochbehar, and the plains of Darjeeling (Figure 1). The study area is located at 25.944–26.606 °N and 89.899–88.786 °E (Terai) 26.278–26.999 °N and 88.066–89.880 °E (Dooars) with the altitude range varying 80–150 m (Chowdhury 2015). The entire area has many rivers and rivulets like Teesta, Torsa, Jarda, Raidak, Jaldhaka, and Sankosh, coming from the Darjeeling, Sikkim Himalaya, Nepal and Bhutan. The protected areas of this region is predominated by tropical evergreen forests, namely: Chapramari Wildlife Sanctuary, Gorumara National Park, Neora Valley National Park, Jaldapara National Park, and Mahananda Wildlife Sanctuary. Moreover, the average rainfall of this region is 120–350 mm with a relative humidity of 99.4%, and temperature ranges from 6.5–35 °C as provided by CTRI, Dinhata. The major tea gardens of this region are the Matigara Tea Garden, Gaya Ganga Tea Garden, Hansqua Tea Garden, Dagapur Tea Garden, Gulma Tea Garden, Denguajhar Tea Garden, Damdim Tea Garden, Bagrakot Tea Garden, Batabari Tea Garden, Dyna Tea Garden, and Dalgaon Tea Garden (Table 1).

Data collection

Extensive taxonomical explorations in different tea gardens of this region were done from March 2018 to September 2022 at proper intervals of time in pre-monsoon (March–May), monsoon (July–September), and post-monsoon (November–January) seasons. A vegetation survey was done by random sampling method, where host species were chosen randomly with exclusive characters like DBH (Freiberg 2000; Nieder et al. 2001) to make a checklist of the vascular epiphytes of the tea gardens. The collected specimens were identified in the field, and the unidentified specimens were preserved following standard Herbarium techniques (Paul et. al 2020). Plants were identified using relevant identification keys (Prain 1903; Noltie 2000; Singh et al. 2005) and digital repositories (POWO). All the identified voucher specimens were deposited at the North Bengal University herbarium (NBU). During the survey, binoculars (Nikon ACULON A211 10x50) were used for the highly developed canopies and in some areas ladders (Image 1) or indigenous tree climbers were used (Tafa 2010). The vertical distribution of the epiphytes was recorded in five vertical tree zones following a zonation

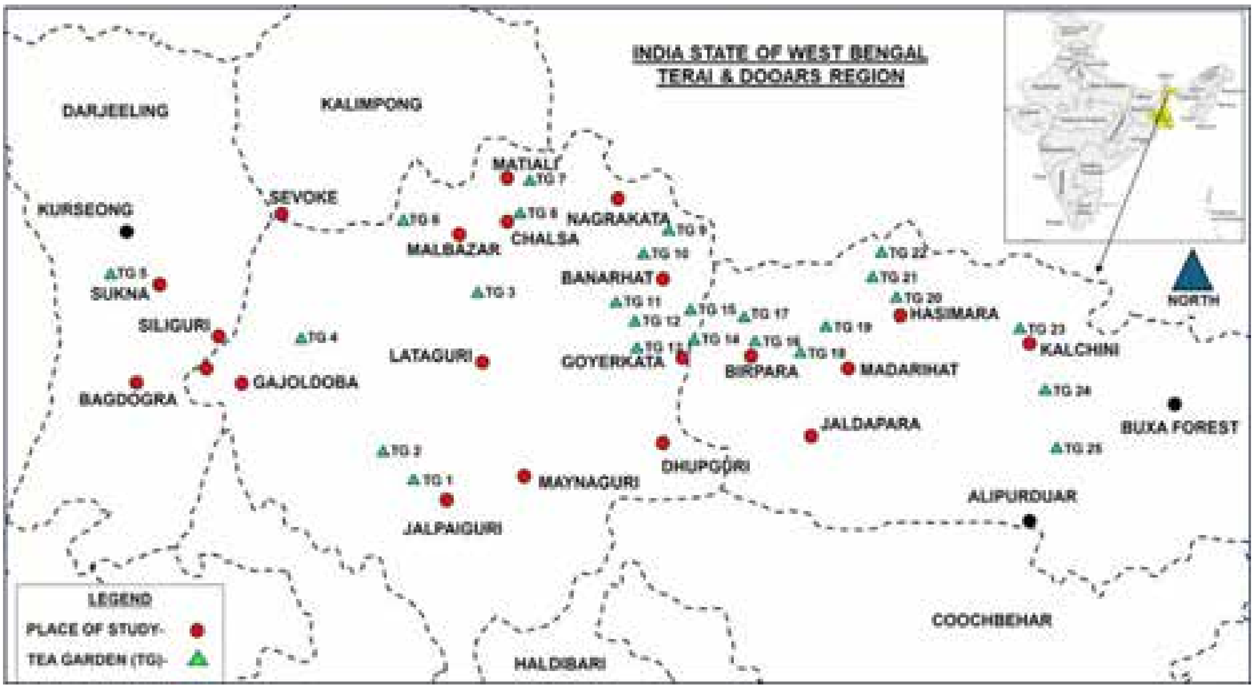

Figure 1. Map of study area showing some major tea gardens.
Abbreviations used: TG1—Denguajhar tea garden | TG2—Rangdhamali tea garden | TG3—Batabari tea garden | TG4—Anandapur tea garden | TG5—New Chumta tea garden | TG6—Damdim tea garden | TG7—Indong tea garden | TG8—Chalsa tea garden | TG9—Chamurchi tea garden | TG10—Palasbari tea garden | TG11—Moraghat tea garden | TG12—Banarhat tea garden | TG13—Goyerkata tea garden | TG14—Binnaguri tea garden | TG15—Haldibari tea garden | TG16—Birpara tea garden | TG17—Nangdala tea garden | TG18—Dumchi tea garden | TG19—Gopalpur tea garden | TG20—Malangi tea garden | TG21—Dalsingpara tea garden | TG22—Toorsa tea garden | TG23—Kalchini tea garden | TG24—Dima tea garden | TG25—Raja Bhatkaha tea garden.

scheme slightly modified after Johansson (1974). For photography, Nikon D5500 and Sigma 150–600 mm F5–6.3 DG OS HSM and Nikon D5600 18–45 mm, 300 mm were used.

Data analysis

The vertical distribution (Johansson 1974; Nadkarni 1994) of vascular epiphytes on phorophytes was studied by observing DBH (Diameter breast height) of the host trees ranging 1–7 m diameter of the tree trunk and VEA (Vascular epiphyte assemblages) on them were counted (Images 2a&b, 3).

Those epiphytes occurring in dense stands were counted as one individual (Johansson 1974; Barthlott et al. 2001). To understand the proper plant diversity of vascular epiphytic species, the Shannon-Weiner index (1948) was followed.

$$H = -\Sigma p_i(\ln p_i)$$

Where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations.

To predict the correlation between the two variables linear regression equation was used depending on which graph is extracted using IBM-SPSS 2022. A linear regression line has an equation of the form

$$Y = a + bX$$

where X is the explanatory variable and Y is the dependent variable. The slope of the line is b, and a is the intercept (the value of y when $x = 0$).

Accordingly, the zonation pattern on the (Figure 2) host is categorised into three zones: i) Basal zone (ZN1), from the ground to tree breast height; ii) Trunk (ZN2), to the first fork; and iii) Canopy, first branching/fork to the ultimate tip (ZN3; ZN4; ZN5). The vertical stratification method of Johansson (1974) was slightly modified by taking the entire trunk of the tree as Zone 1. The species were then classified based on their occurrence on host trees and their zone upon host for preference for proliferation (Mojiol et al. 2009). All the recorded species are summarised in Table 2 regarding their life forms (holoepiphytes: true epiphytes growing on host trees; hemi epiphytes: first grow as terrestrial plant later on adapt epiphytic life form; facultative: not true epiphyte can grow as terrestrial or as epiphyte, and accidental: true terrestrial plants accidentally grow upon host tree), status, zone preference, host preference, and distribution.

RESULTS

The present study recorded a total of 6,704 individuals that belonged to 74 species representing 45 genera of 20 families of vascular epiphytes. Among the collected species 46 species were holoepiphyte (62.16%), 15 species were hemiepiphyte (20.27%), 10 species were accidental epiphytes (13.51%), and two species were facultative epiphytes (2.7%). Orchidaceae was the most dominant family with 21 species (28%) belonging to 12 genera, while Araceae was the second dominant family with 11 species (15%) representing seven genera followed by Polypodiaceae with nine species (12.1%) representing nine genera, Apocyanaceae with six species (8.1%) representing two genera, Pteridaceae, Lycopodiaceae, Moraceae, Piperaceae with three species (4.05%), Smilacaceae, Dioscoreaceae, and Aspleniaceae with two species (2.7%). The remaining nine families had one species (1.35%) each. The species diversity of the vascular epiphytes for the study area is calculated to be H' = 3.88.

Vascular epiphytic assemblages on host trees

The dominant shade tree species recorded with vascular epiphytes were *Samanea saman* (Jacq.) Merr, *Albizia odoratissima* (L.f.) Benth., *A. lebbeck* (L.) Benth., *Ficus religiosa* L., *Alstonia scholaris* (L.) R.Br., *Artocarpus chama* Buch.-Ham., *Artocarpus heterophyllus* Lam., and *Mangifera indica* L. Whereas, other shade trees like *Bombax ceiba* L., *Baccaurea motleyana* (Müll.Arg.) Müll.Arg. and *Populus ciliata* Wall. ex Royle does not have vascular epiphytes. To explore host specificity, 10 dominant tree species from the study area were selected. The vascular epiphytic assemblages (VEA) on them were recorded. *Albizia lebbeck* (L.) Benth. (H2) with VEA of 737, *Albizia odoratissima* (L.f.) Benth. (H6) with 627 VEAs, *Ficus benghalensis* L. (H4) with 554 VEAs, *Artocarpus chama* Buch.-Ham. (H7) with 546 VEAs, *Dillenia pentagyna* Roxb. (H9) with 531 VEAs, *Alstonia scholaris* (L.) R.Br. (H5) with 489 VEAs, *Mangifera indica* L. (H1) with 486 VEAs, *Litsea glutinosa* (Lour.) C.B.Rob. (H10) with 465 with VEAs, *Swietenia mahagoni* (L.) Jacq. (H8) with 452 VEAs, *Gmelina arborea* Roxb. ex Sm. (H3) with 450 VEAs. Vascular epiphytic species richness, abundance, and composition were preferably high on these shade trees therefore, to assess whether differences in the number are affected by the different hosts calculated using interpolation and extrapolation analyses (Chao et al. 2014), which evaluate sample preference based on the dominant tree using iNEXT function in the iNEXT package (Hsieh et al. 2016). H1, H2, H5, H6, H7, H8, H9 & H10 had more than 50% sample coverage area of VEA.

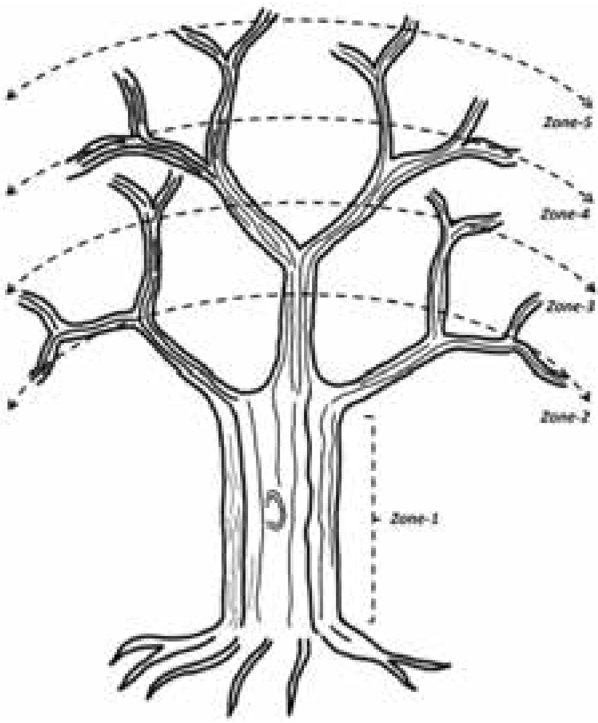

Figure 2. Diagrammatic representations of zones of distribution on the host tree (modification of Johansson ,1974).

Table 1. Major tea gardens with location and area of spreading on Terai & Dooars.

Tea gardens	Co-ordinates		Area (ha)
	Latitude (°N)	Longitude (°E)	
Kalchini tea garden	26.707	89.440	742.15
Matigara tea garden	26.711	88.386	142.09
Denguajhar tea garden	26.558	88.694	660.57
Batabari tea garden	26.840	88.796	299.59
Dyna tea garden	26.848	89.026	418.3
Kurti tea garden	26.926	88.935	417.93
Banarhat tea garden	26.798	89.043	634.21
Dalgaon tea garden	26.703	89.148	656.02
Bagdogra tea garden	26.690	88.307	262.28
Damdim tea garden	26.822	88.674	738.02
Chalsa tea garden	26.930	88.833	442.6
Chamurchi tea garden	26.850	89.061	493.22
Gayerkata tea garden	26.683	89.026	710.63
Moraghat tea garden	26.774	89.011	513.47
Haldibari tea garden	26.746	89.015	851.24
Red bank tea garden	26.849	89.046	361.63
Anandapur tea garden	26.756	88.664	402.25
Bagrakote tea garden	26.865	88.854	488.89
Matelli tea garden	26.949	88.815	730.08
Odlabari tea garden	26.828	88.617	484.18
Binnaguri tea garden	26.763	89.056	602.56

Image 1. Field studies with ladder climbing technique.

In comparison, H4 and H3 had 17% or less than sample coverage (Figure 3).

Vertical stratification

The vertical stratification studies from basal/trunk to top most dense canopies showed variation. The epiphytic species were higher in number in the middle canopy (ZN2, ZN3, and ZN4) and then declined toward the top canopies (ZN4 and ZN5). In the study, ZN5 had the least vascular epiphytes with one species of hemiepiphyte, and two species of holoepiphytes followed by ZN1 which was reported to contain one species of accidental epiphyte, one species of facultative epiphytes, two species of hemiepiphytes, and 32 species of holoepiphyte. ZN2 had the maximum number of epiphytes with one species of facultative epiphytes, nine species of accidental epiphytes, 13 species of hemiepiphytes, and 44 species of holoepiphytes. ZN3 was reported to have one species of facultative epiphyte, five species of accidental epiphytes, 11 species of hemiepiphytes, and 34 species of holoepiphytes. Whereas, ZN4 had two species of accidental epiphytes, seven species of hemiepiphytes, and 16 species of holoepiphytes (Figure 4). Stratification with diameter studies showed that at DBH 1–2m the epiphytic assemblage was less than 20.2%, at 3–5m DBH epiphytic assemblage was increased and highest with 59.4%, but as the DBH attained 6–7m the VEA decreased by 43.2% and attained saturation. Variable regression plotting (Figure 5) using IBM SPSS version 64-bit window version is done which shows a positive correlation between DBH and VEA.

Image 2. Study habitat: A—epiphytic flora of the tea gardens | B—vascular epiphytic assemblages on the host tree.

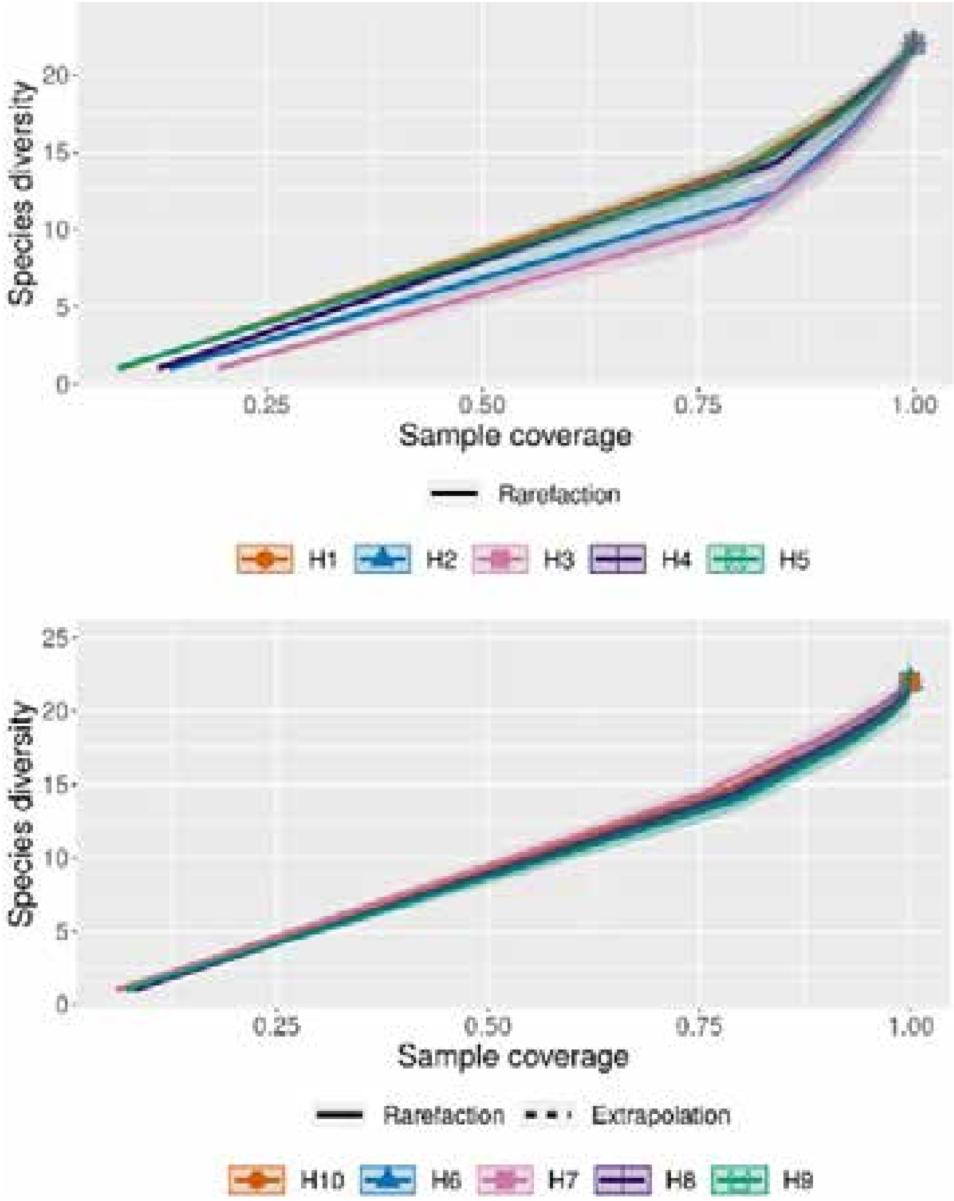

Figure 3. Inter and extrapolation analysis (iNEXT) of epiphyte diversity according sample coverage: H1—*Mangifera indica* L. | H2—*Albizia lebbeck* (L.) Benth. | H3—*Gmelina arborea* Roxb. ex Sm. | H4—*Ficus benghalensis* L. | H5—*Alstonia scholaris* (L.) R.Br. | H6—*Albizia odoratissima* (L.f.) Benth. | H7—*Artocarpus chama* Buch.-Ham. | H8—*Swietenia mahagoni* (L.) Jacq. | H9—*Dillenia pentagyna* Roxb. | H10—*Litsea glutinosa* (Lour.) C.B.Rob. The interpolated (observed) species richness of vascular epiphytes was obtained by merging the number of individual vascular epiphyte assemblages and obtaining an average of individual species. Extrapolated (expected) species richness for each host tree was based on the maximum sample coverage.

DISCUSSION

The study shows that the tea gardens of Terai and Dooars have a good number of vascular epiphytes, characterising them as important vegetation hotspots. Vascular epiphyte assemblage was found to be high on those host shade trees that have rough bark texture with ridges and stripes supporting the proliferation of epiphytes. The finding agrees with the prior works on the Yayu Forest and Gera Forest in Ethiopia (Tafesse et. al. 2015). Whereas, some host trees have no or less vascular epiphytes like *Litsea glutinosa* (Lour.) C.B.Rob. has 465 VEAs and *Gmelina arborea* Roxb. has 450 vascular epiphytic coverage which may be due to the smooth texture of the bark which decreases the water and soil retention (deposited by ants or other insects, old leaf debris) capacity of the host which in turn leads to inhibition of epiphytic growth as discussed by Benzing (1990) working on neotropical forest

Table 2. List of vascular epiphytes recorded from tea gardens of Terai & Dooars, West Bengal.

Scientific name	Family	Life form	Status	Zone preference	Geographical distribution
Selenicereus undatus (Haw.) D.R.Hunt *	Cactaceae	Facultative	Common	ZN2 | ZN3	NAG, CHA
Smilax ovalifolia Roxb. ex D.Don	Smilacaceae	Hemiepiphyte	Common	ZN2 | ZN3 | ZN4	MAI, JPG
Smilax perfoliata Lour.	Smilacaceae	Hemiepiphyte	Common	ZN2 | ZN3 | ZN4	CHA, JPG, RAJ
Pothos scandens L.	Araceae	Hemiepiphyte	Common	ZN1 | ZN2 | ZN3	JPG, NAG, CHA, BAN
Pothos chinensis (Raf.) Merr.	Araceae	Hemiepiphyte	Less common	ZN1 | ZN2 | ZN3	JPG, MAT, CHA
Scindapsus officinalis (Roxb.) Schott	Araceae	Hemiepiphyte	Abundant	ZN2 | ZN3	JPG, NAG, CHA, BAN
Philodendron hastatum K.Koch & Sello	Araceae	Holoepiphyte	Abundant	ZN2 | ZN3	JPG, NAG, CHA, BAN
Philodendron herbaceum Croat & Grayum	Araceae	Hemiepiphyte	Abundant	ZN2 | ZN3 | ZN4	JPG, CHA, MAT
Epipremnum aureum (Linden & André) G.S.Bunting	Araceae	Hemiepiphyte	Abundant, common	ZN2 | ZN3 | ZN4	JPG, NAG, CHA, BAN
Syngonium podophyllum Schott	Araceae	Hemiepiphyte	Common	ZN3 | ZN4	JPG, MAI, PHAN
Colocasia affinis Schott	Araceae	Accidental	Common	ZN2 | ZN3	JPG, NAG, CHA, BAN
Colocasia esculenta (L.) Schott	Araceae	Accidental	Abundant	ZN2 | ZN3	JPG, NAG, CHA, BAN
Rhaphidophora decursiva (Roxb.) Schott	Araceae	Hemiepiphyte	Less common	ZN2 | ZN3 | ZN4	JPG, CHA, MAT
Rhaphidophora glauca (Wall.) Schott	Araceae	Hemiepiphyte	Common	ZN2 | ZN3	JPG, CHA, MAT
Dioscorea bulbifera L.	Dioscoreaceae	Accidental	Common	ZN2 | ZN3 | ZN4	JPG, MAL, BAN, MAI
Dioscorea belophylla (Prain) Voigt ex Haine	Dioscoreaceae	Accidental	Less common	ZN2 | ZN3 | ZN4	CHA, JPG, RAJ
Hellenia speciosa (J.Koenig) S.R.Dutta	Costaceae	Accidental	Common	ZN2 | ZN3	JPG
Streblus asper Lour.	Moraceae	Accidental	Common	ZN2	JPG, MAI, NAG
Ficus religiosa L.	Moraceae	Accidental	Abundant	ZN2 | ZN3	JPG, MAL, BAN, MAI
Ficus benjamina L.	Moraceae	Hemiepiphyte	Rare	ZN2	CHA, JPG
Premna scandens Roxb.	Lamiaceae	Hemiepiphyte	Common	ZN1 | ZN2	CHA, JPG, MAI
Dischidia chinensis Champ. ex Benth	Apocyanaceae	Holoepiphyte	Common	ZN1 | ZN2	JPG, CHA, MAT, NAG
Dischidia bengalensis Colebr.	Apocyanaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3 | ZN5	JPG, CHA, MAT, NAG
Hoya arnottiana Wight	Apocyanaceae	Holoepiphyte	Less common	ZN2 | ZN3	CHA, MAT, PHAN
Hoya bella Hook.	Apocyanaceae	Holoepiphyte	Rare	ZN1 | ZN2	MAT
Hoya verticillata var. verticillata Wall. ex Traill	Apocyanaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3	JPG, CHA, MAT, NAG
Hoya latifolia G.Don	Apocyanaceae	Holoepiphyte	Abundant	ZN2 | ZN3 | ZN5	MAI
Piper longum L.	Piperaceae	Hemiepiphyte	Abundant	ZN2 | ZN3 | ZN4	JPG, CHA, MAT
Piper nigrum L.	Piperaceae	Hemiepiphyte	Abundant	ZN2 | ZN3 | ZN4	JPG, CHA, MAT, NAG
Peperomia pellucida (L.) Kunth	Piperaceae	Facultative	Abundant	ZN1	JPG, NAG, MAI, CHA
Aeschynanthus acuminatus Wall. ex A.DC.	Gesneriaceae	Holoepiphyte	Abundant	ZN2 | ZN3 | ZN4	JPG, MAL, BAN, MAI
Ehretia aspera Willd.	Boraginaceae	Hemiepiphyte	Less common	ZN2	JPG
Heptapleurum arboricola Hayata	Araliaceae	Accidental	Less common	ZN2 | ZN3	JPG, NAG
Commelina benghalensis L.	Commelinaceae	Accidental	Abundant	ZN1 | ZN2	JPG, NAG, MAI, CHA
Pilea microphylla (L.) Liebm.	Urticaceae	Accidental	Abundant	ZN1 | ZN2	JPG, NAG, MAI, CHA
Huperzia phlegmaria (L.) Rothm.	Lycopodiaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3	CHA, MAT
Huperzia squarossa (G.Forst.) Trevis.	Lycopodiaceae	Holoepiphyte	Abundant	ZN1 | ZN2	JPG, CHA, MAT
Huperzia hamiltonii (Spreng.) Trevis.	Lycopodiaceae	Holoepiphyte	Abundant	ZN2 | ZN3	JPG, NAG, MAI, CHA
Nephrolepis cordifolia (L.) C.Presl	Polypodiaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3 | ZN4	JPG, MAL, BAN, MAI
Drynaria quadrifolia (L.) J.Sm.	Polypodiaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4	JPG, CHA, MAT, NAG, BAN
Microsorum punctatum (L.) Copel.	Polypodiaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4 | ZN5	JPG, CHA, MAT, NAG, BAN

Scientific name	Family	Life form	Status	Zone preference	Geographical distribution
Microsorum diversifolium Copel.	Polypodiaceae	Holoepiphyte	Common	ZN1 | ZN2	JPG, CHA, MAT, NAG
Pyrrossia lanceolata (L.) Farw.	Polypodiaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4	JPG, CHA, MAT, NAG, BAN
Pyrrosia adnascens (Sw.) Ching	Polypodiaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4	JPG, CHA, MAT, NAG, BAN
Pyrrosia costata (Wall. ex C.Presl). Tagawa et al.	Polypodiaceae	Holoepiphyte	Common	ZN1 | ZN2	JPG, CHA, MAT
Lepisorus nudus (Hook.) Ching	Polypodiaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3	MAT, NAG, BAN
Davallia trichomanoides Blume	Polypodiaceae	Holoepiphyte	Common	ZN2 | ZN3 | ZN4	JPG, CHA, MAT, NAG, BAN
Haplopteris elongate (Sw.) E.H.Crane	Pteridaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3	JPG, CHA, MAT
Haplopteris flexuosa (Fée) E.H.Crane	Pteridaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3	JPG, CHA, MAT, NAG, BAN
Pteris vittata L	Pteridaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3 | ZN4	JPG, MAL, MAI, NAG
Asplenium crinicaule Hance	Aspleniaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3	MAL, JPG, BAN
Asplenium nidus L.	Aspleniaceae	Holoepiphyte	Abundant	ZN2 | ZN3 | ZN4	MAL, BAN, CHAL
Psilotum nudum (L.) P.Beauv.	Psilotaceae	Holoepiphyte	Common	ZN2 | ZN3	JPG, CHA, BAN
Aerides odorata Lour.	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3	MAL, JPG, BAN
Aerides multiflora Roxb.	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3	MAL, JPG, BAN
Rhynchostylis retusa Blume	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4	MAL, JPG, BAN, NAG, RAJ
Coelogyne corymbosa Lindl.	Orchidaceae	Holoepiphyte	Common	ZN2 | ZN3| ZN4	MAL, BAN, CHAL
Coelogyne cristata Lindl.	Orchidaceae	Holoepiphyte	Common	ZN2 | ZN3 | ZN4	MAL, BAN, CHAL
Dendrobium aphyllum (Roxb.) C.E.C.Fisch	Orchidaceae	Holoepiphyte	Abundant	ZN2 | ZN3	JPG, CHA, BAN
Dendrobium anceps Sw.	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2	JPG, MAL, MAI, NAG
Dendrobium crepidatum Lindl. & Paxton	Orchidaceae	Holoepiphyte	Less common	ZN2 | ZN3 | ZN4	JPG, CHA, BAN
Dendrobium moschatum Wall. ex D.Don	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2	JPG, MAL, MAI, NAG
Dendrobium nobile Lindl.	Orchidaceae	Holoepiphyte	Common	ZN1 | ZN2	JPG, MAL, NAG
Dendrolirium lasiopetalum (Willd.) S.C.Chen & J.J.Wood	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2	JPG, MAL, MAI, NAG
Luisia zeylanica Lindl.	Orchidaceae	Holoepiphyte	Rare	ZN1	NAG
Panisea uniflora (Lindl.) Lindl.	Orchidaceae	Holoepiphyte	Common	ZN2 | ZN3	JPG, CHA, NAG
Gastrochilus dasypogon (Sm.) Kuntze	Orchidaceae	Holoepiphyte	Rare	ZN2 | ZN3	NAG, MAT
Bulbophyllum crassipes Hook.f.	Orchidaceae	Holoepiphyte	Less common	ZN1 | ZN2 | ZN3 | ZN4	JPG, MAL, BAN
Bulbophyllum hirtum Hook.f.	Orchidaceae	Holoepiphyte	Less common	ZN1 | ZN2 | ZN3	JPG, MAL, BAN, MAI
Bulbophyllum reptans (Lindl.) Lindl. ex Wall.	Orchidaceae	Holoepiphyte	Common	ZN1 | ZN2 | ZN3 | ZN4	JPG, MAL, NAG
Cymbidium bicolor Lindl.	Orchidaceae	Holoepiphyte	Abundant	ZN2 | ZN3 | ZN4	JPG, MAL, NAG
Cymbidium aloifolium (L.) Sw.	Orchidaceae	Holoepiphyte	Abundant	ZN2 | ZN3	JPG, MAL, CHAL
Papilionanthe teres Schltr.	Orchidaceae	Holoepiphyte	Abundant	ZN1 | ZN2 | ZN3 | ZN4	JPG, MAL, MAI, NAG
Thunia alba (Lindl.) Rchb.f.	Orchidaceae	Holoepiphyte	Less common	ZN1	MAL, MAT

ZN—Zone preference on host | Blocks of District: JPG—Jalpaiguri | MAL—Malbazar | NAG—Nagrakata | CHAL—Chalsa | MAI—Maitali | MAT—Matigara | BAN—Banarhat | PHAN—Phansidewa. *—non native.

vegetation.working on neotropical forest vegetation. The study on the vertical distribution of vascular epiphytes on shade trees has a difference in species presence from the basal part to the topmost crown. The middle strata of the host have recorded the greatest number of species this may be due to microclimate changes and exposure to sunlight of the host plants in the different zones. This same finding was supported in the works of Bogh (1992), Freiberg (1996), Arévalo & Betancur (2006) with high epiphytic abundance in the center of host crowns due to microclimate differences. From data analysis, it was found that ferns and orchids were major epiphytes of the study area. In total 17 species of epiphytic ferns were recorded from the study sites, which was in accordance with the

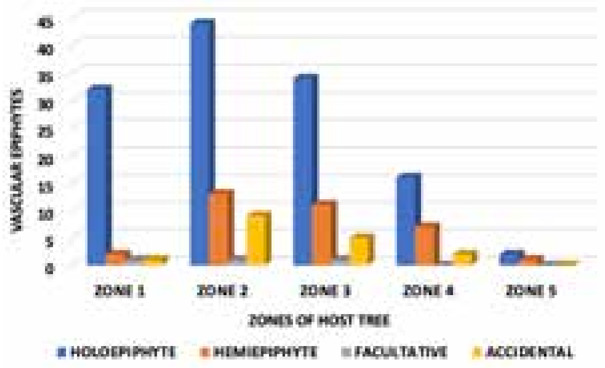

Figure 4. Types of vascular epiphytes distributed on different zones of host trees.

Image 3. Shade tree plantation in the tea garden.

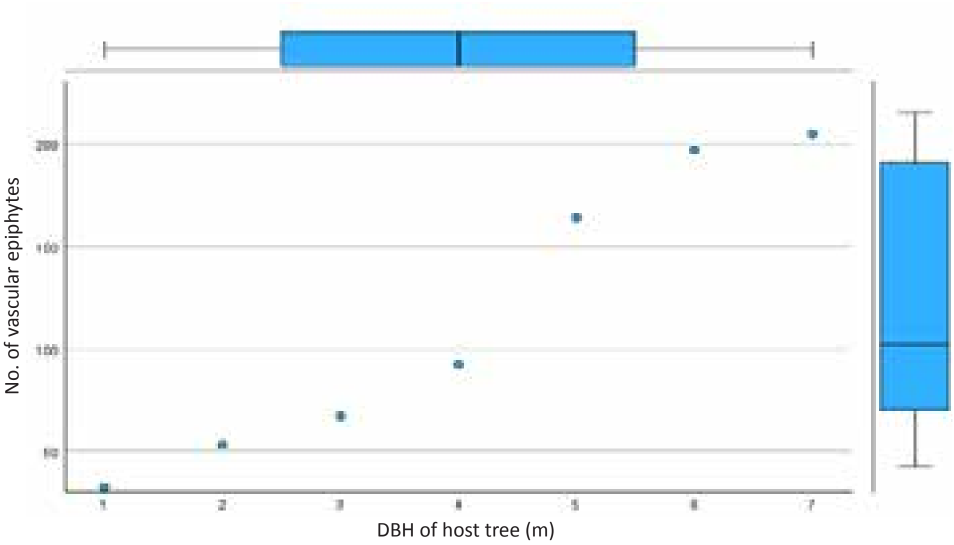

Figure 5. Variable regression plotting using IBM SPSS version 64-bit window version is done which shows a positive correlation between DBH and vascular epiphytes assemblage.

study on Dooars tea gardens with a total of 44 species of pteridophytes including only seven species of epiphytic ferns (Chowdhury et al. 2016). The family Orchidaceae has the maximum number of species recorded which is 12 genera with 21 species. The high number of orchids in this sub-Himalayan region has also been recorded by other authors from different protected areas, for example, from the eastern Himalaya region of India reported 545 species of orchids (Pangtey et al. 1991) and from West Bengal 110 genera with 466 species have been reported (Mitra et al. 2020; Mitra 2021). The overall Shannon diversity index (H' = 3.88) of vascular epiphytes of tea gardens is very high. The diversity index value agrees with the previous works done on the tree diversity of Chapramari Wildlife Sanctuary, eastern Himalaya (Rana et al. 2017). These pragmatic findings suggest that the tea garden of this region harbours a virtuous amount of vascular epiphytic diversity other than forest.

CONCLUSION

The present study is a unique attempt to document the vascular epiphytes vegetation, their assemblage pattern on various zones of tree trunks, and ecology in the tea gardens of sub-Himalayan West Bengal. The rich and diverse assemblage of orchids and fern flora was identified as the most dominant group. The unique climatic factors influencing the diversity and abundance of vascular epiphytes and density towards vertical stratification on host plants. Large DBH and moist bark of host trees provide microclimatic conditions that allow greater numbers of individuals of various species. Vascular epiphytes and host trees make a very healthy ecosystem in this region and also provide shelter to various wild creatures. The fast decline of epiphytic assemblage was also observed may be a result of either improper restoration of vascular epiphytes or the regular use of sticky traps to check insects on tree trunks, which hinder the pollination process of epiphytes. Therefore, there is an urgent need for the conservation of these huge diverse vascular epiphytic floras along with their host in this region to maintain the stable and climax ecosystem.

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COMMUNICATION

Identification and chemical composition analysis of salt licks used by Sumatran Elephants *Elephas maximus sumatranus* in Tangkahan, Indonesia

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Abstract: A crucial aspect of successful conservation strategies is the identification of critical aspects of local habitats required for species preservation in a given region, such as salt licks. Tangkahan is adjacent to the Gunung Leuser National Park in North Sumatra, Indonesia. The park collaborates with the Indonesia Conservation Response Unit using captive Sumatran Elephants *Elephas maximus sumatranus* for forest patrols, mitigation of human-elephant negative interactions, public education, and ecotourism in the area. An initial study on the daily activities of captive Sumatran Elephants revealed their search for salt licks, which are essential for maintaining their optimal daily sodium intake. Information on salt licks in Tangkahan is limited and deserves further investigation. Ethical clearance is deemed unnecessary, as the research employs a non-invasive approach, exclusively observing the natural behaviors, and daily activities of elephants. The well-being of the elephants takes precedence over invasive technologies, with continuous monitoring ensuring their care throughout the research process. The study utilizes a descriptive-analytic methodology, tracking the daily movements of Sumatran Elephants to identify the locations of salt licks in the area. Four salt licks—Encepan-1, Encepan-2, Namo Cencen, and Hot Spring—were identified by participating in the elephants' territorial exploration. Although the salt licks were located adjacently, Encepan-1 was most frequently visited by the elephants. The salt licks were characterized as waterholes containing Na^+ (Sodium ion) rich waters from springs. However, according to the atomic absorption spectrophotometry (AAS) method, the sodium concentration in these salt licks ranged 34–55 ppm, which is estimated to be insufficient for the physiological requirements of the elephants. Therefore, further investigations are needed to explore other complementary salt licks and the incidence of geophagy to support the mineral needs of Sumatran Elephants in the Tangkahan region.

Keywords: Asian Elephant, geophagy, mineral lick, sodium.

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INTRODUCTION

The Sumatran Elephant *Elephas maximus sumatranus* is classified as 'Critically Endangered' by the IUCN Red List of Threatened Species, with habitat conservation being a priority, and conflict mitigation requiring strict management by local conservation sites in Indonesia (Gopala et al. 2011). The Conservation Response Unit (CRU) Tangkahan, located in the Langkat Regency of North Sumatra, part of Gunung Leuser National Park, is a conservation area dedicated to protecting Sumatran Elephants in Indonesia. CRU Tangkahan focuses on supporting the conservation of wild elephant habitats and bridging positive intervention programs with local communities through various involvement in conservation activities such as forest patrol, human-elephant negative interaction mitigation, public education, and ecotourism. CRU Tangkahan has played an instrumental role in facilitating deeper investigations into captive, trained, and wild elephants, leading to a greater understanding of their behavior within the conserved region.

The survival of the Sumatran Elephant greatly depends on its habitat, which includes forest vegetation, open areas, water sources, salt licks, and resting places. This megaherbivore consumes various plant species, but is highly selective depending on the area, weather, and ecosystem where it lives (Pla-ard et al. 2022). Studies conducted on Bornean Elephants *Elephas maximus borneensis* have shown that they consume around 182 plant species, without preference for larger or smaller species (English et al. 2014). Unlike other forest elephants, Bornean Elephants prefer plant species from the Poaceae family rather than other types such as gingers, palms, lianas, and woody trees (English et al. 2014). These differences may reflect their adaptability to different ecological niches.

Elephants have a high feeding rate to meet their energy needs based on body size, age, and sex. During the wet season, both African & Asian elephants tend to graze and spend more time feeding, while during the dry season, they feed less, and are characterized more as browsers (Mohapatra et al. 2013; Greene et al. 2019). Studies have suggested that seasonal deterioration in grass quality may lead to browsing behavior in Asian and African elephants (Weir 1972; Owen-Smith & Chafota 2012; English et al. 2014). The feeding activity of elephants aims to meet their nutritional needs, both qualitatively and quantitatively (Berliani et al. 2018). However, elephants are also known to have difficulty digesting plants with high levels of tannin and other digestive enzyme inhibitors (Karasov & Douglas 2013).

Salt licks are locations that contain essential minerals where animals regularly visit to supplement their diet by licking the soil or water. The presence of animal footprints at these natural deposits consistently confirms their significance to the animals (Sompud et al. 2022). Even endangered species like Asian Elephants and orangutans have been observed visiting these areas (Matsubayashi & Lagan 2014). Therefore, elephants tend to consume mineral-rich soils, also known as geophagy, to feed on essential minerals. There are four primary hypotheses explaining the habitual and intentional soil-eating behavior in animals and people: geophagy, therapeutic, detoxification, and buffering gastric pH (Houston et al. 2001). The most prevalent geophagy hypothesis is the nutrient complementation and/or sodium hypothesis (Dudley et al. 2012). Herbivores consume soil because their typical diets, such as plant leaves, and grasses, lack sufficient mineral concentrations, particularly sodium, to meet their dietary requirements.

The geophagic behavior displayed by elephants and other animals is likely an adaptive practice to remedy a physiological response to mineral nutrient deficiencies in their environment. The therapeutic hypothesis of geophagy is based on the high clay content in some soils, which is known to alleviate gastrointestinal distress & upsets (Risenhoover & Peterson 1986; Tawa et al. 2023). Clay in geophagic soils has also been found to detoxify plant secondary compounds, particularly alkaloids, that are present in many tropical forest trees, counteracting the effects of lactic acidosis. The clay mineral composition has also been found to relate to that of Kaopectate™ used in human medical practice to alleviate various gastroisntestinal disorders such as diarrhea, heartburn, indigestion, and nausea. In contrast, some wild herbivores lick from the deposits for detoxification of elements that are widespread in their habitats or taken up through ingestion (Panichev et al. 2017). Finally, studies have shown that geophagic soil benefits animals by buffering stomach pH and helping them mechanically grind food, which is common for most bird species (Dudley et al. 2012).

Elephants consume minerals as a strategy to detoxify harmful phytochemicals and meet their nutritional requirements due to metabolic constraints (Middleton et al. 2016). Although terrestrial plants, other than halophytes, do not typically accumulate sodium, herbivores still require adequate sodium intake (Cheeseman 2015). It has been hypothesized that mineral lick sites, such as salt licks with Na^+-rich waters, generally provide sodium to supplement the low Na^+

intake of herbivores (Risenhooever & Peterson 1986). Sodium, or Na^+, is the dominant cation found in salt licks, along with other essential minerals such as calcium, magnesium, and potassium. However, the concentration of these minerals may vary considerably depending on the natural conditions of different habitats worldwide (Klaus et al. 1998). For example, in five salt licks in the Amazon Basin, the concentration of Na could range from as low as 29 mg/kg to as high as 1,361 mg/kg (Molina et al. 2013). Interestingly, the mineral concentration in waterholes utilized by elephants may be higher compared to other sites that were not used by elephants (Metsio-Sienne et al. 2013). Elephants intentionally search and allocate some of their energy to locate these mineral hotspots as part of their daily behavior (Berliani et al. 2019).

The majority of studies on salt licks have focused on geophagy by African Elephants *Loxodonta africana*, examining their behavior, populations, and the mineral properties of the licks (Weir 1969; Stark 1986; Ruggiero & Fay 1994; Holdø et al. 2002). Mineral requirements are influenced by several factors, including reproduction, age, sex, growth rate, and physiological condition. Therefore, wild animals, particularly herbivores, require periodic access to mineral sources at salt licks, which elephants often visit in search of mineral-rich salts. The natural characteristics of salt licks thus support wild animals, especially herbivores, in addressing nutritional deficiencies in their diets (Lameed & Adetola 2012).

In the tropical region of North Sumatra, salt licks may take the form of waterholes or sodium-rich waters, which remain understudied despite being a crucial element for the conservation dynamics of Sumatran Elephants. This study aims to characterize a series of salt licks and their mineral composition located around the CRU Tangkahan region inside Gunung Leuser National Park, providing baseline information to support conservation efforts and management by officials. Ethical clearance is deemed unnecessary due to the prioritization of elephant well-being over invasive methodologies and the continuous monitoring of their care throughout the research process.

METHODS

Study Area

Tangkahan is situated in the northern part of Sumatra (03.414°N, 98.040°E) and is one of the ecotourism sites in Langkat Regency, North Sumatra. This study was carried out in Tangkahan, which is famous for its herd of rescued Sumatran Elephants that are trained to patrol the forests with their mahouts. The CRU Tangkahan area is a buffer area zone of Gunung Leuser National Park. Tangkahan is home to virtually untouched forests inhabited by wild orangutans, with waterfalls, caves, and hot springs to explore. The area features a diverse range of flora & fauna, including a variety of food plants that are important for the Sumatran Elephants' diet. The climate in Tangkahan is characterized by its tropical rainforest climate, with high humidity, and significant rainfall throughout the year. The luxuriant vegetation and favorable climatic conditions render Tangkahan an optimal habitat for a myriad of wildlife, notably featuring the 'Critically Endangered' Sumatran Elephants.

Sampling procedure and behavioral observation

To locate salt licks in the region, exploration was carried out by observing the daily behavior of Sumatran Elephants. Four salt licks were selected for this study: Encepan-1 (03.4110°N, 98.0412°E), Encepan-2 (03.411°N, 098.0414°E), Namo Cencen (03.4175°N 098.0423°E), and Hot Spring (03.4129°N, 98.0418°E) (Figure 1). During May–July, Na^+ rich water samples (100 ml) were collected from the CRU Tangkahan area and stored in borosilicate bottles to analyze mineral concentration and composition. Atomic absorption spectrophotometry (AAS) was used to analyze samples for the concentration of Boron (B), Sulfur (S), Phosphorus (P), Potassium (K), Calcium (Ca), Sodium (Na), Magnesium (Mg), Aluminium (Al), Copper (Cu), Zinc (Zn), Iron (Fe), and Manganese (Mn). Dissolved organic C content and pH were measured using digital instrumentation.

RESULTS AND DISCUSSION

Characteristics of salt licks in Tangkahan

Based on the findings of this study, each of the salt licks in the Tangkahan area had distinct characteristics and different sulfuric odors (Table 1). The Sumatran Elephants were observed to periodically visit these four salt licks for drinking or performing geophagy to fulfill their nutritional requirements (Image 1). The salt licks were primarily composed of limestone, and the water temperature ranged 20–58 °C. Sulphuric gas was detected in all salt licks at varying levels, with the highest levels found at Hot Spring due to the natural weathering of minerals such as sulfur (S), which released the sulfuric odors around the licks. Encepan-2 had the highest organic C content, while the lowest was found

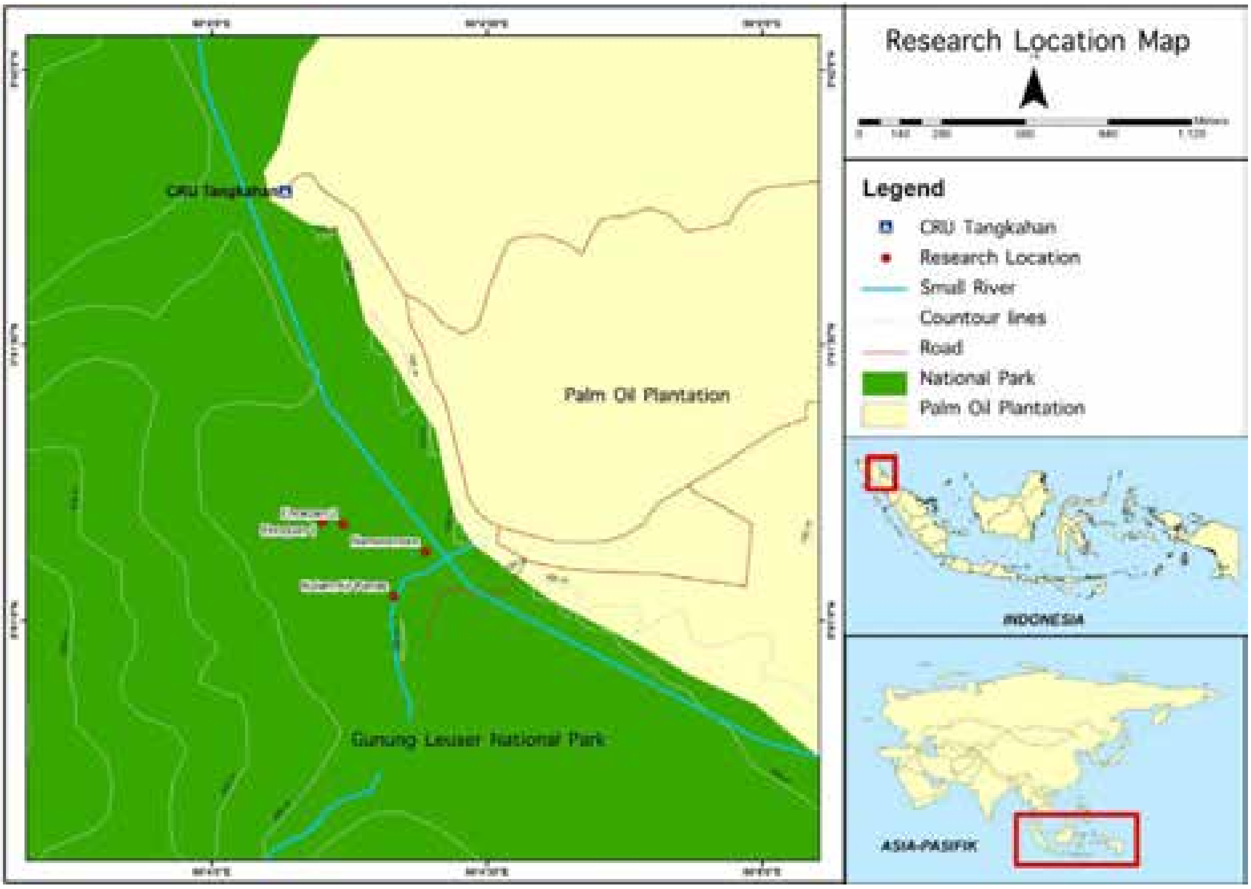

Figure 1. Study area shows the salt licks area in the CRU Tangkahan region, North Sumatra.

at Hot Spring. The water pH in each of the salt licks was stable and fell within the range of 7.35–7.59. These characteristics of salt licks are significant for elephants and the ecosystem in several ways. Salt licks provide essential minerals which are necessary for the elephants physiological functions, including nerve function, and muscle contraction. The existence of salt licks is not only important for elephants but also for a wide range of other wildlife species.

Encepan-1, situated along the patrol route for elephants in the CRU Tangkahan, stands out as the most frequently visited salt lick, given its proximity to the patrol pathway. The structure of Encepan-1 was primarily composed of sandstones mixed with clays from nearby riparian soils. The waterhole at Encepan-1 was fed by springs that emerged from the ground and mixed with the river flow passing through the area. The mineral composition of the sand fraction of soils can affect the long-term potential fertility of the area due to the weathering of the material (Molina et al. 2013). Further investigation into the geomorphological formation of the region may help determine the mineralogical composition of specific clay materials and their relation to the characteristics of the salt licks (Table 2).

The high organic C content found in Encepan-2 (924.61 ppm) may be attributed to the natural decomposition of litter in the salt lick. Additionally, the high level of organic C content could be due to the chelation of essential minerals such as Cu, Fe, Al, and Mn dissolved in the soil materials (Cambardella & Elliott 1992; Obi 1999). Moreover, the waterholes formed in this salt lick may provide sufficient nutrients for the elephants to maintain their dietary intake of minerals. The salt and mineral composition are presented in Table 2, which shows the dominant and less dominant elements in the salt licks. A high concentration of sulphur was detected in both Encepan-1 and Namo Cencen, whereas Hot Spring had a comparatively lower concentration of sulfur, which was unusual in this study. Animals need to receive an appropriate and balanced diet that meets their nutritional requirements, including sulfur, without exceeding safe levels. Sulfur is a component of certain amino acids, vitamins, and coenzymes that play crucial roles in various physiological processes. It is particularly

Table 1. Characteristics of salts licks in CRU Tangkahan area.

Characteristics	Salt Licks			
	Encepan-1	Encepan-2	Namo Cencen	Hot Spring
Structure	Sandstone	Limestone	Limestone	Limestone
Temperature (°C)	44	30	20	58
Sulphuric gas	+++	++	+	++++
Formation	Notched	Notched	Notched	Notched
Water clarity	Clear	Clear	Clear	Clear, covered with moss
Depth (cm)	10	20	40	100
Litter	Absent	Present	Present	Absent
Organic C content (ppm)	109.94	924.61	594.99	1.12
pH	7.59	7.57	7.38	7.35

Table 2. Salt and mineral composition in salt licks in CRU Tangkahan.

Parameter(s)	Concentration (ppm) at salt licks			
	Encepan-1	Encepan-2	Namo Cencen	Hot Spring
Boron (B)	0.33	1.09	3.68	4.56
Sulphur (S)	100.51	18.18	185.08	55.11
Phosphorus (P)	0.98	0.96	3.16	2.26
Potassium (K)	50.22	41.25	94.15	75.92
Calcium (Ca)	49.48	58.99	405.43	28.34
Sodium (Na)	34.02	43.70	55.55	44.20
Magnesium (Mg)	39.57	35.20	349.38	64.78
Aluminium (Al)	18.10	16.96	26.89	22.77
Copper (Cu)	0.08	0.08	0.43	0.34
Zinc (Zn)	0.44	0.40	1.60	0.97
Iron (Fe)	11.6	12.38	12.74	12.58
Manganese (Mn)	0.32	0.27	2.43	2.47

important for the synthesis of proteins, the formation of connective tissues, and the maintenance of the structural integrity of hair, skin, and hooves. Salt-licks can supply a variety of nutrients including iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), selenium (Se), calcium (Ca), phosphorus (P), potassium (K), sodium (Na), sulfur (S), and chlorine (Cl). Naturally occurring salt-licks (NSs) are therefore considered significant landscape resources. Studies in the Segaliud–Lokan Forest Reserve, Sandakan, Sabah, Malaysia, have shown that they have an impact on the density & composition of fauna in the vicinity, and appropriateness for salt-lick tourism (Lim & Mojiol 2022; Chaiyarat et al. 2023).

The salt concentration ranged from 34–55 ppm. The ideal Na^+ intake is known to be correlated with the body mass of the studied animals, revealing a dynamic measurement for some species (Belovsky & Jordan 1981). In addition, a study of a 5,000 kg African Elephant in Zimbabwe showed the importance of Na^+ rich water, which supplied about 112 g of daily sodium intake from 200 l of water from the Sinamatella River (Holdø et al. 2002). However, it is noteworthy that the sodium supply from these salt-licks in Tangkahan may not be sufficient to meet the daily requirements of the elephants due to the limited access to waterholes and resources. The incidence of geophagy or soil consumption with high minerals by the elephants may require further investigation as another strategy to fully satisfy their requirements. Some researchers also argue that the phenomenon of salt-licks may only become valid in a Na^+-balance experiment using fecal Na^+ as an indicator to reflect the connection between the movement and habitat-use patterns of elephants (Holdø et al. 2002).

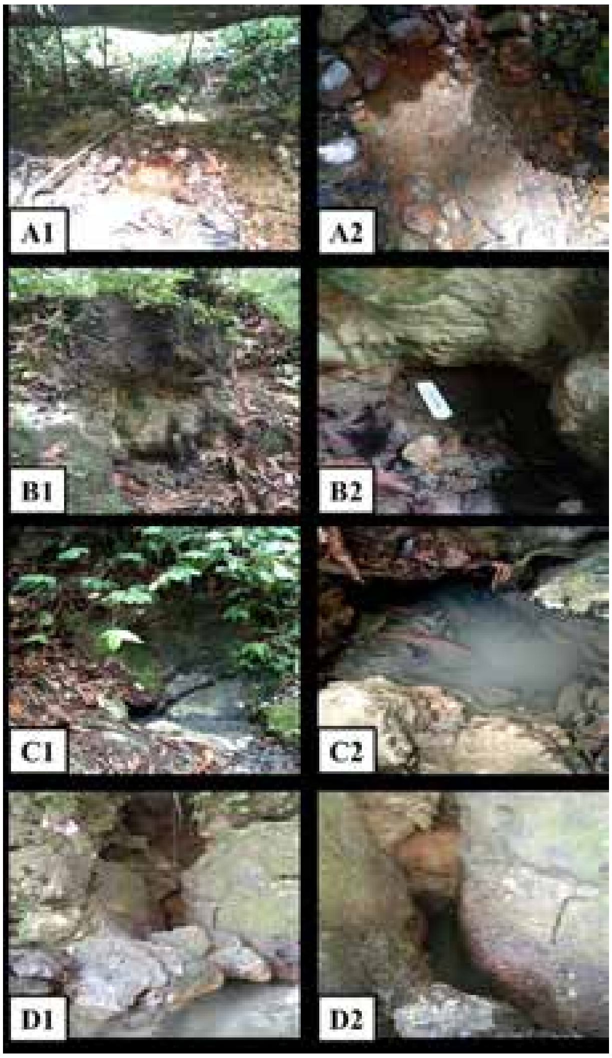

Image 1. Salt licks located in the CRU Tangkahan area: A1—Encepan-1 | A2—Water Spring | B1—Encepan-2 | B2—Small cave | C1—Namo Cencen | C2—Puddle | D1—Hot Spring | D2—Crevice.

CONCLUSION

The findings of our study confirm the presence of salt-licks for Sumatran Elephants in Tangkahan, highlighting the importance of conservation efforts in the area. With a better understanding of the elephants' use of salt-licks, officials can focus on protecting these sites and potentially identify additional ones in the deeper forest regions. Maintaining salt-licks as essential components of the forest's ecological functions will contribute to the long-term sustainability of the elephant population in CRU Tangkahan. This study was conducted within a specific timeframe, limiting the understanding of seasonal variations or long-term patterns. Investigating the broader ecological impact of salt-licks on the biodiversity, and functioning of the surrounding forest ecosystem, and exploring the relationship between salt-lick locations and human-elephant negative interactions to develop mitigation strategies are recommended for future and collaborative research.

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Abstract : Aspek penting dari strategi konservasi yang sukses adalah identifikasi mikrohabitat yang signifikan untuk pelestarian spesies di wilayah tertentu. Proses menggaram menyediakan mineral penting dan mendukung perilaku hewan yang berbeda dari lingkungan sekitarnya. Tangkahan, yang berbatasan dengan Taman Nasional Gunung Leuser di Sumatera Utara, Indonesia, bekerja sama dengan Indonesia Conservation Response Unit, menggunakan gajah Sumatera (*Elephas maximus sumatranus*) yang ditangkarkan untuk patroli hutan, mengurangi konflik antara manusia dan gajah, edukasi publik, serta ekowisata. Studi awal mengenai aktivitas harian gajah ini mengungkapkan pencarian mereka terhadap penggaraman, yang penting untuk menjaga asupan natrium yang optimal. Namun, penemuan penggaraman di Tangkahan masih terbatas dan perlu penelitian lebih lanjut. Penelitian ini tidak memerlukan izin etik karena menggunakan pendekatan non-invasif, hanya mengamati perilaku alami dan aktivitas harian gajah. Kesejahteraan gajah diutamakan dengan pemantauan terus-menerus selama proses penelitian. Metodologi yang digunakan adalah deskriptif-analitik, dengan melacak pergerakan harian gajah Sumatera untuk mengidentifikasi lokasi jilatan garam. Empat lokasi jilatan garam—Encepan-1, Encepan-2, Namo Cencen, dan Sumber Air Panas—diidentifikasi melalui penjelajahan teritorial gajah. Meskipun lokasi-lokasi ini berdekatan, Encepan-1 adalah yang paling sering dikunjungi. Penggaraman ini dikarakterisasi sebagai lubang air yang mengandung air kaya Na+ dari mata air. Namun, analisis dengan spektrofotometri serapan atom (AAS) menunjukkan konsentrasi natrium di jilatan garam ini berkisar antara 34 hingga 55 ppm, yang kemungkinan tidak mencukupi kebutuhan fisiologis gajah. Oleh karena itu, diperlukan investigasi lebih lanjut untuk mengeksplorasi jilatan garam tambahan dan kejadian geofagi guna mendukung kebutuhan mineral gajah Sumatera di wilayah Tangkahan.

Keywords: *Elephas maximus sumatranus*, geofagi, penggaraman, natrium.

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COMMUNICATION

Occurrence of a female melanistic leopard *Panthera pardus delacouri* (Linnaeus, 1758) (Mammalia: Carnivora: Felidae) in Ulu Sat Permanent Forest Reserve, Machang, Kelantan, Peninsular Malaysia from camera traps reconnaissance survey 2023

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Abstract: The Indochinese leopard, *Panthera pardus delacouri* is classified as Critically Endangered in the Red List of Threatened Species by the International Union for Conservation of Nature (IUCN). The subspecies has been recorded for the first time in Ulu Sat Permanent Forest Reserve (USPFR). Camera trap records show the presence of a female melanistic leopard, which is of additional biological interest. It is hoped that these observations will stimulate long-term studies on leopards of USPFR and promote conservation efforts in the area.

Keywords: Biodiversity, camera trapping, carnivores, conservation, ecosystem, endangered species, felid conservation, forest ecology, habitat, monitoring, predators, wildlife.

Malay abstrak: Harimau bintang Indochina, *Panthera pardus delacouri* diklasifikasikan sebagai Terancam Teruk dalam Senarai Merah Spesies Terancam oleh Kesatuan Antarabangsa bagi Pemuliharaan Alam Semula Jadi (IUCN). Subspesies ini telah direkodkan buat kali pertama di Hutan Simpan Kekal Ulu Sat (HSKUS). Rekod perangkap kamera menunjukkan kehadiran harimau bintang melanistik betina, yang mempunyai kepentingan biologi tambahan. Pemerhatian ini diharapkan dapat merangsang kajian jangka panjang mengenai harimau bintang di HSKUS dan menggalakkan usaha pemuliharaan di kawasan tersebut.

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Competing interests: The authors declare no competing interests.

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Author contributions: WHIWMH, MHSAR and HH collected data, analysed and wrote the initial draft of the manuscript. AA and KH read and revised the final manuscript.

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INTRODUCTION

The leopard is one of the most adaptable large carnivores on the planet (Sunquist & Sunquist 2002). It is present in a wide range of habitats, from deserts to rainforests, from humid tropics to temperate zones (Jacobson et al. 2016; da Silva et al. 2017). The natural habitat for leopards in Malaysia had decreased substantially when 14% of Malaysia's forest cover had been lost from years 2000 to 2012 (Hedges et al. 2015). Paved roads have been constructed in the remaining forest blocks in the Peninsula Malaysia (Hedges et al. 2015). The leopard's geographic range extends from Africa, central Asia, and the Indian subcontinent, including Sri Lanka, to much of eastern Asia, and the Russian Far East (Chew 2019). In Southeast Asia, it occurs from Myanmar to Thailand and Vietnam, south to Peninsular Malaysia, and the Indonesian island of Java (Stein et al. 2016).

Indochinese leopard (*P. p. delacouri*) might be extinct in Lao PDR, Vietnam, and Singapore and may occur in small fragmented populations in Cambodia, southeastern China, Malaysia, Myanmar, and Thailand. The Indochinese Leopard is classified as 'Critically Endangered'. At present, this species is at high risk of extinction due to poaching and high deforestation rates in southeastern Asia (Rostro-García et al. 2016). Due to prey depletion, the leopard is restricted to a few small fragmented areas and protected areas (Forbes 2024).

Melanistic leopards can be distinguished by their intense black pigments which almost obscure the rosettes. Melanistic leopards or black panthers can be found mostly in the southern part of Isthmus Kra encompassing Peninsular Malaysia and southern Thailand (Kawanishi et al. 2010; Hedges et al. 2015).

Ulu Sat Forest Reserve is one of the 12,000 ha of permanent forest reserve (PFR) in Kelantan and is under the management of the Forestry Department of Peninsula Malaysia which had been protected and reserved from any illegal logging activities. In this article, the presence of a melanistic leopard was reported in Ulu Sat Permanent Forest Reserve, Machang District, Kelantan, Peninsular Malaysia. The leopard was recorded by a camera trap installed between 9 April 2023 and 26 May 2023. Camera traps were placed in the area for reconnaissance survey prior to an extensive camera trapping survey targeting wild felids in the study area and also Chabang Tongkat Forest Reserve.

Study area

The study area is located in Ulu Sat Permanent Forest Reserve (USPFR) (5.717 ^{0}N & 102.317 ^{0}E), an approximately 148 km² protected area located in Machang District, eastern Kelantan, Peninsular Malaysia (Image 1). This site is an ecologically important forest habitat for water catchments in producing, maintaining, and reserving water for natural and human consumption. It makes the area very significant for the nearby local community (Samsudin et al. 2020; Abas et al. 2021). Ulu Sat Forest Reserve's natural vegetation is still intact and covered with approximately over 0.65 p/pet and the forest is classed as tropical wet with a tropical moist forest biozone (Abas et al. 2021). Ulu Sat Forest Reserve and Chabang Tongkat Forest Reserve together with Temangan Forest Reserve are put under secondary linkage (D-SL 3: Chabang Tongkat FR–Ulu Sat FR–Temangan FR). The types of forest in the USPFR are lowland and the hill is of dipterocarp forest. The area is undulating, and the full elevation range of USPFR is 60–600 m.

MATERIALS AND METHODS

In this study, two camera trap units (Reconyx Hyperfire) were installed at two random locations in USPFR. The main purpose of the study was to have prior information on the presence of wild felid species. Camera traps were mounted on the trees bordering forest trails at a height of about 0.5 m above the ground to permit the detection of medium and large-sized mammals without using any bait (Jansen et al. 2014). The camera traps were programmed at a one-second interval between three series of images to maximize the chance to capture wildlife photos. The location of each camera was recorded with a global positioning system (Garmin GPSMAP 64s) to record their local information such as date of installation, the coordinates, and elevation range. The GPS units also made it easy for colleagues to return to the area to retrieve the cameras. Precautions were taken to minimize the risk of letting the cameras be stolen or damaged by wildlife. The reconnaissance survey lasted from 9 April 2023 until 26 May 2023. The surveyors visited the camera traps only twice, during their setting up and retrieval. All images have been extracted, sorted, and identified accordingly. Images that phantom or remain unidentified due to blurry images were excluded from the results. The cameras and memory card were tagged and identified with unique camera trap numbers for reference.

Image 1. Map of the study area, camera traps location and camera detected leopard.

RESULTS

From this study, a total of 603 photos of terrestrial vertebrates were captured during the sampling period. The camera traps operated between 9 April to 26 May 2023 and the images were obtained from a total of 94 trap nights. The 603 photos yielded 41 independent photos of wildlife, and 13 phantom images were discarded. The image of the melanistic leopard clearly shows it to be a female, with traces of torn skin on the back of the body. The image was recorded on 11 May 2023 at 0701 h (Image 2). This leopard was detected at the old logging road built on the ridge at 0701 h at 428 m elevation. This discovery is expected to arouse interest in leopards in Malaysia and their habitat in the Ulu Sat Permanent Forest Reserve.

Besides melanistic leopard, other wildlife which were detected consisted of wild boar *Sus scrofa*, Asiatic Brush-tailed Porcupine *Atherurus macrourus*, Barking Deer *Muntiacus muntjak*, Malayan Tapir *Tapirus indicus*, Asiatic Leopard Cat *Prionailurus bengalensis*, Malayan Porcupine *Hystrix brachyura*, Southern Serow *Capricornis sumatraensis*, Malayan Sunbear *Helarctos malayanus*, Yellow-throated Marten *Martes flagivula*, White-thighed Surili *Presbytis siamensis*, and Crestless Fireback *Lophura erythrophthalma*.

DISCUSSION

In 2018, a Biological Diversity Scientific Expedition program in the Ulu Sat Forest Reserve was organized by the Kelantan State Forestry Department in collaboration with Universiti Malaysia Kelantan. On the expedition, a preliminary study of the installation of camera traps was carried out to assess the presence of terrestrial vertebrates. The results of the study have recorded eight species of terrestrial vertebrates, namely Wild Boar *Sus scrofa*, Malayan Sun Bear *Helarctos malayanus*, Malayan Tapir *Tapirus indicus*, Southern Red Muntjac *Muntiacus muntjak*, Clouded Leopard *Neofelis nebulosa*, Leopard Cat *Prionailurus bengalensis*, Dhole *Cuon alpinus*, and Asiatic Golden Cat *Catopuma temminckii* (Hazizi et al. 2020). The study was not intensive on the Ulu Sat Forest Reserve. Apart from the eight species above, a rare felid species was also recorded for the first time, the Marbled Cat *Pardofelis marmorata* on the same expedition but in a different location (Hambali et al. 2019).

The present research has been able to make a first-time record of the remarkable morphological variation, the melanistic leopard *Panthera pardus delacouri* in USPFR. Previously in Malaysia, leopards were recorded in Belum-Temengor, Taman Negara, Endau Rompin, Krau Wildlife Reserve, Pasoh, Ayer Hitam Forest Reserves (Chew 2019), Jeli and Ulu Muda (Hambali et al. 2021). This discovery is considered important as the leopard subspecies is classified as 'Critically Endangered' in the

Image 2. A female melanistic leopard was photographed at 0701 h on 11 May 2023.

IUCN Red List of Threatened Species (Rostro-García et al. 2019). According to the Red List of Mammals for Peninsular Malaysia Version 2.0, this animal species is categorized as endangered (PERHILITAN 2017). *Panthera pardus* has been placed in Schedule 2 where it is a protected animal (Wildlife Conservation Act 2010). This protected animal requires a special permit to carry out any activity against it and if there are no special permits strict measures such as summons, and imprisonment can be imposed.

The Indochinese leopard faces multiple threats that contribute to its dwindling and endangered status. These threats include habitat loss, fragmentation, and degradation due to factors such as agriculture (Sodhi et al. 2010; Miettinen et al. 2011; Wilcove et al. 2013) and infrastructure development especially roads (Clements et al. 2014). As the human population expands and exploits natural resources, the leopard's habitat is encroached upon and diminished. From 2011 to 2018 a total of 54,224 human-wildlife negative interaction cases were recorded. In these, a total of 207 cases of human leopard conflicts occurred from 2011 to 2018 (Xin et al. 2024). From the total of leopard cases, it was stated that 104 cases come from black panthers and the rest from non-melanistic leopards (Xin et al. 2024).

Ulu Sat is known for its rich biodiversity and dense tropical rainforest. Preserving the integrity of USPFR is essential for safeguarding its unique biodiversity of flora including rafflesia, araceae (*A. cochinchinense* and *A. puber*), and fauna such as the leopard, Malayan tapir, and Sumatran serow in supporting sustainable ecosystem services in the area (Meisery et al. 2020). The discovery of a melanistic leopard within the boundaries of Ulu Sat Forest Reserve highlights the importance of this protected area in safeguarding rare and elusive wildlife species amidst the challenges posed by deforestation and illegal wildlife trade in southeastern Asia. The melanistic leopard found in the present study shows that further study is needed to determine their population, their basic ecology, activity pattern, and distribution. In the future, it is expected that conservation actions for leopards in the study area and the state of Kelantan can be developed. To protect the leopard population in Malaysia, collaboration and cooperation between governmental and non-governmental organizations will be imperative. Also, by integrating conservation education into the curriculums and research programs of local schools and universities, larger audiences can be reached to strengthen conservation efforts for leopards in Malaysia and their habitat which is the Ulu Sat Permanent Forest Reserve. Residents living around the study area need to be given exposure and awareness about the species and the importance of conserving them in their natural habitat.

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Diversity and distribution of large centipedes (Chilopoda: Scolopendromorpha) in Nui Chua National Park, Vietnam

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Abstract. Field surveys on large centipedes of Nui Chua National Park, south-central part of Vietnam, were conducted in September 2023 and February 2024. As a result, a total of 12 species/subspecies belonging to five genera and two families of the order Scolopendromorpha were recorded. Of two families, Scolopendridae has nine species in four genera, while Cryptopidae has only two species in one genus. In addition, the distribution pattern of the large centipedes is discussed based on the season (rainy versus dry), altitudes, and different habitats.

Keywords: Altitudes, biodiversity, bioinvestigation, distribution, habitats, scolopendromorph, season, south-central Vietnam, taxon.

Vietnamese: Các đợt điều tra về rết lớn tại Vườn quốc gia Núi Chúa được thực hiện vào tháng 9 năm 2023 và tháng 2 năm 2024. Kết quả đã ghi nhận được 12 loài và phân loài thuộc 5 giống, 2 họ của bộ rết lớn Scolopendromorpha. Trong đó, họ Scolopendridae đã ghi nhận được 9 loài, họ Cryptopidae đã ghi nhận được 2 loài cùng một giống. Bên cạnh đó, nghiên cứu cũng phân tích, đánh giá về đặc điểm phân bố của các loài theo các mùa (mùa mưa và mùa khô) trong năm, theo độ cao và các sinh cảnh khác nhau.

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Author contributions: All authors equally contribute to the current paper, including sample collecting, analyzing, photographing and manuscript writing.

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INTRODUCTION

Centipedes are the largest group of terrestrial carnivorous invertebrates and have an important role in balancing the ecosystem or controlling harmful organisms (Lewis 1981). Therefore, it is very essential to have a better understanding of this group. The large centipede fauna (Scolopendromorpha) in Vietnam was initially studied by foreign researchers such as Attems (1930) and Schileyko (1992, 1995, 2007). Recently, Vietnamese systematists started to conduct more research on the taxonomy and diversity of scolopendromorph centipedes, such as Tran et al. (2013), Vu et al (2020, 2022), and Le et al. (2018, 2021, 2023).

Nui Chua National Park (NP) in Ninh Thuan province, south-central Vietnam, has been recognized as a World Biosphere Reserve since 2021 (Figure 1). This is in recognition by the international community of its natural landscape, biodiversity, and indigenous cultural values. The biosphere reserve has a total area of 106,000 ha , including forests, seas, and semi-deserts. With the core area being Nui Chua National Park, this region possesses much biodiversity value for its rare species of animals and plants. In addition, it has a harsh climate, low rainfall, and hot weather all year round, creating for Nui Chua a natural landscape with unique characteristics of the dry climate region of Ninh Thuan. This is also a unique and rare characteristic of Vietnam and southeastern Asia. However, up to now, large centipedes in the Nui Chua NP area are still poorly known. According to Tran et al. (2013), *Scolopendra morsitans* is the only species recorded in Ninh Thuan province. The recorded location is about 20 km south-west of Nui Chua NP.

This study aims to provide the species composition of the large centipedes and their distribution pattern in Nui Chua NP.

MATERIAL AND METHODS

Field surveys were carried out in September 2023 and February 2024 in different habitats in Nui Chua NP, including natural broadleaf forests (NF), planted forests (PF) and coniferous forests (CF). Samples were also collected at different altitudes (including below 300 m, 300–600 m, and 600–1,000 m) according to Vu (2012) and Bain & Hurley (2011).

Centipede samples were collected by pitfall trapping (Mesibov & Churchill 2003), leaf-sifting (Górny & Grum 1993) and manually collecting from rotting trees, under rocks, and forest litter. A total of 156 samples were collected during the two field surveys. All specimens were preserved in 75–80 % ethanol and kept at the Joint Vietnam-Russia Tropical Science and Technology Research Centre (VRTC).

Specimens were identified using Attems (1930), Schileyko (2007, 2020), Siriwut et al. (2016), and Vu et al. (2020). Ecological indices including the number of species, Shannon-Weaver (H'), and uniformity (J') were calculated using the software Primer ver. 7.0 for each habitat type and altitude. A similarity index was calculated using the software R ver. 4.0.4.

RESULTS AND DISCUSSION

Diversity composition and distribution of Scolopendromorpha

From 156 specimens collected in the Nui Chua NP, 12 species/subspecies of five genera belonging to two families were identified. Eleven species were new records to the fauna of Nui Chua, including *Scolopendra morsitans, S. subspinipes, S. dehaani, S. japonica, Scolopendra* sp.*, Otostigmus spinosus, O. scaber, O. multidens, Asanada brevicornis, Ethmostimus rubripes platycephalus, Cryptops* (*Cryptops*) sp., and *Cryptops* (*Paracryptops*) *indicus* (Table 1).

With the harsh climate in the area, the rainy season is of short duration, from September to November, while the dry season lasts from December to August of the following year. The seasonal diversity of large centipedes in the Nui Chua NP area does not differ significantly. In the rainy season, 10 species were recorded, while in the dry season nine species were recorded. Centipedes are likely to be more active in the rainy season than in the dry season. This is evident from the number of specimens collected in each season, with 106 specimens found during the rainy season compared to 50 during the dry season. This phenomenon can be explained by the characteristic of centipedes to prefer to live in humid environments.

Three species, *Scolopendra morsitans*, *S. dehaani*, and *Scolopendra* sp., were recorded only in the rainy season, while *Scolopendra japonica* and subspecies *Ethmostimus rubripes platycephalus* were found only in the dry season.

Among the habitats, the NF is the most diverse one in terms of species and collected specimens (12 species and 123 individuals). The PF habitat is less diverse with five species and 27 individuals. The lowest number of species and collected specimens was recorded in the CF habitat (four species and only six individuals). This result

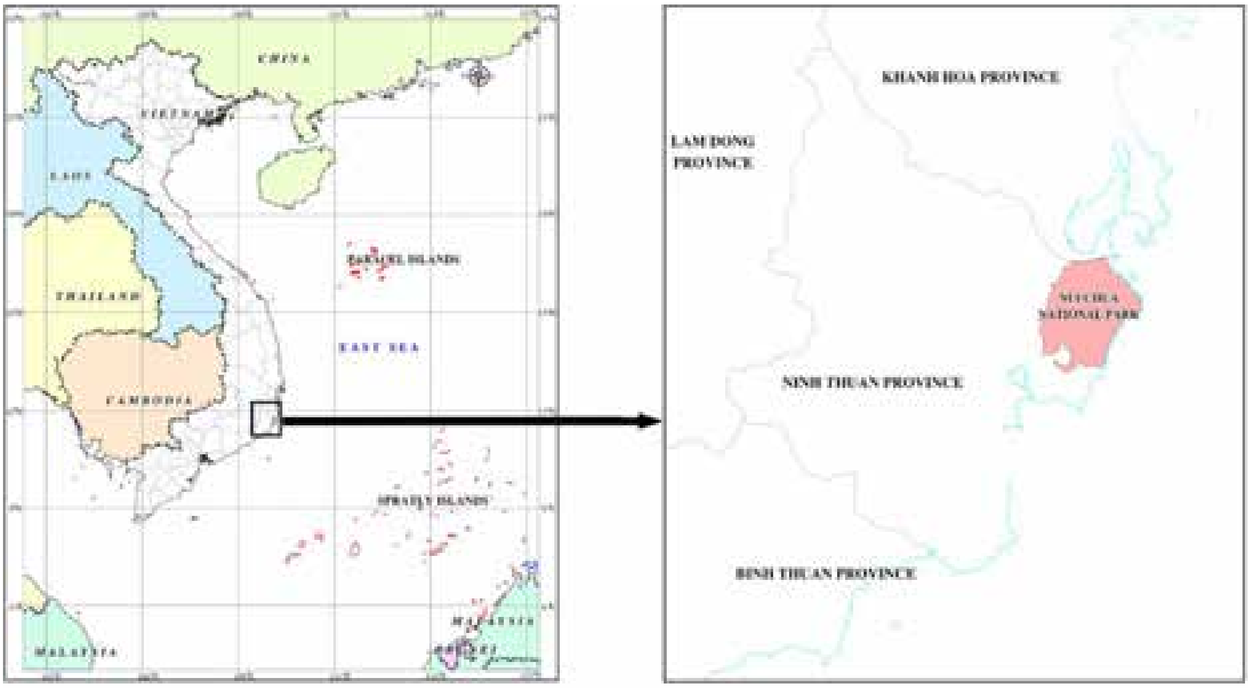

Figure 1. Location of Nui Chua National Park, Vietnam.

Table 1. Species composition and distribution of scolopendromorphs in Nui Chua National Park, Ninh Thuan province.

	Taxon	Season		Elevation range (m)			Habitat		
		Dry	Rain	0–300	300–600	600–1,000	NF	PF	CF
	Family Scolopendridae Pocock, 1895								
	Genus *Scolopendra* Linnaeus, 1758								
1	*Scolopendra morsitans* Linnaeus, 1758		+(6)	+(4)	+(2)		+(2)		+(4)
2	*Scolopendra subspinipes* Leach, 1815	+(13)	+(2)	+(4)	+(7)	+(4)	+(15)		
3	*Scolopendra dehaani* Brandt, 1840		+(1)	+(1)			+(1)		
4	*Scolopendra japonica* Koch, 1878	+(2)				+(2)	+(2)		
5	*Scolopendra* sp.		+(2)	+(2)			+(2)		
	Genus Otostigmus Porat, 1876								
6	*Otostigmus spinosus* Porat, 1876	+(4)	+(26)	+(24)	+(3)	+(3)	+(19)	+(11)	
7	*Otostimus scaber* Porat, 1876	+(6)	+(3)	+(2)	+(1)	+(6)	+(9)		
8	*Otostigmus multidens* Haase, 1887	+(9)	+(5)	+(3)	+(4)	+(7)	+(12)	+(2)	
	Genus *Asanada* Meinert, 1886								
9	*Asanada brevicornis* Meinert, 1886	+(7)	+(24)	+(19)	+(12)		+(26)	+(4)	+(1)
	Genus *Ethmostigmus* Newport, 1845								
10	*Ethmostimus rubripes platycephalus* (Newport, 1845)	+(1)				+(1)	+(1)		
	Family Cryptopidae Kohlrausch, 1881								
	Genus *Cryptops* Leach, 1815								
11	*Cryptops (Cryptops) sp.*	+(6)	+(33)	+(28)	+(7)	+(4)	+(28)	+(10)	+(1)
12	*Cryptops (Paracryptops) indicus* Silvestri, 1924	+(2)	+(4)	+(3)	+(3)		+(6)		
	Total number of individuals	**50**	**106**	**90**	**39**	**27**	**123**	**27**	**6**
	Total species	**9**	**10**	**10**	**8**	**7**	**12**	**5**	**3**

NF—natural broadleaf forests | PF—planted forests | CF—coniferous forests | +—present | The number in parantheses indicates samples collected.

is similar to previous research in other areas, in which the CF habitat has a lower number of species in comparison with the other habitats (Le & Vu 2018; Le et al. 2021). This is even more clearly shown in Nui Chua NP, where the terrain and climate are typical, and coniferous forests are concentrated mainly on the coast, so only species with wide distribution and adaptability can be found. There are only two species, *Asanada brevicornis* and *Cryptops* (*Cryptops*) sp. recorded in all three habitats; *Scolopendra morsistans*, *Otostigmus spinosus*, and *Otostigmus multidens* were recorded in two habitats; the remaining species were only recorded in NF.

Regarding topological distribution, the highest species diversity was recorded in the elevation range of less than 300 m (10 species), while other elevation ranges had lower diversity, with eight species recorded in the elevation of 300–600 m, and seven in the elevation of 600–1,000 m. Five species were recorded at all three different altitudes, including *Scolopendra subspinipes, Otostigmus spinosus, O. scaber, O. multidens*, and *Cryptops* (*Cryptops*) sp. Two species, *Scolopendra dehaani* and *Scolopendra* sp., were recorded only at altitudes below 300 m, while *Scolopendra japonica* and *Ethmostimus rubripes platycephalus* were recorded only at altitudes of 600–1,000 m. The remaining species were recorded at two altitude ranges below 600 m.

Taxon diversity

Only two families, Scolopendridae and Cryptopidae, were recorded in Nui Chua National Park. Of these, Scolopendridae had a higher diversity in terms of the number of recorded genera and species (four genera and 10 species). Cryptopidae had only one genus and two species recorded (Figure 2). This result is similar to previous studies on large centipede fauna in Vietnam (Tran et al. 2013, 2018; Le & Vu 2018; Nguyen et al. 2019).

Of five genera (Figure 3), *Scolopendra* was the genus with the highest number of species (five species, accounting for 42% of the total number of species), followed by *Otostigmus* with three species (accounting for 25%). The remaining two genera, *Asanada* and *Ethmostigmus*, had only one species each (accounting for 8%).

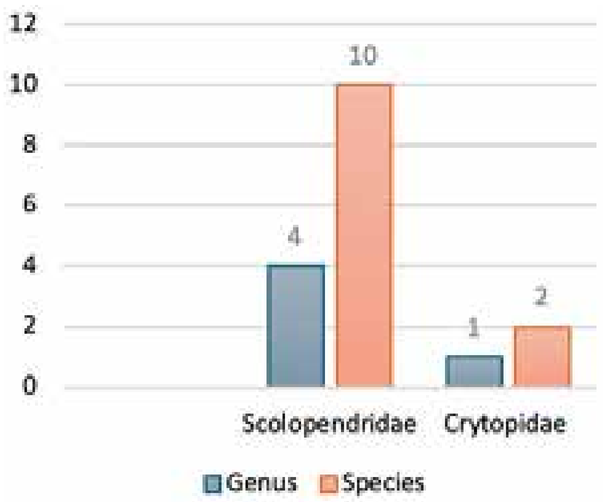

Figure 2. Family taxon diversity - Number of species in families.

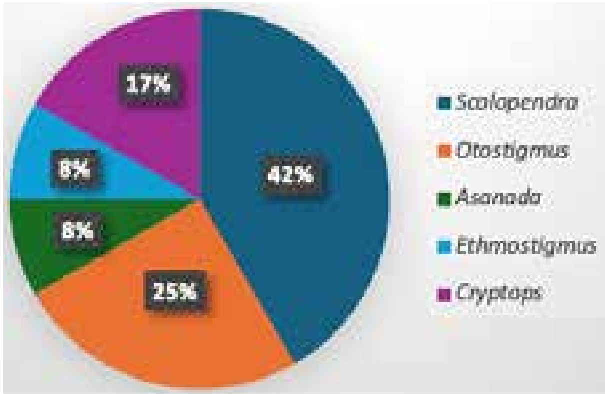

Figure 3. Generic taxon diversity - Percentage of species in genera.

Table 2. Diversity index and uniformity index by habitat and altitude.

Habitat/elevation (m)	Amount		Index	
	Species	Individual	J'	H'
NF	12	123	0.83	2.06
PF	4	27	0.87	1.21
CF	3	6	0.79	0.87
0–300	10	90	0.77	1.77
300–600	8	39	0.89	1.85
600–1,000	7	27	0.93	1.81

Biological indicators

The results of the biological indicators are presented in Table 2, in which the NF habitat had the highest H’ index of 2.06, this value showing that the diversity in this habitat was quite high. In contrast, the CF habitat had very poor diversity (H’ = 0.87). The PF habitat presented an average diversity (H’ = 1.21). For the altitude, all three altitudes showed moderate diversity with H’ ranging from 1.77 (0–300 m) to 1.81 (300–600 m). The uniformity index J’ showed that this index did not differ significantly among habitats. The uniformity was highest in the PF habitat (0.87), and lowest in the CF habitat (0.79). Regarding the altitude, J’ index expressed more

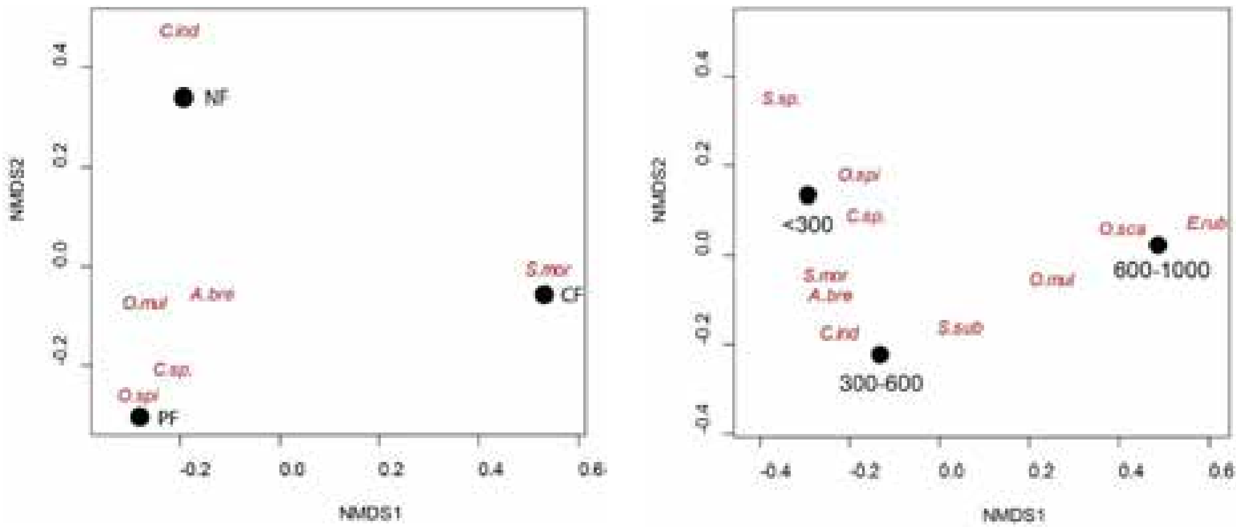

Figure 4. Non-metric multidimensional scaling (NMDS) analysis: A—by habitat | B—by elevation | *A.bre—Asanda brevicornis* | *C.ind—Cryptops* (*Cryptops*) *indicus* | *C.*sp.*—Cryptops* (*Cryptops*) sp. | *E.rub—Ethmostimus rubripes platycephalus* | *O.mul—Otostigmus multidens* | *O.spi—Otostigmus spinosus* | *O.sca—Otostigmus scaber* | *S.deh—Scolopendra dehaani* | *S.jap—Scolopendra japonica* | *S.mor—Scolopendra morsitans* | *S.sp.—Scolopendra* sp. | *S.sub—Scolopendra suspinipes.*

difference, whereby it was highest at altitudes of 600–1,000 m, with 0.89, and lowest at altitudes below 300 m with 0.77. Thus, at an altitude of 300 m, although there was the greatest diversity and richness, the uniformity of species is the lowest. This was due to differences in the number of collected specimens such as *Cryptops* (*Cryptops*) sp. (28 specimens), *Otostigmus spinosus* (24 specimens), while *Scolopendra dehaani* was represented by only one specimen.

The similarities in species composition among habitats and altitudes are shown in Figure 4 by NMDS analysis. According to the results in Figure 4A, the habitats express little similarity in species composition, made plain by the distance among the habitats in the figure. The close relationship of species to habitats is also clearly shown, whereby the species *Cryptops* (*Cryptops*) *indicus* is close to the NF, the *Scolopendra morsitans* is close to the CF habitat, three species (*Asanda brevicornis* (Image 1), *Cryptops* (*Cryptops*) sp., *Otostigmus multidens*, and *Otostigmus spinosus*) are closer to PF, but *Otostigmus spinosus* was the closest. Other species have not been seen to have associations with habitats.

The similarity by altitude (Figure 4B) shows that altitudes below 300 m are closer to altitudes 300–600 m than to altitudes 600–1,000 m. The recorded species also show close relationships with different altitudes. Among them, *Ethmostimus rubripes platycephalus* and *Otostigmus scaber* are closely related at altitudes of 600–1,000 m, *Cryptops* (*Cryptops*) sp. and *Otostigmus spinosus* are closer to altitudes below 300 m, while *Cryptops* (*Cryptops*) *indicus* and *Scolopendra subspinipes* are closer to altitudes of 300–600 m.

DISCUSSION

Nui Chua NP is located in the hottest and driest area in Vietnam with a very short rainy season, little annual rainfall, and a long dry season. The species diversity of the large centipedes was not very low (12 species). The results are similar to the diversity of Hoang Lien National Park, Thuong Tien, and Xuan Nha Nature Reserve in the northwestern region of Vietnam, where there is more diversity in habitat types, altitudes, and humid climates, more favourable for the growth and development of centipedes (Nguyen et al. 2018, 2019a,b).

In previous studies, it was noted that the genus *Otostigmus* has the highest diversity, but in this study, *Scolopendra* is shown to be the most diverse genus. Notably, the species *Scolopendra japonica* was recorded, previously mentioned by Siriwut (2016), to be distributed in Sapa (altitude above 1,600 m) in the north of Vietnam, in which the climate is completely different from Nui Chua NP. The geographical distance of the two recorded locations is very far apart, which shows that this species is most likely widely distributed in Vietnam. Additional studies are needed for different regions in Vietnam to confirm its distributional pattern.

Image 1. *Asanada brevicornis* Meinert, 1886.

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COMMUNICATION

Diversity of butterfly habitats in and around Udanti-Sitanadi Tiger Reserve, Chhattisgarh, India

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Abstract: A survey of Lepidoptera was conducted in habitats including forest trails, nullah, forest gap, and small water bodies, in and around the Udanti-Sitanadi Tiger Reserve (USTR) and agroforest habitats at Nagri block in Dhamtari district of Chhattisgarh State between January 2020 and August 2022. The study recorded 95 species belonging to 69 genera. *Erionota torus* and *Rathinda amor* although common in the Indian mainland, were not documented by previous researchers. This indicates the necessity for a more thorough survey of Lepidoptera in the region.

Keywords: Agroforest, biodiversity, checklist, *Erionota torus*, Hesperiidae, host plant, Lepidoptera, Lycaenidae, new record, *Rathinda amor*.

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Author contributions: HNT—Main contributor and corresponding author, led the team in field observations of butterflies. GKS—Conducted observations and photography of butterflies in Garhdongari village, Nagri block. He captured all the images of *Erionota torus* at Nagri. KD—Observed butterflies in urban habitats, recording *Rathinda amor* in her backyard in Raipur. GC—Focused on butterfly observations in Dhamtari district and recorded *Rathinda amor* at Chingrapagar Waterfall, Kodomali, Gariaband. RN—Documented biodiversity in Chhattisgarh since 2015, first recorded Rathinda amor in Kanger Valley National Park. RA—Documented butterflies in Gariaband district, recorded Erionota thrax in Deobhog.

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INTRODUCTION

Udanti-Sitanadi Tiger Reserve (USTR) in Chhattisgarh has not been extensively characterized with regard to Lepidoptera and their habitats. The USTR is located in the Gariaband and Dhamtari districts of Chhattisgarh State and covers about 1,872 km^2. The USTR has two core areas: Core-I, Udanti Wildlife Sanctuary (UWS) Gariaband, established with 247.59 km^2 area in 1983 under the Wildlife Protection Act, 1972, lies between 20.000—20.250 °N & 82.500—80.000 °E on the south-east to the capital city Raipur on National Highway 130C; and Core–II, Sitanadi Wildlife Sanctuary (SWS) Dhamtari, was established with 553.36 km^2 area in 1974 and it lies between 20.183°N & 81.933°E.

In earlier studies, 35 species belonging to five families and 13 subfamilies of butterflies were documented in USTR (Chandra & Boaz 2018). Around 95 species were observed during the present survey, with 60 observed for the first time in USTR. This survey also updated the list of butterflies in Chhattisgarh State, adding two additional species to the previous 170 species (Chandra et al. 2014; Dubey et al. 2015; Sisodia 2019; Sisodia & Kshirsagar 2020; Tandan et al. 2020, 2021a,b; Nihlani et al. 2021; Chand et al. 2022; Jangde et al. 2023).

MATERIAL AND METHODS

Habitats such as forest trails, nullah, small water bodies, agricultural farms, and grasslands within the USTR and small villages around it including Tumdibahra (20.251°N, 82.101°E), Arsikanhar (20.249°N, 82.129°E), Behradih (20.190°N, 82.218°E), Kodomali (20.191°N, 82.247°E), Taurenga (20.144°N, 82.277°E), and Jugad (20.136°N, 82.285°E) were surveyed. An agroforest habitat adjacent to USTR at Garhdongari village (20.270°N, 81.900°E) of Nagri block from January 2020 to August 2022, for the preparation of a database of the butterflies in Chhattisgarh were also surveyed. Paddy is the major crop in Chhattisgarh and some small paddy fields still exist inside the USTR, while the present study may help in planning for the conservation programs of butterflies and other pollinating agents in the reserve area.

For the present survey, binoculars were used for field observation of butterflies, a Canon 1300D DSLR Camera, and occasionally by iPhone. The identification of species was based on Evans (1932), Wynter-Blyth (1957), Haribal (1992), Smetacek (2016), and Kehimkar (2018). Species were identified & verified with the expert's help and following the website www.ifoundbutterflies.org.

OBSERVATIONS

Photographs were taken and a checklist of 95 butterfly species was prepared (Table 1). Among them, two widely spread species in mainland India were curiously absent from previous records:

Family Hesperiidae
Subfamily Hesperiinae

***Erionota torus* Evans, 1941 — Rounded Palm-redeye (Image 5 & 6)**

Known distribution in India: Uttarakhand to northeastern India; Karnataka, Kerala, Tamil Nadu (Varshney & Smetacek 2015).

Host plant: Coconut – *Cocos nucifera* and Banana - *Musa x paradisiaca* is the best-known larval host plant of *E. torus* (Nitin et al. 2018).

Remarks: *Erionota torus* inhabits to hill forest, recorded up to 1,370 m elevation and flying from June to October (Kehimkar 2018). These species were observed first time in Chhattisgarh by GS in Garhdongari village of Nagri block in October 2020 at 456 m elevation. An adult butterfly was sighted in a Banana plant during an opportunistic visit (Image 5). It was further spotted in October and November 2021 at the same plant in later visits, counted in 14 individuals (Image 6), and found some eggs on Banana leaves (Image 1 to 4). Later regular observations were made in December 2021 and 11 individuals at the same plant were photographed.

Family Lycaenidae
Subfamily Theclinae

***Rathinda amor* (Fabricius, 1775) - Monkey Puzzle (Image 7 & 8)**

Known distribution in India: Kerala to northeastern India. (Varshney & Smetacek 2015); India (Western Ghats, Andhra–Jharkhand, West Bengal, Sikkim–Arunachal, northeastern India), Bangladesh, Sri Lanka (Kehimkar 2016)

Host plant: *Mangifera indica, Meiogyne pannosa, Calophyllum, Hopea*, *Blachia*, *Croton, Barringtonia acutangula, Careya arborea*, *Loranthus*, *Eugenia roxburghii*, *Ixora, Ixora brachiate, Schleichera*, *Quassia indica.* (Nitin et al. 2018).

Remarks: *Rathinda amor* or Monkey Puzzle inhabits mainly forests, recorded in low elevations and flying from April to October (Kehimkar 2018). This butterfly was first time observed in Chhattisgarh on 12.x.2019

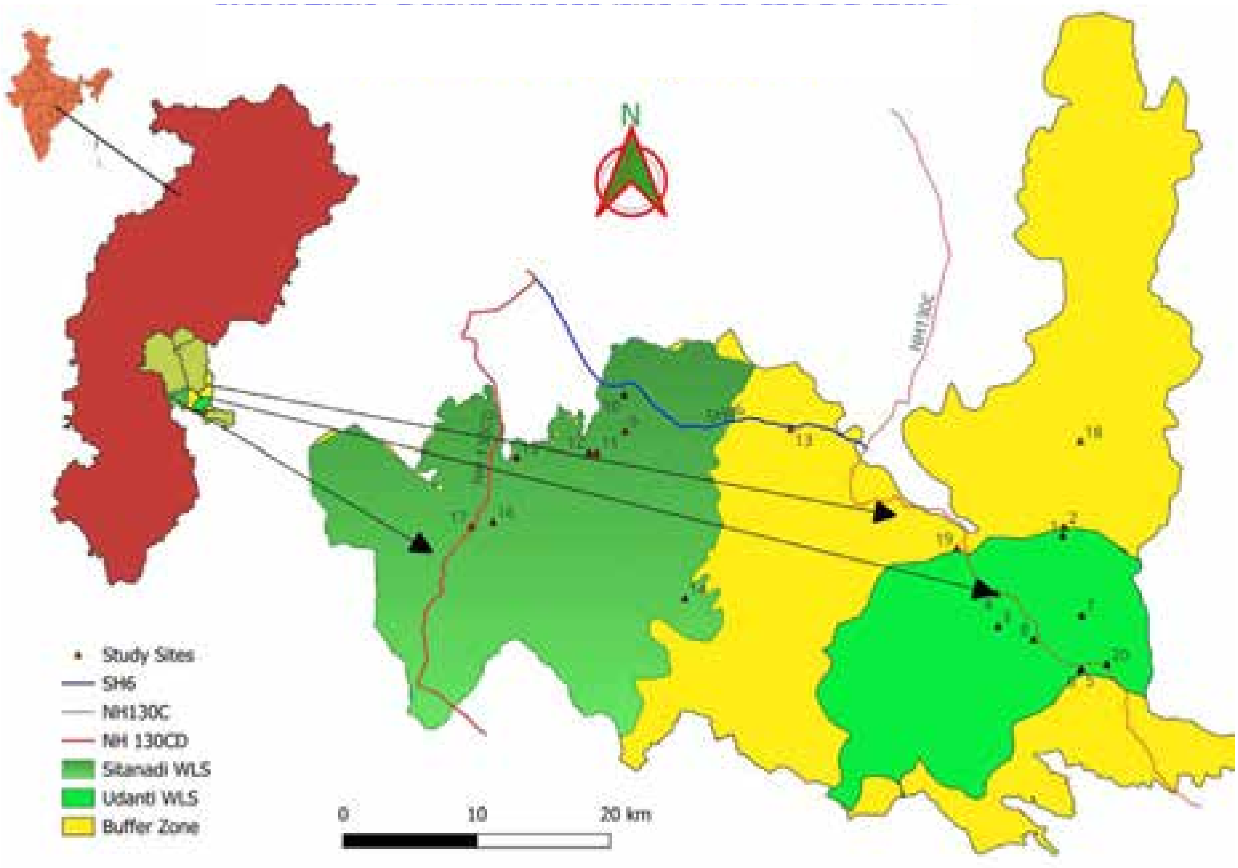

Image 1. Map of the study area and location of study sites.

at KVNP, subsequently observed in various parts of Chhattisgarh on 10.x.2020 & 12.x.2021 in Tatamari Eco-center Keshkal, it was observed in agricultural land at Garhdongari Village of Nagri block on 15.x.2021, also recorded from Chingrapagar Waterfall on 23.x.2021 and 30.viii.2022 Kodomali in Gariaband. This butterfly is inhabited mainly in forest habitat (Kehimkar 2018), and also observed in very densely populated Raipur City, the capital of Chhattisgarh.

RESULT AND DISCUSSION

The unique ecosystem of small paddy fields, in the villages including Nullah (Rivulet), small water bodies, small ponds, and grasslands inside the tiger reserve area provides a good habitat for butterflies. Agroforests, with their diverse vegetation, tree canopies, and flowering plants, create a unique habitat for butterfly communities. It was found that most of the butterflies were partially dependent on these small habitats for nectaring, puddling, and host plants.

The paddy field and agroforest areas are very suitable habitat for the butterflies. The study by Johnson et al. (2021) highlights the positive correlation between agroforestry systems and butterfly diversity and abundance. These findings emphasize the importance of considering agroforestry as a viable strategy for creating butterfly-friendly habitats in agricultural ecosystems (Johnson et al. 2021).

The present study showed the rich diversity of butterflies in agroforest habitats and agriculture fields due to the presence of host and nectar plants that are there because of the availability of water supplies during irrigation. About 95 species of butterflies documented belonged to six families and 19 subfamilies, of which 92 species have been observed in the present survey, and 3 species, were reported in the list of 35 species from USTR by Chandra & Boaz (2018), but not observed in the present survey. The absence of records for several common butterfly species from the state fauna of Chhattisgarh and the present study area can be attributed to a lack of concessive surveys. The present report has updated the checklist of butterflies of USTR hereby as 95 species of 69 genera belonging to six families. The two species *Rathinda amor* and *Erionota torus* were first

Table 1. Updated checklist of the butterflies recorded from habitats in and around Udanti-Sitanadi Tiger Reserve (USTR), Chhattisgarh, India.

	Common name	Scientific name	Recorded in USTR			
			Present survey (During 2020–2022)			
			UWLS	SWLS	NAGRI	Chandra & Boaz 2018
Order: Lepidoptera						
Super Family: Papilionoidea						
Family: Papilionoidae						
Subfamily: Papilioninae						
1*	Lime Swallowtail	*Papilio demoleus* (Linnaeus, 1758)	+	+	+	+
2*	Common Mormon	*Papilio polytes* (Linnaeus, 1758)	+	+	+	+
3	Blue Mormon	*Papilio polymnestor* Cramer, 1775	+	+	+	-
4	Common Banded Peacock	*Papilio crino* Fabricius, 1793	+	+	+	-
5*	Common Mime	*Papilio clytia* Linnaeus, 1758	-	+	-	+
6	Common Jay	*Graphium doson* (C.& R. Felder, 1864)	-	-	+	-
7	Tailed Jay	*Graphium agamemnon* (Linnaeus, 1758)	+	-	+	-
8**	Spot Swordtail	*Graphium nomius* (Esper, 1799)	-	-	-	+
Family: Riodinidae						
Subfamily: Riodininae						
9	Double-banded Judy	*Abisara* bifasciata (Moore, 1877)	+	+	+	-
Family: Pieridae						
Subfamily: Coliadinae						
10*	Common Emigrant	*Catopsilia pomona* (Fabricius, 1775)	+	+	+	+
11*	Mottled Emigrant	*Catopsilia pyranthe* (Linnaeus, 1758)	+	+	+	+
12*	Common Grass Yellow	*Eurema hecabe* (Linnaeus, 1758)	+	+	+	+
13	Small Grass Yellow	*Eurema brigitta* (Stoll, [1780])	+	+	+	-
14	Spotless Grass Yellow	*Eurema laeta* (Boisduval, 1826)	+	+	+	-
Subfamily: Pierinae						
15*	Indian Jezebel	*Delias eucharis* (Drury, 1773)	+	+	+	+
16*	Psyche	*Leptosia nina* (Fabricius, 1793)	-	+	+	+
17	Indian Wanderer	*Pareronia hippia* (Fabricius, 1787)	+	+	+	-
18*	Common Gull	*Cepora nerissa* (Fabricius, 1775)	+	-	+	+
Family: Lycaenidae						
Subfamily: Miletinae						
19	Apefly	*Spalgis epius* (Westwood, [1851])	+	-	+	-
Subfamily: Curetinae						
20	Indian Sunbeam	*Curetis thetis* (Drury, [1773])	-	-	+	-
Subfamily: Theclinae						
21	Common Shot Silverline	*Spindasis ictis* (Hewitson, 1865)	+	+	+	-
22*	Common Silverline	*Spindasis vulcanus* (Fabricius, 1775)	+	+	+	+
23	Redspot	*Zesius chrysomallus* (Hübner, 1819)	-	-	+	-
24	Purple Leaf Blue	*Amblypodia anita* (Hewitson, 1862)	+	+	+	-
25	Indigo Flash	*Rapala varuna* (Horsfield, 1829)	+	-	+	-
26	Common Red Flash	*Rapala iarbus* (Fabricius, 1787)	-	-	+	-
27	Orchid Tit	*Chliaria othona* (Hewitson,1865)	+	-	+	-
28	State Flash	*Rapala manea* (Hewitson, 1863)	-	-	+	-

	Common name	Scientific name	Recorded in USTR			
			Present survey (During 2020–2022)			
			UWLS	SWLS	NAGRI	Chandra & Boaz 2018
29	Common Guava Blue	*Virachola Isocrates* (Fabricius, 1793)	+	-	+	-
30*	Large Oakblue	*Arhopala amantes* (Hewitson, 1862)	+	+	+	+
31	Silver Royal	*Ancema blanka* (de Niceville, 1894)	+	-	-	-
32#	Monkey Puzzle	*Rathinda amor* (Fabricius, 1775)	+	+	+	-
33**	Yamfly	*Loxura atymnus* (Stoll, 1780)	-	-	-	+
Subfamily: Polyommatinae						
34*	Common Pierrot	*Castalius rosimon* (Fabricius, 1775)	+	+	+	+
35	Lesser Grass Blue	*Zizina otis* (Fabricius, 1787)	+	+	+	-
36	Forget-me-not	*Catochrysops strabo* (Fabricius, 1793)	+	-	+	-
37	Angled Pierrot	*Caleta decidia* (Hewitson, 1876)	+	+	+	-
38	Common Lineblue	*Prosotas nora* (C. Felder, 1860)	+	+	+	-
39	Tailless Lineblue	*Prosotas dubiosa* (Semper, [1879])	+	-	+	-
40	Pointed Ciliate Blue	*Anthene lycaenina* (R. Felder, 1868)	-	-	+	-
41	Small Grass Jewel	*Freyeria putli* (Kollar, [1844])	-	+	+	-
42	Lime Blue	*Chilades lajus* (Stoll, [1780])	+	+	+	-
43	Indian Cupid	*Everes lacturnus* (Godart, [1824])	-	-	+	-
44	Dingy Lineblue	*Petrelaea dana* (de Nicéville, 1884)	+	+	+	-
45	Common Hedge Blue	*Acytolepis puspa* (Horsfield, 1828)	-	+	+	-
46	Common Cerulean	*Jamides celeno* (Cramer, 1775)	-	-	+	-
47	Dark Cerulean	*Jamides bochus* (Stoll, 1782)	+	-	+	-
48*	Pea Blue	*Lampides boeticus* (Linnaeus, 1767)	+	-	+	+
49	Zebra Blue	*Leptotes plinius* (Fabricius, 1793)	+	+	+	-
50	Dark Grass Blue	*Zizeeria karsandra* (Moore, 1865)	+	+	+	-
51	Tiny Grass Blue	*Zizula hylax* (Fabricius, 1775)	+	+	+	-
52	Gram Blue	*Euchrysops cnejus* (Fabricius, 1798)	+	+	+	-
53	Black Spotted Pierrot	*Tarucus balkanica* (Freyer, 1844)	+	+	+	-
Family: Hesperiidae						
Subfamily: Coeliadnae						
54	Common Banded Awl	*Hasora chromus* (Cramer, [1780])	+	+	+	-
Subfamily: Hesperiinae						
55	Dark Palm-Dart	*Telicota bambusae* (Moore, 1878)	+	+	+	-
56	Paint-brush Swift	*Baoris farri* (Moore, 1878)	-	-	+	-
57*	Rice Swift	*Borbo cinnara* (Wallace, 1866)	+	+	+	+
58	Palm Redeye	*Erionota thrax* (Linnaeus, 1767)	+	+	+	-
59 #	Banana Skipper	*Erionota torus* Evans, 1942	-	-	+	-
60	Chestnut Bob	*Iambrix salsala* (Moore, 1866)	-	-	+	-
61*	Grass Demon	*Udaspes folus* (Cramer, 1775)	+	+	+	+
Subfamily: Pyrginae						
62	Golden Angle	*Caprona ransonnettii* (R. Felder, 1868)	-	-	+	-
63*	Indian Skipper	*Spialia galba* (Fabriciu, 1793)	+	+	-	+

	Common name	Scientific name	Recorded in USTR			
			Present survey (During 2020–2022)			
			UWLS	SWLS	NAGRI	Chandra & Boaz 2018
Family: Nymphalidae						
Subfamily: Biblidinae						
64	Angled Castor	*Ariadne ariadne* (Linnaeus, 1763)	_	_	+	-
65*	Common Caster	*Ariadne merione* (Cramer, 1777)	+	-	+	+
Subfamily: Charaxinae						
66	Cryptic Nawab	*Charaxes bharata* C. & R. Felder, [1867]	_	_	+	-
Subfamily: Danainae						
67*	Plain Tiger	*Danaus chrysippus* (Linnaeus, 1758)	+	+	+	+
68*	Striped Tiger	*Danaus genutia* (Cramer, [1779])	+	+	+	+
69*	Blue Tiger	*Tirumala limniace* (Cramer, [1775])	+	-	+	+
70*	Common Crow	*Euploea core* (Cramer, [1780])	+	+	+	+
Subfamily: Satyrinae						
71	Common Palmfly	*Elymnias hypermnestra* (Linnaeus, 1763)	+	+	+	-
72*	Common Evening Brown	*Melanites leda* (Linnaeus, 1758)	+	+	+	+
73	Bamboo Treebrown	*Lethe europa* (Fabricius, 1775)	-	-	+	-
74*	Common Bushbrown	*Mycalesis perseus* (Fabricius, 1775)	+	+	+	+
75**	Common Four-ring	*Ypthima huebneri* Kirby, 1871	-	-	-	+
Subfamily: Heliconiinae						
76*	Common Leopard	*Phalanta phalantha* (Drury, [1773])	+	-	+	+
Subfamily: Limenitidinae						
77*	Common Sailer	*Neptis hylas* (Linnaeus, 1758)	+	+	+	+
78	Chestnut-streaked Sailer	*Neptis jumbah* Moore, [1858]	+	-	-	-
79	Short-banded Sailer	*Phaedyma columella* (Cramer, [1780])	-	+	-	-
80	Common Lascar	*Pantoporia hordonia* (Stoll, [1790])	-	+	-	-
81	Grey Count	*Tanaecia lepidea* (Butler, 1868)	+	+	_	-
82	Common Baron	*Euthalia aconthea* (Cramer, [1777])	+	+	+	-
83	Gaudy Baron	*Euthalia lubentina* (Cramer, [1777])	-	-	+	-
84*	Commander	*Moduza procris* (Cramer, [1777])	+	+	+	+
85*	Staff Sergeant	*Athyma selenophora* (Kollar, [1844])	+	+	-	+
86*	Baronet	*Euthalia nais* (Forster, 1771)	+	+	+	+
Subfamily: Nymphalinae						
87	Peacock Pansy	*Junonia almana* (Linnaeus,1758)	+	+	+	-
88*	Gray Pansy	*Junonia atlites* (Linnaeus, 1763)	+	+	+	+
89	Lemon Pansy	*Junonia lemonias* (Linnaeus, 1758))	+	+	+	-
90*	Chocolate Pansy	*Junonia iphita* (Cramer, [1779])	+	+	+	+
91	Blue Pansy	*Junonia orithya* (Linnaeus, 1758)	+	+	+	-
92	Yellow Pansy	*Junonia hierta* (Fabricius, 1798)	-	-	+	-
93*	Danaid Eggfly	*Hypolimnas misippus* (Linnaeus, 1764)	+	+	+	+
94	Great Eggfly	*Hypolimnas bolina* (Linnaeus, 1758)	+	+	+	-
Subfamily: Acraeinae						
95*	Tawny Coster	*Acraea violae* (Fabricius, 1793)	+	+	+	+

#—New records added to the state fauna of butterflies, Chhattisgarh in the present study | *—Documented in Udanti Sitanadi Tiger Reserve by Chandra & Boaz (2018) | **—Documented only by Chandra & Boaz (2018) in Sitanadi-Udanti Tiger Reserve.

Table 2. New records were added to the list of butterflies (Lepidoptera: Rhopalocera) of Chhattisgarh (Chandra et al. 2014; Dubey et al. 2015; Sisodia 2019).

	Scientific name	Common name	Recorder/ Author name
	Order: Lepidoptera		
	Super Family: Papilionoidea		
	Family: Hesperiidae		
	Subfamily: Hesperiinae		
1	*Notocryptacurvifascia* (C. & R. Felder, 1862)	Restricted Demon	Chandra et al. 2014
2	*Borbo cinnara* (Wallace, 1866)	Rice Swift	
3	*Telicota colon* (Fabricius, 1775)	Pale Palm-Dart	
	Subfamily: Pyrginae		
4	*Celaenorrhinusambareesa* (Moore, [1866])	Malabar Spotted Flat	
5	*Coladeniaindrani* (Moore, [1866])	Tricolour Pied Flat	
6	Tagiadesjapetus (Stoll, [1781])	Common Snow Flat	
	Family: Lycaenidae		
	Subfamily: Polyommatinae		
7	*Anthene emolus* (Godart, [1824])	Common Ciliate Blue	
8	*Acytolepis puspa* (Horsfield, [1828])	Common Hedge Blue	
9	*Everes lacturnus* (Godart, [1824])	Indian Cupid	
10	*Freyeria trochylus* (Freyer, 1845)	Grass Jewel	
11▲	*Petrelaea dana* (de Nicéville, [1884])	Dingy Lineblue	
12	*Prosotus dubiosa* (Semper, [1879])	Tailless Lineblue	
13	*Catochrysops panormus* (C. Felder, 1860)	Silver Forget-me-not	
	Subfamily: Theclinae		
14	*Amblypodia anita* Hewitson, 1862	Purple Leaf Blue	
15	*Rapala pheretima* (Hewitson, [1863])	Copper Flash	
16	*Virachola isocrates* (Fabricius, 1793)	Common Guava Blue	
17	*Zesius chrysomallus*Hübner, [1819]	Redspot	
	Subfamily: Biblidinae		
18	*Ariadne ariadne* (Linnaeus, 1763)	Angled Castor	
	Subfamily: Cyrestinae		
19	*Cyrestis thyodamas* Doyère, [1840]	Common Map	
	Subfamily: Danainae		
20	*Parantica aglea* (Stoll, [1782])	Glassy Tiger	
21	*Tirumala septentrionis* (Butler, 1874)	Dark Blue Tiger	
	Subfamily: Papilioninae		
22	*Graphium doson* (C. & R. Felder, 1864)	Common Jay	
	Family:Hesperiidae		Dubey et al. 2015
	Subfamily:Coeliadinae		
23	*Badamia exclamationis* (Fabricius, 1775)	Brown Awl	
24	*Burara jaina* (Moore, [1866])	Common Orange Awlet	
25	*Hasora vitta* (Butler, 1870)	Plain Banded Awl	
	Subfamily: Pyrginae		
26	*Caprona ransonnettii* (R. Felder, 1868)	Golden Angle	
27	*Odontoptilum angulata* (C. Felder, 1862)	Chestnut Angle	
	Family: Lycaenidae		Sisodia 2019
	Subfamily: Curetinae		
28	*Curetis acuta* Moore, 1877	Acute Sunbeam	
29	*Curetis thetis* (Drury, [1773])	Indian Sunbeam	
	Subfamily: Miletinae		
30	*Spalgis epius* (Westwood, [1851])	Apefly	
	Subfamily: Polyommatinae		
31	*Chilades lajus* (Stoll, [1780])	Lime Blue	
32	*Chilades parrhasius* (Fabricius, 1793)	Small Cupid	
33	*Megisba malaya* (Horsfield, [1828])	Malayan	
34	*Neopithecops zalmora* (Butler, [1870])	Common Quaker	
35	*Prosotus nora* (C. Felder, 1860)	Common Lineblue	
36	*Azanus ubaldus* (Stoll, [1782]	Bright Babul Blue	
37▲	*Petrelaea dana* (de Nicéville, [1884])	Dingy Lineblue	
	Subfamily: Poritiinae		
38	*Poritia hewitsoni* Moore, [1866]	Common Gem	
	Subfamily: Theclinae		
39	*Horaga onyx* (Moore, [1858])	Common Onyx	
40	*Rapala varuna* (Horsfield, [1829])	Indigo Flash	
41	*Zeltus amasa* (Hewitson, [1865])	Fluffy Tit	
	Family: Nymphalidae		
	Subfamily: Charaxinae		
42	*Charaxes agrarius*Swinhoe, [1887]	Anomalous Nawab	
43	*Charaxes psaphon* Westwood, 1847	Plain Tawny Rajah	
	Subfamily: Danainae		
44	*Euploea sylvester* (Fabricius, 1793)	Double-branded Crow	
	Subfamily: Heliconiinae		
45	*Vagrans egista* (Cramer, [1780])	Vagrant	
	Subfamily: Satyrinae		
46	*Ypthima asterope* (Klug, 1832)	Common Threering	

▲ Added by Chandra et al., (2014) and repeated by Sisodia, (2019) as new record.

Table 3. Updates on the butterflies of Chhattisgarh: recent findings post 2019.

	Family	Subfamily	Scientific name	Common name	Recorder/Author name
01.	Hesperiidae	Pyrginae	*Tagiades litigiosa* (Moeschler, 1878)	Water Snow Flat	Sisodia & Kshirsagar 2020
02.	Hesperiidae	Hesperiinae	*Gangara thyrsis* (Fabricius, 1775)	Giant Redeye	
03.	Lycaenidae	Theclinae	*Horaga viola* Moore, 1882	Brown Onyx	
04.	Lycaenidae	Polyommatinae	*Jamides bochus* (Stoll, 1782)	Dark Cerulean	Tandan et al. 2020
05.	Lycaenidae	Polyommatinae	*Anthene lycaenina* (R. Felder, 1868)	Pointed Ciliate Blue	
06.	Hesperiidae	Pyrginae	*Caprona agama* (Moore, 1858)	Spotted angle	Nihlani et al. 2021
07.	Lycaenidae	Polyommatinae	*Freyeria putli* (Kollar, 1844)	Lesser Grass Jewel	Tandan et al. 2021a
08.	Lycaenidae	Theclinae	*Spindasis ictis* (Hewitson, 1865)	Common Shot Silverline	
09.	Nymphalidae	Danainae	*Euploea klugii* (Moore, 1858)	King Crow	
10.	Lycaenidae	Theclinae	*Ancema blanka* (de Nicéville 1894)	Silver Royal	Tandan et al. 2021b
11.	Lycaenidae	Polyommatinae	*Tarucus balkanicus* Bethune-(Baker, 1918)	Black-spotted Pierrot	Chand et al. 2022

Image 1–4. *Erionota torus* (eggs). © Gulshan Kumar Sahu.

Image 5. *Erionota torus* (adult). ©Gulshan Kumar Sahu.

Image 6. *Erionota torus* (adult). © Gulshan Kumar Sahu.

Image 7. *Rathinda amor* (adult). © Gulshan Kumar Sahu.

Image 8. *Rathinda amor* (adult). © H.N. Tandan.

Image 9. *Erionota thrax*. © Ramanand Agrawal.

Image 10. *Ancema blanka*. ©H.N. Tandan.

documented here in the Chhattisgarh State and added to the butterfly fauna of Chhattisgarh.

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COMMUNICATION

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A short-term impact of enriched CO_2 [eCO_2] on select growth performance of *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) and its host plant *Gossypium barbadense* L. (Malvaceae)

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Abstract: Natural interactions between herbivorous insect pests and their host plants are expected to be altered significantly as atmospheric CO_2 concentrations (aCO_2) continue to rise according to climate change scenario. The possible effect of enriched CO_2 (eCO_2) environments on these interactions is under attention. To better understand such effects on select insect growth parameters; early (3rd) and penultimate (6th) instar larvae of the Cotton Leaf Worm *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae), reared on the cotton plant leaves *Gossypium barbadense* L. (Malvacae) grown under either ambient (aCO_2 = 350 ppm) or enriched (eCO_2 = 700 ppm) atmospheres were investigated.

Keywords: Ambient CO_2, CO_2-enriched atmosphere, growth parameters.

Japanese: 気候変動シナリオに従って大気中の二酸化炭素濃度（aCO_2）が上昇するにつれて、草食性害虫と被食植物の間の自然な相互作用は大きく変化すると予測されます。高濃度のCO_2（eCO_2）環境がこれらの相互作用に及ぼす影響が注目されています。そのような効果が昆虫の成長に与える影響を調べるために、鱗翅目ヤガ科の*Spodoptera littlralis*（Boisd）の初期幼虫（3齢）と終齢幼虫（6齢）を、通常の二酸化炭素濃度（aCO_2=350ppm）条件下と高濃度の二酸化炭素濃度(eCO_2=700ppm)で栽培した綿植物*Gossypium barbadense* L. （ アオイ科)で飼育して、成長を比較しました。

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INTRODUCTION

The ever-increasing combustion of fossil fuels, such as energy generation in coal-fired power plants, cement plants, oil refineries, and land-use changes has contributed towards the increase of atmospheric CO_2 concentration (aCO_2) (Houghton et al. 1992; Leakey et al. 2009; Goufo et al. 2014). The aCO_2 level has gone from the pre-industrial value of 280 ppm to a current level of 418 ppm (December 2022) where a high aCO_2 concentration is a big risk to human health, for example, it can trigger respiratory illnesses when the aCO_2 concentration is over 600 ppm (NOAA 2022; Åhlén et al. 2023).

The rate of change of aCO_2 levels has accelerated with models predicting that by the middle of this century; the aCO_2 levels will escalate to 550 ml L^{-1} and expected to rise to about 800 ml L^{-1} by the end of this century (Long & Ort 2010; Feng & Cheng 2014).

Increasing amount of CO_2 in the atmosphere affects the global climate temperature, which can have an adverse effect on all life forms on this planet (Bazzaz 1990; Abu ElELa & ElSayed 2018; Ashok et al. 2022). Thus, numerous studies have focused on understanding the CO_2 effects on various aspects of plant growth, productivity, and survival in crops. Only a few studies have dealt with the nutritional quality of food crops and even fewer studies on the health-promoting phytochemicals in food crops (Rajashekar 2018).

Little is known about the effects of the eCO_2 environments, which are anticipated to exist in the next century, on natural plant-insect herbivore interactions. Because of the crucial role of CO_2 in photosynthesis, the expected increase in global aCO_2 levels will exert a significant influence on the biological systems.

Climate change has a marked impact on the biology and population ecology of insect pests with direct impact on the physiology and behavior of the insect (Berrigan 2000). Insect life cycle is influenced by climate, this includes total duration of life span, fecundity, mortality, and genetic adaptation (Helmuth et al. 2002; Hoffmann et al. 2003; Stillman 2003; Abu ElEla & ElSayed 2018). Moreover, the indirect effects could be observed through the impact on host plant, parasitoids, and predators of insect pests (Manimanjari & Rao 2022). In addition to this, eCO_2 will affect the quality of foliage and in turn influence the potential herbivorous behavior of the insect pest.

Often, plant species grown in eCO_2 environments have a higher foliar water content than those grown under aCO_2 conditions (Wong 1979; Fajer et al. 1991; Lincoln et al. 1993), potentially enhancing insect herbivore performance (Scriber 1977, 1979). However, plant species reared in eCO_2 environments also showed comparatively reduced nitrogen concentrations in leaves (Wong 1979; Williams et al. 1981; Fajer et al. 1991; Lincoln et al. 1993).

Studies dealing with lepidopteran larvae have revealed that insect herbivores consistently respond to changes in plant foliar quality induced by eCO_2 environments by consuming more foliage (Osbrink et al. 1987; Johnson & Lincoln 1990; Fajer et al. 1991, Abu ElEla & ElSayed 2018). It is assumed that insects consume more foliage to compensate for reduced foliar nitrogen concentrations (Slansky & Feeny 1977). Some species showed a lower rate of larval development or even incomplete development of larvae; decreased fecundity , and increased mortality (Osbrink et al. 1987; Fajer 1989; Fajer et al. 1991).

In Egypt, one of the most important fiber crops is the cotton, *Gossypium barbadense* L. (Malvaceae), and because of its economic importance; the phytophagous insect *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) larva is considered as one of the major and injurious noctuid predator of cotton in Egypt (Abu ElEla & ElSayed 2018).

Laboratory feeding studies and growth chamber experiments have provided useful information about the responses of insect herbivores to specific foliage or plant species grown under aCO_2 and eCO_2 conditions (Caulfield & Bunce 1994; Abu ElEla & El Sayed 2018; Rao et al. 2012; Manimanjari & Rao 2022).

Indeed, there is a shortage of knowledge and the information pertaining to the possible influence of eCO_2 regime on natural interactions between the noctuid pest, *S. littoralis* (Boisd.), and its host plants especially those of economic importance (such as *G. barbadense* L.) are fragmentary. Thus, the aim of this research work is to focus some light on some select biological and life cycle parameters of *S. littoralis* (Boisd.) fed with cotton plant leaves, *G. barbadense* L. var. Super Giza 85, grown under both aCO_2 (350 ppm) & eCO_2 (700 ppm).

MATERIALS AND METHODS

The study was conducted at the Laboratory of Applied Entomology, Cairo University, Egypt. Cotton seeds of *Gossypium barbadense* L. (var. Super Giza 85) were obtained from Seeds Bank at the Ministry of Agriculture, Cairo, Egypt. Five seeds/4-liter soil were germinated in plastic pots containing sand & clay through summer season from May to September and were irrigated regularly by tap water. These pots were placed inside designated cuboid open top chambers (80 *l* x 80 *w* x 80 *h* cm). Natural lighting, ranging from 600 µ mol-2s^{-1} to 2,000 µ mol-2s^{-1}, was primarily used. Although white fluorescent Philips® lamps, automatically programmed were used to maintain a 12D: 12L light regime, added additional light at 1,000 µmol-2s^{-1} were used when light levels fell below 600 µmol-2s^{-1} (Carlson & Bazzaz 1980). These chambers containing the *G. barbadense* L. var. Super Giza saplings were exposed to aCO_2 (350 ppm) and eCO_2 (700ppm) regimes. Plants were grown for 30 days before offering the foliage as a diet for the experimental insect.

Leaf nutritional quality

Leaf nutritional quality was measured at 30 days and 45 days by chemical analyses of contents for total nitrogen, total carbohydrates, and phenolic compounds. Chemical analysis was done for total amino acids according to the method described by Russell (1944), total carbohydrates according to Streeter & Jeffers (1979), and total phenolic compounds according to the method by Jindal & Singh (1975).

Growth conditions of *S. littoralis* (Boisd.)

Eggs were obtained from the females of *S. littoralis* (Boisd.) reared from standard laboratory colony maintained at the Department of Entomology, Cairo University since 2000s. Two groups of 50 eggs were placed in plastic petridishes (Ø 14 cm) with moist paper towel strips taped to the lid to maintain suitable air humidity. One group of hatched larvae was offered cotton plant leaves grown in aCO_2 regime while the other group was fed on leaves grown in eCO_2 regime.

Hatched larvae were kept in growth chambers with a 14 h day: 10 h night light regime and 25°C day: 20°C night temperature regime. Fresh leaves were provided every other day. Each CO_2 treatment had 20 replicates of 10 larvae per petridish. Larvae were reared & fed from the 1st instar till last instar and ceased feeding as they reached prepupal stage.

The 3rd (hereafter considered as the early instar) and the 6th (considered as the penultimate instar) (Image 1) were used as main larval instars in this experiment due to their potential herbivory (ElEla & ElSayed 2018). Usually, *S. littoralis* (Boisd.) shows six larval instars, however, we treated the 3rd larval instar as an early instar since the 1st and 2nd instars showed less herbivory attitude to cotton leaves (personal observations) and only nibbling of soft leaves could be observed. Also, the 6th instar showed strong voracious tendency to consume leaves until reaching the prepupal stage which showed unambiguous cessation of feeding.

The number and average fresh weights of newly formed prepupae were recorded. The prepupae were then placed in sieved, sterilized, and moistened wood dust to proceed in forming the pupal cases. Percentage pupation and mean pupal duration were recorded. By the emergence of adults, number of emerged adults, longevity, and sex ratio were recorded. The freshly emerged adults were fed on 10% sugary solution (sucrose solution) and were offered small fresh twigs bearing leaves of *Nerium oleander* L. to serve as ovipositional sites for adult females.

Statistical analysis

The effects of CO_2 regimes on the select larval parameters were evaluated by one-way Analysis of Variance (ANOVA). The differences between the mean values of treatments were determined by Duncan's multiple range test. Treatment means were compared and separated using least significant difference (LSD) at $p < 0.05$. All statistical analyses were computed by using SPSS version 16.0.

RESULTS AND DISCUSSION

Data depicted in Table 1 revealed insignificant difference ($p > 0.05$) between mean larval duration for the 3rd and 6th larval instars fed cotton plant leaves grown under aCO_2 and eCO_2 regimes. In general, the larval duration for either 3rd (early) and 6th (penultimate) larval instars were slightly greater for those fed cotton leaves grown in eCO_2 regime. However, significant difference ($p < 0.05$) in the percentage larval survival was observed between the two regimes (Table 1). The percentage larval survival was greater for larvae fed aCO_2 grown cotton leaves compared to those fed enriched-grown leaves (Table 1). It was clear that relatively greater number of larvae fed aCO_2 could successfully complete the larval duration when compared to those fed eCO_2-grown cotton leaves. Also, it seemed that larval mortality could be related to the nutritional deficiency that resulted from reduced foliar nitrogen levels in eCO_2 grown plants (Brooks & Whittaker 1999; Abu ElEla & ElSayed 2018).

Although we found that penultimate *S. littoralis* (Boisd.) larvae consumed additional eCO_2-grown cotton leaves (based on personal observations), they showed relatively slower growth rate with longer larval duration (Table 1). Moreover, these penultimate larvae produce

Table 1. Select parameters of larval stages of *Spodoptera littoralis* (Boisd.) fed the leaves of *Gossypium barbadense* L. grown in ambient (aCO2 = 350 ppm) and enriched (eCO2 = 700 ppm) CO2 regimes.
*** Results followed by different letters are significantly different (p <0.05)**

Insect parameters	CO_2 treatment	
	aCO_2 (350 ppm)	eCO_2 (700 ppm)
Larval stage		
Larval duration (day)		
3rd instar (early)	3.6 ± 0.116[a*]	3.83 ± 0.27[a]
6th instar (penultimate)	4.5 ± 0.27[a]	4.83 ± 0.253[a]
Percentage total larval survival (%)	90.83 ± 0.19[a]	83 ±2.27[b]
Prepupal stage		
Prepupal fresh weight (g.)	2.27 ± 0.158[a]	1.27 ± 0.014[b]
Pupal stage		
Percentage pupation (%)	90.53 ± 1.486[a]	84.66 ± 4.83[a]
Pupal fresh weight (g)	2.583 ± 0.036[a]	1.87 ± 0.027[b]
Pupal duration (day)	11.33 ± 0.026[a]	7.66 ± 0.068[b]
Adult stage		
Percentage adult emergence (%)	96.27 ± 2.21[a]	82.24 ± 3.98[b]
Sex ratio		
Male (%)	56.33 ± 3.82[a]	58.33 ± 3.21[a]
Female (%)	46.67 ± 4.38[a]	44.33 ± 3.82[a]

pupae with relatively lighter fresh weights compared to those produced from the penultimate instars fed aCO_2-grown leaves (Table 1). This could be attributed to their inability to fully compensate for the diet which is relatively poor in nitrogen as they were forced to metabolize food at higher flow rates, such as when they consumed additional eCO_2-grown leaves, they could not effectively process enough food for the compensation of relatively lower nitrogen concentrations (Rogers et al. 1994; Davis & Potter 1989; Abu ElEla & ElSayed 2018). However, it is far from precise to generalize this finding among other insect pest species since Hughes & Bazzaz (1997) reported no effect on populations of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) fed with *Ascelpias syriaca* L. (Asclepiadaceae) grown in eCO_2 atmosphere.

Prolonged larval duration, such as those induced by the eCO_2-grown diets in this study, may prevent larvae from completing development in climatically limited environments with short growing seasons (Davis & Potter 1989; Watt et al. 1995). Reduced growth rates and increased larval duration of the larvae fed eCO_2-grown leaves may also increase their exposure to predators & parasitoids (Carlson & Bazzaz 1980; Davis & Potter 1989; Ottman et al. 2001).

As penultimate larvae reached the prepupal stage, the interruption of feeding was noticeable (Montezano et al. 2019). The prepupae started to build the pupal case which made it possible to observe metamorphosis and determine the end of the prepupal period which was relatively short duration (1–2 days) in both the CO_2 regime.

The recorded prepupal fresh weight showed significant difference ($p <0.05$) between the aCO_2 and eCO_2 regimes (Table 1). Pre-pupae resulted from penultimate larvae fed cotton leaves grown in aCO_2 regime were remarkably heavier than those resulted from larvae fed eCO_2-grown leaves (Table 1).

Although the mean percentage pupation was found to be lower for larvae fed cotton leaves grown in eCO_2 regime (84.66 ± 4.83) rather than from aCO_2 regime (90.53 ± 1.486), insignificant difference ($p > 0.05$) was observed between the two regimes (Table 1). However, the mean pupal duration showed significant difference ($p <0.05$) for pupae resulting from larvae fed on cotton leaves grown in aCO_2 regime (Table 1) where pupae of ambient condition showed relatively prolonged duration compared to pupae of enriched condition.

Moreover, significant difference ($p <0.05$) was observed in the mean pupal fresh weight between the two CO_2 regimes where pupae resulted from larvae fed grown cotton leaves grown at aCO_2 regime showed greater fresh weight (2.583 ± 0.036) compared to those fed eCO_2-grown leaves (Table 1). Robinson et al. (2012) stated that growth rates when consuming high CO_2 foliage are reduced, and duration increased, resulting in lower prepupal, pupal, and adult weights.

Adults emerged from larvae reared on ambient grown cotton leaves showed a significant ($p <0.05$) greater mean percentage emergence compared to those fed eCO_2-grown cotton leaves (Table 1). The mortality rate for adults resulted from larvae fed eCO_2-grown leaves was much greater (ca. 15%) compared to adults emerged from larvae fed aCO_2-grown leaves (Table 1).

More males emerged, but the Co_2 regimes did not influence the sex ratio as insignificant difference ($p >0.05$) was observed between the CO_2regimes for both sexes (Table 1).

Measures of plant quality during the present study are thus of importance in understanding natural interactions between herbivorous insect and its host plant species under eCO_2 environment since insect feeding and growth is a function of both the variation since diverse plant species respond differently to atmospheric eCO_2 alterations in foliage quality composition (Rao et al. 2012; Abu ElEla & ElSayed 2018; Manimanjari & Rao 2022). Increase in aCO_2 levels can cause increases in plant growth rates, and changes in the physical and chemical composition of the plant tissues (Stockle 1992; Sudderth 2005; Abu ElEla & ElSayed 2018).

Treatment of cotton plants with eCO_2 regime caused a significant alteration in plant quality in term of chemical characteristics (Table 2). It was observed that nitrogen content was drastically reduced in cotton leaves grown in eCO_2 concentration to show 50% less nitrogen contents (0.281 ± 0.029 mg g^{-1}d.wt) compared to nitrogen contents in leaves grown at aCO_2 regime (Table 2). In accordance with this finding, other studies have also showed that many plant species grown under eCO_2 condition showed a reduction in leaf nitrogen content (Stitt & Krapp 1999; Rao et al. 2012; Manimanjari & Rao 2022).

Significant difference ($p < 0.05$) in total foliar carbohydrates was observed between the two CO_2 regimes (Table 2). In the present study, eCO_2 typically increases the concentration of foliar total carbohydrates (42.82 ± 0.381 mg g^{-1}d.wt) which showed 15% greater concentration than total carbohydrates concentration in foliar grown in aCO_2 (Table 2).

Results shown in Table 2 showed that the total concentration of phenolic contents were higher under eCO_2. A significant difference ($p < 0.05$) in the total phenolic contents was observed between the two CO_2 treatments (Table 2) where the total phenolic contents in cotton leaves increased by more than double its value under eCO_2 compared to the contents of phenolics in aCO_2-grown cotton leaves. This improvement in plant secondary metabolites could be attributed to increased total non-structural carbohydrates (TNC) as suggested by Ibrahim & Jafaar (2012). Phenolics are considered as one of the most important groups of secondary metabolites and bioactive compounds in plant species (Kim et al. 2005) and increased levels of CO_2 concentrations can influence the levels of total phenolics (Fine et al. 2006).

The eCO_2 exhibited a significant impact on cotton plant by altering the biochemical constituents of the foliage such as reduced nitrogen content, increased phenolics, increased carbon, C:N, and total carbohydrates. It was clear that eCO_2 amplified decreases in foliar total nitrogen, causing substantial increases in foliar C:N ratio (Zvereva & Kozlov, 2006) which in turn affect the growth & development of the phytophagous early & penultimate

Table 2. Select nutritional quality of cotton plant leaves of *Gossypium barbadense* L. grown in ambient (aCO2 = 350 ppm) and enriched (eCO2 = 700 ppm) CO2 regimes.

Leaf nutritional quality(mg g^{-1}d.wt)	CO_2 Treatment	
	aCO_2 (350 ppm)	eCO_2 (700 ppm)
Total carbohydrates	36.49 ± 0.19[a*]	42.82 ± 0.381[b]
Total nitrogen	0.565 ± 0.046[a]	0.281 ± 0.029[b]
Phenolic compounds	0.645 ± 0.012[a]	1.524 ± 0.016[b]

* Results followed by different letters are significantly different ($p < 0.05$).

Image 1. Larvae of *Sopdoptera littoralis* (Boisd.) feeding on cotton plant leaves *Gossypium barbadense* L.: a—3rd larval instar (early) | b—6th larval instar (penultimate) | c—cotton leaves | d—faeces of the larvae. © Wael M. ElSayed.

instars, and subsequent stages of *S. littoralis* (Boisd.).

Consuming more eCO_2-grown leaves is an unambiguous indicator that eCO_2 reduces insect growth rates by altering the chemical and physical properties of foliage. In our study, cotton leaves grown in eCO_2 regime possessed relatively high total carbohydrates and low nitrogen content (Table 2). Consequently, increasing C:N which causes apparent increase in the consumption of relatively low-quality food to meet critical nutrient limitations which is referred to as "compensatory feeding" and may portend greater herbivore damage to both managed & natural ecosystems as CO_2 continues to increase (Cornelissen 2011).

CONCLUSION

It was clear that the phytophagous pests respond in an immediate fashion to the leaves grown in eCO_2. Larvae fed aCO_2-grown cotton leaves showed shorter duration, comparatively heaviest prepupae & pupae, and greatest percentage of adult emergence. On the other hand, larvae fed eCO_2- grown cotton leaves showed relatively longer duration and lighter prepupae & pupae with smaller percentage adult emergence. Consequently, the population dynamics of *S. littoralis* (Boisd.) and the nutritional quality of the host plant, *G. barbadense* L., could be influenced by the future increase of aCO_2 levels.

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COMMUNICATION

Diversity and distribution of springtails (Collembola) from Jharkhand, India

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Abstract: This paper included the diversity and distribution of collembolan fauna in Jharkhand. A checklist of collembolan fauna from Jharkhand has been formulated. Endemic species from Jharkhand have also been reported. Affinities between species and habitat as well as another species of Collembola is basic character for diversity as well as distribution. Different types of methodologies have been deployed for collection from distinctive habitats. Climatic conditions are the limiting factor for species distribution and endemism. *Lepidocyrtus* is the most diverse and distributed genus. *Isotomurus* is the highest endemic genus. Some collembolan fauna from Jharkhand are prevailing only in this state while some are distributed in different biogeographic zone in world.

Keywords: Affinities, checklist, collembolan fauna, endemic species, *Isotomurus*, *Lepidocyrtus*.

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INTRODUCTION

Collembola are among the most widespread and abundant terrestrial arthropods (Hopkins 1997). As of August 2023, over 9,400 species of Collembola have been indentified, distributed across 715 genera and 33 families within four orders: Poduromorpha, Entomobryomorpha, Symphypleona, and Neelipleona (Bellinger et al. 2023). Mandal conducted several surveys on Collembolan fauna in Jharkhand between 2012 and 2015. Collembola was reported from Jharkhand and distributed in five Symphypleona species under three genera with one endemic species. Additionally, one Poduromorpha species and 30 Entomobryomorpha species with five endemic species were also reported.

Taxonomic History

Mandal & Hazra (2004) documented eight species of six genera in two families from Jharkhand. Mandal & Suman (2013) newly recorded *Yosiia dehradunia* from Jharkhand state. Mandal et al. (2016) described four new species from Jharkhand and in 2017, they documented additional five new Isotomidae species from Jharkhand state.

The first record from the taxonomy study of Collembola especially from Jharkhand was *Lepidocyrtus exploratorius* Carpenter, 1924 from the district of Latehar. Many species have been described from many districts in the following years. In 2013, Mandal first recorded the family Paronellidae from Latehar and Hazaribagh districts. First *Salina* species was recorded in 2015. Dhanbad has been marked the first district to describe Orchesellidae species. Six species of Isotomidae have also been reported in the following years. *Calvatomina pagoda* Yosii, 1966 is the first species of Symphypleona from this state.

MATERIALS AND METHODS

Sampled sites

After the first survey conducted in 2012, a total of 40 sites from 16 districts have been surveyed for Collembola specimens. Collections have been made by soil and litter extraction, bush beating, and by using mouth operated aspirator in these following district with the number of sample sites in parentheses: Ranchi (four), Hazaribagh (one), Koderma (one), Sahibganj (four), Pakur (three), Jamtara (two), Dhandab (one), Deogarh (one), East Singbhum (four), West Singbhum (four), Seraikhela-Kharsawan (four), Khunti (one), Ramgarh (five), Bokaro (three), Giridih (one), and Latehar (one) (Figure 1).

Diversity from Jharkhand State

In total, 36 species of Collembola which are classified under 20 genera and eight families from this state are distributed among Symphypleona (13.9%), Poduromorpha (2.8%), and Entomobryomorpha (83.3%). Symphypleona has been reported from eastern districts of this state, especially the border of West Bengal (Tables 1,2).

In Entomobryomorpha, the family Isotomidae has been recorded with at least one species in eight districts, while Paronellidae and Entomobryidae have been recorded from almost all surveyed districts. In the case of Poduromorpha, Hypogastruiridae species have been documented from the Hazaribagh district where this family is found together with Isotomidae, Paronellidae, and Entomobryidae. Entomobryidae is also registered from 10 districts together with Isotomidae and Paronellidae (Tables 1,2).

Family Entomobryidae reported to have the highest species richness with 13 species followed by family Paronellidae with eight species, family Isotomidae with seven species, and family Sminthuridae with two species. Family Entomobryidae is also registered with the highest generic level of richness with six genera followed by family Paronellidae with five species (Tables 1,2).

East-Singhbhum district is documented with the highest species richness with 10 species from nine genera under the families Sminthuridae, Isotomidae, Paronellidae, and Entomobryidae. Dhanbad district also has the highest species richness with 10 species under nine genera which include all families except Hypogastruiridae and Entomobryidae. This district uniquely has all Symphypleona families. Ten species under six genera are reported from Hazaribagh district belonging to the families Hypogastruiridae, Isotomidae, Paronellidae, and Entomobryidae. Ramgarh district has reported 10 species under six genera, distributed among the families Isotomidae, Paronellidae, and Entomobryidae. Pakur district is recorded as the second highest species enriched region with eight species under eight genera where seven Entomobryomorpha genera and one Symphypleona genera. Saraikela-Kharsawan has species richness with nine species under seven genera distributed among the families Sminthuridae, Paronellidae, and Entomobryidae. Ranchi district has four species under three genera, all within Entomobryomorpha. Koderma district is rich with five species under five genera only under Paronellidae and Entomobryidae. Jamtara district is

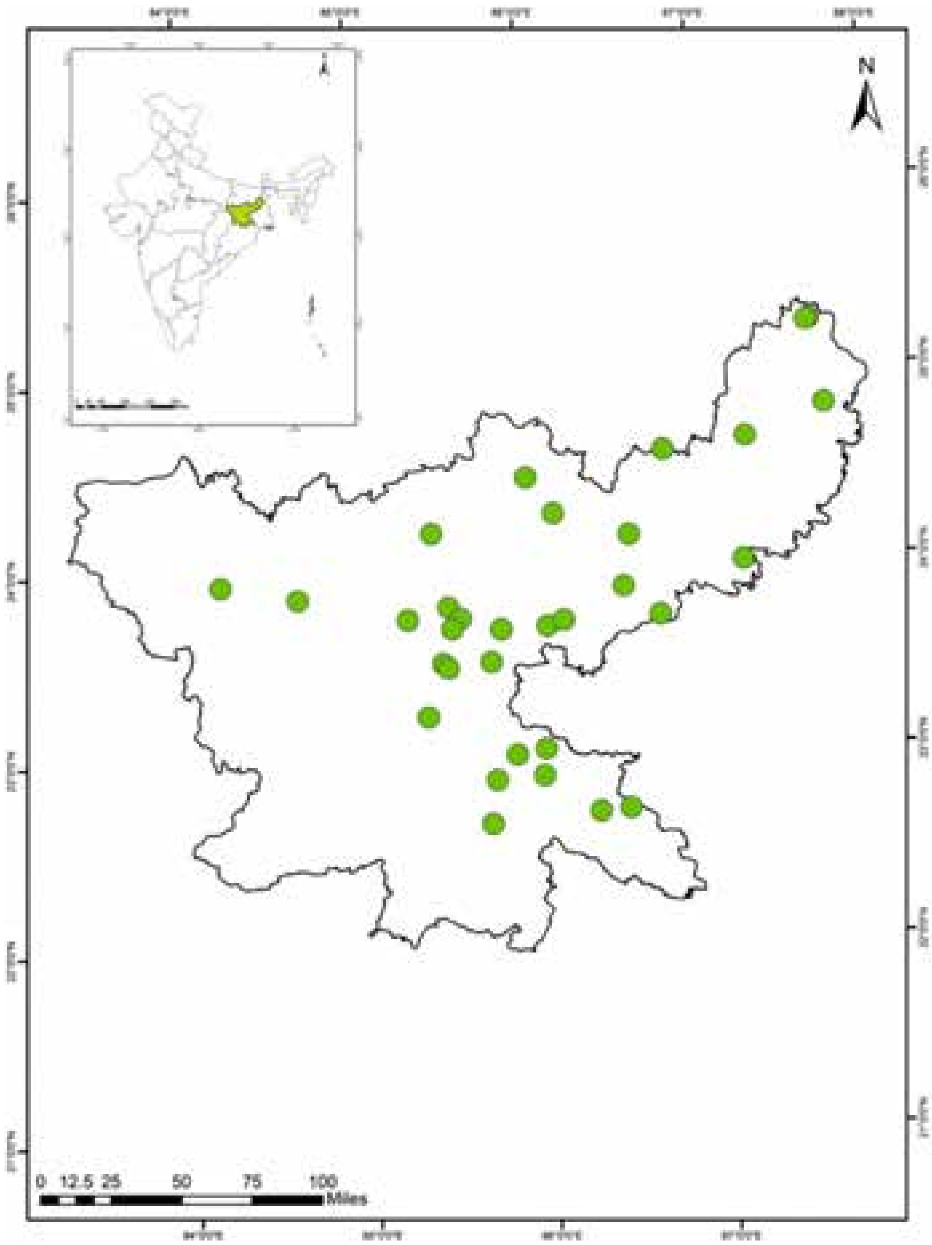

Figure 1. Map of Jharkhand (collection sites).

diversified with three species under three genera only under Entomobryomorpha. Bokaro district is rich with four species under four genera only under the families Paronellidae and Entomobryidae. Three species under three genera are reported from West Singbhum under the families Paronellidae and Entomobryidae. Sahebganj district enriched with six species under five genera from Entomobryomorpha. Deoghar district has three species under three genera from the families Dicyrtomidae and Paronellidae. Latehar district has five species under four genera from the families Paronellidae and Entomobryidae. Khunti district has the least diversity with two species under two genera from the family Paronellidae. Giridih district has the least diversity with single species from the family Dicyrtomidae (Tables 1,2).

From all surveyed sites, eight species under five genera belong to the family of Paronellidae. Thirteen species under six genera belong to the family of Entomobryidae, of which six species are *Lepidocyrtus*. Seven species in two genera belong to the family of Isotomidae. Genus *Isotomurus* and genus *Seira* are the other two diverse genera with six and three species, respectively. Genus *Lepidocyrtus*, the most distributed genus, has been reported from 11 districts. The second

Table 1. Checklist of the Collembola from Jharkhand, India.

	Scientific names	Record regions	Distribution	Reference
Symphypleona				
Sminthurididae				
1	*Sminthurides parvulus* (Krausbauer, 1898) Heymons, R & Heymons, H in Brauer, A, 1909	Db: Amaghata;	PAL, ORT	NZC
Dicyrtomidae				
Dicyrtominae				
2	*Calvatomina pagoda* Yosii, 1966	Dg: Khijuria; Db: Amaghata; Gd: Lachhudih	ORT	NZC
3	*Calvatomina trivandrana* Prabhoo, 1971	ES: Dimna Lake, Rakha Mines; SK: Kharswan;	Endemic#	NZC
Sminthuridae				
Sphyrothecinae				
4	*Sphyrotheca* (*Sphyrotheca*) *gangetica* Yosii, 1966	Db: Amaghata; Pk: Litti Para;	Endemic#	NZC
Sminthurinae				
5	*Temeritas dimna* Mandal, Suman & Bhattacharya, 2016	ES: Dimna Lake;	Endemic*	Mandal et al. 2015: 49–51
Poduromorpha				
Hypogastruridae				
6	*Ceratophysella indovaria* (Salmon, 1970)	Hb: Hazaribagh National Park;	Endemic#	Mandal 2014: 197
Entomobryomorpha				
Isotomidae				
Proisotominae				
7	*Proisotoma pakurensis* Mandal, Suman & Bhattacharya, 2017	Pk: Litti Para;	Endemic*	Mandal, Suman & Bhattacharya 2017: 98
Isotominae				
8	*Isotomurus balteatus* (Reuter, 1876) Handschin, 1929	Hb: Hazaribagh National Park;	PAL, NEO, AUS, ORT	Mandal 2014: 199
9	*Isotomurus dhanbadensis* Mandal, Suman & Bhattacharya, 2017	Db: Amaghata; Pk: Litti Para;	Endemic*	Mandal, Suman & Bhattacharya 2017: 100
10	*Isotomurus indicus* Mandal, Suman & Bhattacharya, 2017	Jt: Amlachatar; Rg: Rajrappa;	Endemic*	Mandal, Suman & Bhattacharya 2017: 102
11	*Isotomurus jharkhandensis* Mandal, Suman & Bhattacharya, 2017	Db: Amaghata; ES: Asanpani Pk: Litti Para Rg: Rajrappa, Kujju range; Rn: Sambar Fencing Park; Sg: Dhobijharna;	Endemic*	Mandal, Suman & Bhattacharya 2017: 103
12	*Isotomurus sahebganjensis* Mandal, Suman & Bhattacharya, 2017	Sg: Dhobijharna;	Endemic*	Mandal, Suman & Bhattacharya 2017: 105
13	*Isotomurus stuxbergi* (Tullberg, T, 1877) Babenko & Bulavintsev, 1993 {syn. *Isotomurus ciliatus* Stach, 1947}	Sg: Dhobijharna;	NEA, PAL, ORT, NEO	NZC
Orchesellidae				
Heteromurinae				
14	*Dicranocentrus cercifer* (Imms, 1912) Mari Mutt, 1979	Pk: Litti Para;	Endemic#	NZC
15	*Alloscopus tetracanthus* (Börner, 1906) Handschin, 1928	Db: Amaghata;	ORT, AUS	NZC
Paronellidae				
Paronellinae				
16	*Cyphoderus indicus* Mandal, Suman & Bhattacharya, 2016	Bo: Sector I;ES: Rakhamines;	Endemic#	Mandal et al. 2015: 45–47
17	*Cyphoderus jharkhandensis* Mandal, Suman & Bhattacharya, 2016	Dg: Khijuria; Jt: Amlachatar; Lt: Betla National Park; Pk: Litti Para, Hiranpur; Sg: Sahibganj, Rajmahal, Karam pahar; SK: Kuchia forest; WS: Kundruhati, Chaibasa;	Endemic*	Mandal et al. 2015: 47–48
Salininae				
18	*Salina* (*Salina*) *striata* (Handschin, 1928) Handschin, 1929	Kt: Birsa Mrig Bihar; Rg: Kujju range;	Endemic#	NZC

	Scientific names	Record regions	Distribution	Reference
19	*Salina* (*Salina*) *indica* (Imms, 1912) Salmon, 1957	Dg: Khijuria; Db: Amaghata; ES: Asanpani; Jt: Damka; Pk: LittiPara,Ramnathpur; Rg: Kujju range; Sg: Dhobijharna; SK: Kotwalbadi;	ORT	NZC
20	*Yosiia dehradunia* Mitra, 1967	Db: Amaghata; Hb: Hazaribagh National Park; Km: Koderma WLS; Pk: Litti Para; Rg: Rajrappa, Kujju range; Rn: Hundru;	Endemic#	Mandal 2014: 201
21	*Callyntrura* (*Handschinphysa*) *lineata* (Parona, 1892)	Bo: Balidihi, City Park lake; Hb: Hazaribagh National Park; Kt: Birsa Mrig Bihar; Km: Koderma WLS; Lt: Betla National Park; Pk: Litti Para; Rg: Kujju range;	PAL, ORT	Mandal 2014: 201
22	*Callyntrura* (*Handschinphysa*) *vestita* (Handschin, 1925) Uchida, 1954	ES: Asanpani; Hb: Hazaribagh National Park;	ORT	Mandal 2014: 201
23	*Dicranocentroides flavescens* Yosii, 1966	Db: Amaghata ES: Asanpani; Rg: Kujju range;	Endemic#	NZC
Entomobryidae				
Entomobryinae				
24	*Calx kailashi* Mandal, 2018	Km: Koderma WS;	Endemic#	Mandal 2018: 108
25	*Homidia cingula* (Borner, 1906) Yosii, 1959	SK: Giliganda Forest;	PAL, ORT	NZC
26	*Sinella curviseta* Brook, 1882	Hb: Hazaribagh National Park;	PAL, NEA, NEO, ORT, AUS	NZC
Seirinae				
27	*Seira* (*Seira*) *indica* (Ritter, 1911) Yosii, 1966	Hb: Hazaribagh National Park; Sg: Sahibganj;	Endemic#	Mandal 2014: 199
28	*Seira* (*Seira*) *indra* Imms, 1912	Bo: City Park lake; Hb: Hazaribagh National Park; Km: Koderma WS; Rg: Kujju range; WS: Chandil Dam	Endemic#	NZC
29	*Seira* (*Seira*) *lateralis* Yosii, 1966	ES: Jaduguda;	Endemic#	NZC
Lepidocyrtinae				
30	*Lepidocyrtus exploratorius* Carpenter, 1924	Lt: Betla National Park;	ORT	NZC
31	*Lepidocyrtus* (*Lepidocyrtus*) *curvicollis* Bourlet, 1839	Km: Koderma WS; Lt: Betla National Park;	PAL, ORT, NEA	NZC
32	*Lepidocyrtus* (*Lanocyrtus*) *cyaneus* Tullberg, 1871	ES: Asanpani; Hb: Hazaribagh National Park; SK: Kotwalbadi;	COS	Mandal 2014: 199
33	*Lepidocyrtus* (*Cinctocyrtus*) *medius* Schaeffer, 1898	Bo: Balidihi; ES: Asanpani, Burudihi; Rg: Rajrappa; Rn: Rukka dam; Sg: Dhobijharna; WS: Chaibasa;	ORT	NZC
34	*Lepidocyrtus* (*Setogaster*) *indicus* Handschin, 1929	Hb: Hazaribagh National Park; Rg: Kujju range;	ORT	NZC
35	*Lepidocyrtus* (*Acrocyrtus*) *heterolepis* Yosii, 1959	Db: Amaghata; Hb: Hazaribagh National Park; Rn: Ormanjhi	ORT	Mandal 2014: 199
36	*Acanthurella betlaensis* Mandal, Suman & Bhattacharya, 2016	Lt: Betla National Park;	Endemic#	Mandal et al. 2015: 41–44

Notes: Abbreviations of surveyed districts: Bo—Bokaro | Dg—Deoghar | Db—Dhanbad | ES—East Singbhum | Gd—Giridih | Hb—Hazaribagh | Jt—Jamtara | Kt—Khunti | Km: Koderma | Lt—Latehar | Pk—Pakur | Rg—Ramgarh | Rn—Ranchi | Sg—Sahebganj | SK—Seraikhela-Kharswan | WS—West Singbhum.
Abbreviations of Distributions: PAL—Palearctic | ORT—Oriental | NEO—Neotropical | AUS—Australian | NEA—Nearctic | COS—Cosmopolitan.
NZC—National Zoological Collection | Zoological Survey of India | Kolkata | India. #—refers to the endemic to India | *—refers only found in the surveyed state (Jharkhand).

most distributed genus is *Isotomurus*, which has been reported from eight districts (Tables 1,2).

Endemism

The state of Jharkhand recorded seven endemic species which are distributed into four genera of Symphypleona and Entomobryomorpha except Poduromorpha, which is almost 19.44% as compared with 36 species found in this state. Besides these species, 13 endemic species to India are also reported from this state. Almost all surveyed district of Jharkhand are reported with endemic species. Genus *Isotomurus*, with four species, is reported to have the highest endemism from this state as well as India. Three species of genus *Seira* are followed by endemic species which are also found in this state (Table 1).

Fifteen species under nine genera are also found in almost the same geographical region globally. Only

Table 2. Registration number of collembolan specimen in NZC with distribution in India (N.B. Serial Number are same as Table 1).

	Scientific names	Registration no.	Distributed in India
Symphypleona			
Sminthurididae			
1	*Sminthurides parvulus* (Krausbauer, 1898) Heymons, R & Heymons, H in Brauer, A, 1909	804/H14	Jharkhand, West Bengal, Uttar Pradesh
Dicyrtomidae			
Dicyrtominae			
2	*Calvatomina pagoda* Yosii, 1966	802/H14	Jharkhand, West Bengal
3	*Calvatomina trivandrana* Prabhoo, 1971	799/H14	Jharkhand, Kerala
Sminthuridae			
Sphyrothecinae			
4	*Sphyrotheca (Sphyrotheca) gangetica* Yosii, 1966	797/H14	Jharkhand, West Bengal, Maharashtra, Uttar Pradesh
Entomobryomorpha			
Isotomidae			
Isotominae			
13	*Isotomurus stuxbergi* (Tullberg, T, 1877) Babenko & Bulavintsev, 1993	2003/H14	Jharkhand, West Bengal
Orchesellidae			
Heteromurinae			
14	*Dicranocentrus cercifer* (Imms, 1912) Mari Mutt, 1979	790/H14	West Bengal, Kerala, Jharkhand
15	*Alloscopus tetracanthus* (Börner, 1906) Handschin, 1928	791/H14	Jharkhand, Kerala, West Bengal
Paronellidae			
Salininae			
18	*Salina (Salina) striata* (Handschin, 1928) Handschin, 1929	742/H14	Tamil Nadu (Nilgiri), West Bengal, Uttarakhand, Andaman and Nicobar Islands
19	*Salina (Salina) indica* (Imms, 1912) Salmon, 1957	743/H14	Jharkhand, Uttar Pradesh, West Bengal, Maharashtra, Uttarakhand, Himachal Pradesh, Andaman & Nicobar Islands
23	*Dicranocentroides flavescens* Yosii, 1966	727/H14	Jharkhand, Uttarakhand, West Bengal, Manipur, Maharashtra, Mizoram, Nagaland, Sikkim, Tripura, Arunachal Pradesh, Uttar Pradesh
Entomobryidae			
Entomobryinae			
25	*Homidia cingula* (Borner, C., 1906) Yosii, 1959	777/H14	Jharkhand, West Bengal, Maharashtra, Andhra Pradesh, Himachal Pradesh, Uttar Pradesh, Uttarakhand, Arunachal Pradesh, Manipur, Sikkim, Mizoram, Nagaland, Odisha
26	*Sinella curviseta* Brook, 1882	778/H14	Jharkhand, Tamil Nadu, Himachal Pradesh, Uttar Pradesh, Uttarakhand, Jammu & Kashmir, Arunachal Pradesh, Assam, Punjab, Sikkim, West Bengal, Andaman and Nicobar Islands
Seirinae			
28	*Seira* (*Seira*) *indra* Imms, 1912	793/H14	Jharkhand, West Bengal
29	*Seira* (*Seira*) *lateralis* Yosii, 1966	796/H14	Jharkhand, Maharashtra
Lepidocyrtinae			
30	*Lepidocyrtus exploratorius* Carpenter, 1924	699/H14	Jharkhand, Meghalaya, Maharashtra, West Bengal
31	*Lepidocyrtus* (*Lepidocyrtus*) *curvicollis* Bourlet, 1839	781/H14	Jharkhand, Andaman & Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Lakshadweep, Odisha, Puducherry, West Bengal, Uttarakhand
33	*Lepidocyrtus* (*Cinctocyrtus*) *medius* Schaeffer, 1898	786/H14	Jharkhand, Bihar
34	*Lepidocyrtus* (*Setogaster*) *indicus* Handschin, 1929	784/H14	Jharkhand

one species of genus *Lepidocyrtus* is reported from all biogeographic zones of the world, making it a cosmopolitan species (Table 1).

Geographic and habitat distributions

The state of Jharkhand (21.950–25.233 °N; 83.333–87.967 °E) is a part of the Chota Nagpur Plateau as well as river sheds. Chota Nagpur Plateau was formed from the Deccan Plateau by continental uplift in the Gondwana period. Furthermore, the climate of the Chota Nagpur Plateau is analogous with to that of the Deccan Plateau. The climatic condition of Jharkhand State varies from subtropical humid to tropical wet and dry when temperature and precipitation also varies from very hot, dry summers (99°F) to cold winters (50°F) and 40 inches of rainfall, respectively. The soil of the Jharkhand State is composed mainly by of rocks, stones, and different types of minerals, especially mica. The geographical condition of Jharkhand creates such condition which promotes floral diversity, such as Sal, Jackfruit, Jamun, Kendu, Shisham, Mahua, Lac, Mango, Aasan, Baheda, and Bamboo as well as faunal diversity. Springtails are euedaphic species, usually saprophagous by nature. Collembola solely depend on the kind of foods which include fungi, lichens, and deteriorated animal or plant materials. Collembolan fauna is distributed in many strata of soil due to food availability. Euedaphic springtails feed on living plants, pollen, and algae which are available on plant bark. Instead of this, some collembola are specific for a definite food material. An abundance of collembola fauna in a definite part of the habitat forms microarthropod-fauna-associated soil. Most species live on the soil surface and are epiedaphic. Some species are also found on seedlings or plant surfaces. Edaphic, epiedaphic, hemiedaphic, and euedaphic Collembola, including the members of Sminthurididae, Isotomidae, and Poduromorpha, are distributed among many horizons of soil due to types of humus and vegetation. The distribution of Collembola in Jharkhand state is associated with the physical or geographical features of this state. A series of plateaus, hills, and valleys are characterized by the Chota Nagpur plateau. Dominated tropical moist and tropical dry deciduous forest create similar climatic conditions which generalize similar life to survive. The north-east side of the state has different vegetation due to many river basins. Endemism is bounded, at the species level, in the single specific locality with its vegetation and geographical parameters. Temperature and humidity are signifying an important role in endemism.

Affinities

Collembola species dispersal and distribution are signified by phylogenetic evolution. In the Symphypleona, species of *Sminthurides* disperse in the Palearctic and Oriental regions; while other species of *Calvatomina*, *Sphyrotheca*, and *Temeritas* are restricted to a definite locale (Table 1). In the Entomobryomorpha, some species of *Isotomurus* are distributed across many continents. The genus *Seira* is cosmopolitan but three species (*Seira* (*Seira*) *indica* (Ritter 1911) Yosii, 1966, *Seira* (*Seira*) *indra* Imms, 1912, and *Seira* (*Seira*) *lateralis* Yosii, 1966) are restricted to India (Table 1; Images 17–19). *Lepidocyrtus* is notably diverse in the Oriental region whereas *Lepidocyrtus* (*Lanocyrtus*) *cyaneus* Tullberg, 1871 is cosmopolitan (Table 1). In addition, the genus *Cyphoderus* is a cosmopolitan whereas *Cyphoderus indicus* Mandal, Suman, and Bhattacharya, 2016 have only been found in India (Table 1). Genus *Yosiia* is restricted only to the Indian region (Table 1).

DISCUSSION

Edaphic springtails or collembolan faunal diversity and distribution depend on their resources in their habitat. The morphology of collembolan is greatly parallelized with the vegetation. Taxa, such as Sminthurididae, Isotomidae, and Poduromorpha, bear vestigial appendages which are very much proportionate to movement. For some euedaphic species of Genus *Cyphoderus* in the aphotic environment, morphological characteristics are similar to cave dwellers such as the absence of pigmentation and eyes. Genus *Salina* is one type of this species which gives it with advantage of long appendages. *Isotomurus jharkhandensis* Mandal, Suman & Bhattacharya, 2017 and *Cyphoderus jharkhandensis* Mandal, Suman, & Bhattacharya, 2016 (Images 27,29) are two among the endemic species that are distributed all over the state at different elevations. Some species, such as *Temeritas dimna* Mandal, Suman & Bhattacharya, 2016, *Proisotoma pakurensis* Mandal, Suman & Bhattacharya, 2017, *Isotomurus sahebganjensis* Mandal, Suman & Bhattacharya, 2017 (Images 24,28) are show restricted distribution in a certain area. From this study, we found that one species, *Lepidocyrtus* (*Lanocyrtus*) *cyaneus* Tullberg, 1871, is a cosmopolitan species as well as seven species are endemic to Jharkhand. After the first collection and reported collembolan species from the state of Jharkhand, it was found that species endemism is very high, especially in Entomobryomorpha. Other states of India also show endemic species along

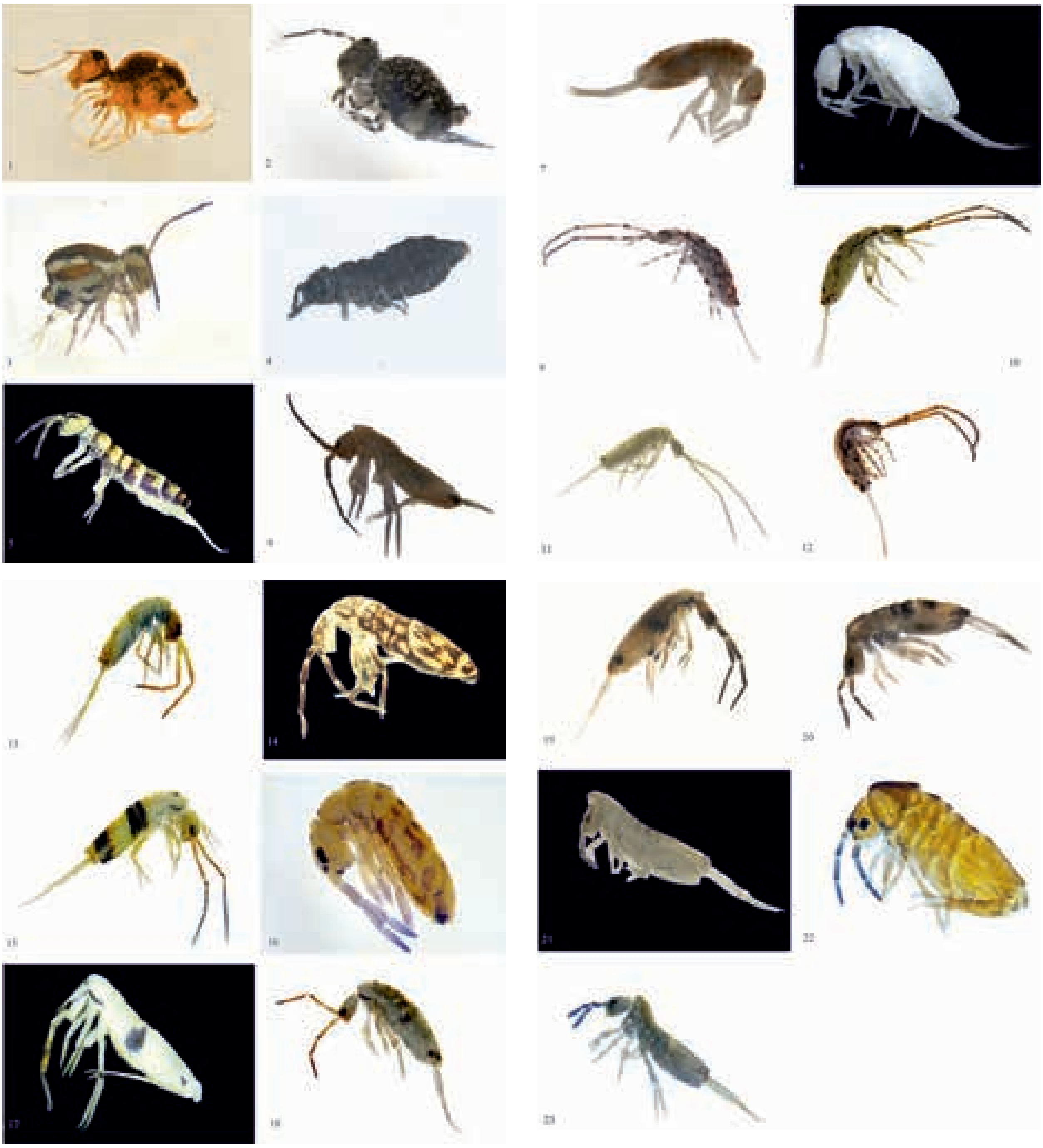

Image 1–23. Some collembolan species photographs from Jharkhand, India. 1—*Sminthurides parvulus* (Krausbauer, 1898) Heymons, R & Heymons, H in Brauer, A, 1909 | 2—*Calvatomina pagoda* Yosii, 1966 | 3—*Calvatomina trivandrana* Prabhoo, 1971 | 4—*Ceratophysella indovaria* (Salmon, 1970) | 5—*Isotomurus balteatus* (Reuter, 1876) Handschin, 1929 | 6—*Dicranocentrus cercifer* (Imms, 1912) Mari Mutt, 1979 | 7—*Alloscopus tetracanthus* (Börner, 1906) Handschin, 1928 | 8—*Cyphoderus indicus* Mandal, Suman & Bhattacharya, 2016 | 9—*Salina* (*Salina*) *striata* (Handschin, 1928) Handschin, 1929 | 10—*Salina* (*Salina*) *indica* (Imms, 1912) Salmon, 1957 | 11—*Yosiia dehradunia* Mitra, 1967 | 12—*Callyntrura* (*Handschinphysa*) *lineata* (Parona, 1892) | 13—*Dicranocentroides flavescens* Yosii, 1966 | 14—*Calx kailashi* Mandal, 2018 | 15—*Homidia cingula* (Borner, C., 1906) Yosii, 1959 | 16—*Sinella curviseta* Brook, 1882 | 17—*Seira* (*Seira*) *indica* (Ritter, 1911) Yosii, 1966 | 18—*Seira* (*Seira*) *indra* Imms, 1912 | 19—*Seira* (*Seira*) *lateralis* Yosii, 1966 | 20—*Lepidocyrtus* (*Lepidocyrtus*) *curvicollis* Bourlet, 1839 | 21—*Lepidocyrtus* (*Cinctocyrtus*) *medius* Schaeffer, 1898 | 22—*Lepidocyrtus* (*Setogaster*) *indicus* Handschin, 1929 | 23—*Lepidocyrtus* (*Acrocyrtus*) *heterolepis* Yosii, 1959. © Authors.

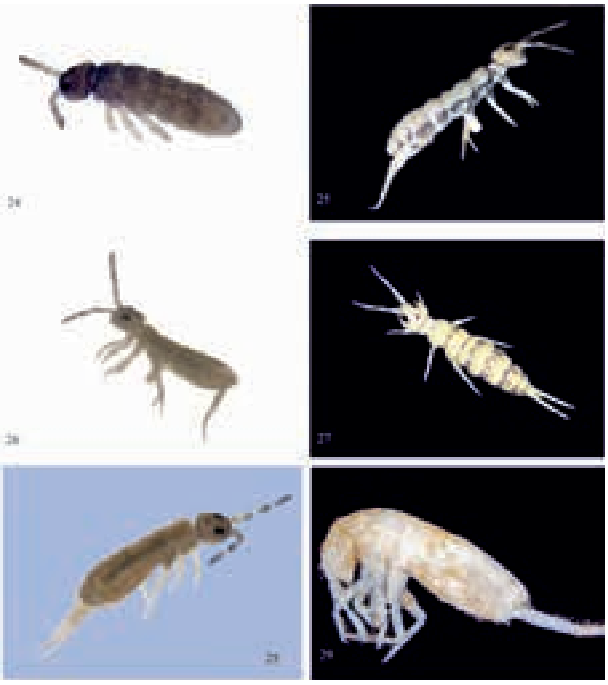

Image 24–29. Some endemic species of Collembola recorded from Jharkhand, India: 24—*Proisotoma pakurensis* Mandal, Suman & Bhattacharya, 2017 | 25—*Isotomurus dhanbadensis* Mandal, Suman & Bhattacharya, 2017 | 26—*Isotomurus indicus* Mandal, Suman & Bhattacharya, 2017 | 27—*Isotomurus jharkhandensis* Mandal, Suman & Bhattacharya, 2017 | 28—*Isotomurus sahebganjensis* Mandal, Suman & Bhattacharya, 2017 | 29—*Cyphoderus jharkhandensis* Mandal, Suman & Bhattacharya, 2016. © Authors.

with Jharkhand in some cases. Further study is needed to justify this finding. The collembola fauna from this state is little documented, ascribable to lack of survey. However, approvable work was done by G.P. Mandal et al. to survey and record these species. Besides, more surveys and exploration are required, from all types of habitats of this state, for detailing species diversity in this region.

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SHORT COMMUNICATION

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Lindernia tamilnadensis (Linderniaceae) from Indo-Gangetic plains: no more endemic to the Deccan

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Abstract: This study documents the first record of *Lindernia tamilnadensis* (M.G.Prasad & Sunojkumar) in the states of Uttar Pradesh, Bihar, Jharkhand, and West Bengal. Previously, 16 species of *Lindernia* have been reported from different parts of India. The newly acquired specimen exhibits distinct morphological characteristics compared to previously described taxa from the Indo-Gangetic plains. A brief description, field notes, photographs, location, and distribution of the species are provided to facilitate identification.

Keywords: Amphibious hydrophytes, Bihar, Ganga River Basin, Jharkhand, range extension, tributaries, Tamil Nadu, Uttar Pradesh, West Bengal, Western Ghats wetland.

A biogeographic zone is a geographic region characterized by a distinct set of species and ecological communities that differ from those in other zones. India has been classified into 10 biogeographic zones, further subdivided into 27 biogeographic provinces (Rodgers & Panwar 1988; Singh & Kushwaha 2008). Among these, the Indo-Gangetic plains are particularly notable for their fertile alluvial soil, which sustains extensive agriculture, and rich diversity of wild flora, each uniquely adapted to the region's environmental conditions.

Linderniaceae is a family of flowering plants consisting of nearly 25 genera recorded from all around the world (POWO 2024). Quite recently segregated from Schrophulariaceae based on molecular studies and the presence of an abaxial staminal filament, Linderniaceae is now recognized as a separate family confirming its monophyly. The centers of diversity of this family are situated in southeastern Asia and Africa (Fischer 1992).

The genus *Lindernia* comprises 200 species, catalogued throughout the tropical and temperate regions of the world (Lewis 2000). It is characterized by the presence of a unique abaxial staminal filament with club shaped appendage (Rahmanzadeh et al. 2005). So far, a total of 28 species, one subspecies, and one variety have been reported from India (Mukherjee

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1945; Sivarajan & Mathew 1983; Tandyekkal & Mohanan 2010).

The genus *Lindernia* is mainly characterized by erect or prostrate annual herbs. They have opposite, petiolate or sessile leaves. In most cases, the margins of leaf blades are toothed, while in rare instances they are entire whet veins can be pinnate or palmate. Axillary or terminal inflorescences, racemose or pseudo-umbellate, occasionally in panicles or appear solitary. Flowers are either opposite or alternate and sometimes pedicellate. Usually, bracteoles are missing. Five- lobed calyx can be parted, or split on one side, equal or subequal. Corolla of the lower lip is larger and extended, while the upper lip is erect. Typically, four fertile stamens or two anterior reduced where filaments are appendaged. Coherent anthers or apex of locules of anterior ones are either pointed or spurred, mostly two-lamellated styles. Seeds are small and numerous.

Methods

The present study was conducted to survey the plant diversity along the Ganga, Gandak, Ajay, Rupnarayan, and Damodar rivers in February 2024. Transects were laid, both perpendicular and parallel to the river to document plant diversity in the high flood line (riparian zone). During this survey, we encountered an intriguing *Lindernia* species growing alongside *L. rotundifolia* in the riparian zones. Specimens of the species were collected for further examination, and detailed photographs were taken to record its habit, habitat, leaves, stem, and flowers. A few specimens were processed by following standard method (Rao & Sharma 1990) and deposited in the Herbarium of Wildlife Institute of India (WII), Dehradun, Uttarakhand, India. On critical examination with the help of relevant literature, the specimen was confirmed as *L. tamilnadensis* Prasad & Sanojkumar. Through the available literature from the states; Uttar Pradesh, Bihar, Jharkhand, and West Bengal (David 1903; Haines 1921–1925; Bennet 1979; Verma 1981; Guha 1984; Naskar 1993; Bhattacharya & Hajra 1998; Bandyopadhyay & Mukherjee 2005; Singh & Ali 2008; Maliya & Bhaskar 2010; Chowdhury & Das 2010; Mandal & Mukherjee 2012; Singh et al. 2013; Singh 2015; Mukherjee & Kumar 2020; Paul & Kumar 2023) it was established that the species is no longer confined or endemic to southern India and has marked its presence in northern Indian states, especially in the Gangetic plains.

L. tamilnadensis was described from Vijayanarayanam village of Tamil Nadu (Prasad & Kumar 2014). *L. tamilnadensis* is allied to well-known *L. rotundifolia* but can be differentiated by characters like coloured blotches at each corolla lobe, lanceolate calyx lobes, absence of trichomes at the base of the anterior corolla lobes,

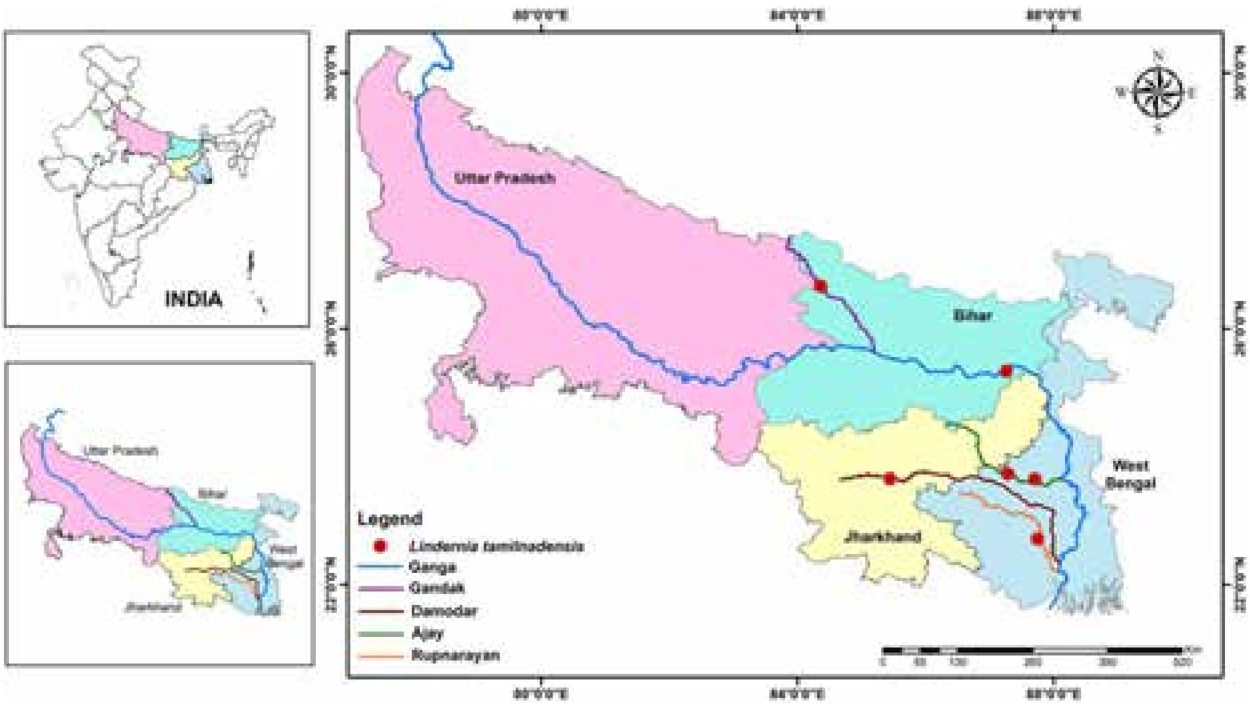

Figure 1. Location map of *Lindernia tamilnadensis* Prasad & Sunojkumar, for the specimens recorded from Indo-Gangetic plains.

undeflexed fruiting pedicels, and globose capsules, and said to be endemic to Western Ghats. Undirwade (2020) reported this species from northern Maharashtra.

A brief description, location/maps, field notes, and photographs are provided for the identification of the species. Hence, this paper can serve as a new distribution for *L. tamilnadensis* from the Gangetic plains covering four states viz. Uttar Pradesh, Bihar, Jharkhand, and West Bengal.

Results

Lindernia tamilnadensis **Prasad & Sunojkumar.**

Annual, erect or prostrate tufted semi-aquatic herb, stilt roots (from basal nodes of the stem), roughly 15 cm high. Stem herbaceous, weak, smooth (no hair or projections), 4-angled, slender, branches projecting from the base; internodes roughly 2.5 cm long. Leaves sessile, 0.4–1.5 × 0.5–1.2 cm, ovate, subcordate base, apex acute or sometimes rounded, margins entire (older parts) & dentate at apex, glabrous, distinct veins, basally 3–5 nerved, lamina glandular, and punctate. Flowers solitary, axillary, pedicellate, arranged alternately on leaf axils, one per node; pedicel hairy & slender; fruiting pedicel are erect and glabrous. Calyx 1.5–2.5 mm long, 5-lobed, deeply lobed, glandular outside, lanceolate lobes, apex acute. Corolla 3–5 mm long, 2-lipped, white with deep-purple or pale blue blotches on lower lip; corolla tube cylindrical, 3–5 mm long, glabrous hairy; lower lip-3 distinct lobes, rounded, glabrous; upper lip has a small notch or indentation. Staminodes 2-perfect stamens, filaments usually 1 mm long, glabrous, glandular hairy throughout, dense yellow glandular hairs at the base of filaments, and corolla tube below, bluish purple towards apex, a distinct spur present just below the staminodal apex, anthers 2- lobed, lobes ovate, acute. Gynoecium 3–3.1 mm long, ovary 1.0 × 0.5 mm, bicarpellary, syncarpous, ovate-acute, sub-globose, glabrous/hairy; style roughly 2 mm long, glabrous; stigma bilobed & simple. The fruit is a globose capsule, 2.5 × 2 mm; capsule spherical, globose, glabrous, shiny, exceeding the length of persistent calyx. Seeds 0.3 × 0.15 mm, minute, distinctly 5-ridged, numerous, golden yellowish.

Specimen in herbarium (with accession number): West Bengal (Rupnarayan, WII/NMCG/UK/22212) and Jharkhand (Damodar, WII/NMCG/UK/22214 and Ajay, WII/NMCG/UK/22213)

Flowering and fruiting: July to March.

Ecology: Grows primarily in marshy habitats and also as marginal plant alongside flowing waters, along with *Grangea maderaspatana*, *Wahlenbergia marginata*, *Torenia crustacea*, *Gnaphalium polycaulon*, *Eclipta alba*, *Glinus oppositifolius*.

Table 1. A comparative analysis of *Lindernia tamilnadensis* Prasad & Sunojkumar with other closely related species of northern India, L. rotundifolia (L.) Alston.

Distinguishing characters	*L. tamilnadensis* Prasad & Sunojkumar	*L. rotundifolia* (L.) Alston
Calyx	Calyx lobes 2.5–4.2 mm long and are unequal with sparsely scattered glandular hairs.	Calyx lobes are 7–9.2 mm long and are equal with dense glandular hairs.
Corolla	Almost less than half the size of *L. rotundifoila* (1 × 1 mm) and trichomes absent at base of lobes.	About 3.5 × 3 mm with trichomes present at the base of lobes.
Staminode	0.5–0.6 mm long	2–2.2 mm long
Pedicel	Deflexed or undeflexed during fruiting	Undeflexed during fruiting

Table 2. Locations of *Lindernia tamilnadensis* Prasad & Sunojkumar, for the specimens recorded from Indo-Gangetic plains.

River	Latitude/ Longitude	Elevation (m)	Location
Ganga	25.339°N, 87.261°E	48	Bateshwar, Bhagalpur District, Bihar
Gandak	26.667°N, 84.360°E	99	Jabahi Dayal, Kushinagar District, Uttar Pradesh
Rupnarayan	22.706°N, 87.738°E	16	Dirghagram, Paschim Medinipur District, West Bengal
Damodar	23.643°N, 85.525°E	331	Ramgarh cantonment, Hazaribagh District, Jharkhand
Ajay	23.618°N, 87.709°E	58	Bolpur, Birbhum District, West Bengal
Ajay	23.732°N, 87.278°E	79	Bhimgara, Birbhum District, West Bengal

Distribution: India: Tamil Nadu, Maharashtra, Gujarat, and now from Uttar Pradesh, Bihar, West Bengal, and Jharkhand.

Photographic evidences: Uttar Pradesh and Bihar (Image 1)

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Lindernia rotundifolia **(L.) Alston** ***Lindernia tamilnadensis*** **Prasad & Sunojk**

Habit

Leaves

Flower

Fruit

Image 1. *Lindernia tamilnadensis* along with allied species *Lindernia rotundifolia* for comparative studies. ©: Revan Y. Chaudhari.

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OPEN ACCESS

SHORT COMMUNICATION

Discovery of a new Myristica swamp in the northern Western Ghats of India

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Abstract: Myristica swamps are one of the world's unique freshwater ecosystems. In recent years there has been an increase in reports about their distribution along the Western Ghats. In this paper, we present a new distribution record for Myristica swamps in the northern part of the Western Ghats in Maharashtra. The Myristica swamp is located within the Bhalandeshwar Sacred Grove of Kumbral Bagwadi, Dodamarg Maharastra, India. This forms the second report from the state of Maharastra. Frequent field visits were made to study and document the floral assemblage and biodiversity in the swamp from November 2023 to January 2024. The swamp is dominated by *Myristica magnifica* Bedd. and is part of a sacred grove protected by villagers due to religious beliefs. The second discovery of a Myristica swamp with a gap of just six years points out to the potential existence of more swamps in the region. Therefore, systematic surveys are needed to document undocumented swamps in various areas.

Keywords: Bhalandeshwar Sacred Grove, endemic flora, freshwater ecosystems, Maharashtra, threatened wetland ecosystem, traditional knowledge.

Myristica swamps represent highly important yet one of the threatened freshwater ecosystems of the world. As the name suggests, the plants of the family Myristicaceae dominate the swamps. They offer various ecological services, such as providing fruits of Myristica, which are an important source of food for the threatened hornbills and the habitat for the vulnerable Asian Short-clawed Otters *Aonyx cinereus*. The high watershed value of these swamps supports many rare, endemic flora and fauna (Chandran et al. 2010). With an evolutionary origin of about 140 million years, the swamps are valuable for evolutionary studies (Chandran et al. 1999; Dharmapalan & Asokhan 2013).

Krishnamoorthy (1960) for the first time, shed light on the occurrence of this unique ecosystem from the south Western Ghats of Kerala, India. Since then, their occurrence has also been studied and reported in the states of Karnataka, Goa, and Maharashtra (Gadgil & Chandran 1989; Santhakumaran et al. 1995; Sreedharan & Indulkar 2018). The Myristica swamp reported from Bambarde-Hewale (Sreedharan & Indulkar 2018) of Maharashtra forms the first record of the presence of such an ecosystem in the state and the northernmost record in the Western Ghats.

The literature survey indicates that the swamps have restricted distribution along the Western Ghats of India, occurring in small fragmented areas. In this communication, it is reported that a new site where a Myristica swamp was found in Maharashtra State, India. Pravin Desai runs a homestay and conducts wildlife trails in the different parts of Dodamarg Tilari Bioregion in Dodamarg Taluka of Sindhudurg District of Maharashtra.

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Methods

During the regular birding trail to Bhalandeshwar Sacred Grove, while searching for Brown Wood-Owls *Strix leptogrammica*, Pravin observed a huge tree of *Myristica magnifica* Bedd. which led to him discovering the Myristica swamp. This finding was subsequently followed by visits to the swamp for further studies. The plants were identified using the book 'Trees of Sahyadri' a leaf-based field guide by Shrikant Ingalharikar and by consulting Dr. Navendu Page.

The area of the sacred grove and the area of the swamp were estimated within the sacred grove using Garmin GPS 72s by walking around the grove and swamp. All the trees in the swamp with a girth at breast height (GBH) of ≥ 30 cm by using a measuring tape, and height by using a Leica geosystem D1 distometer. For *Myristica magnifica*, an obligate swamp specialist, the height and girth of all individuals were recorded. For trees having less than 1.3 cm in height, their girth was visually estimated. Tree seedlings (GBH <10 cm) were enumerated from the sample plots to determine the regeneration status of tree species in the Myristica swamps. Additionally, a checklist was made for other woody plant species to understand the species diversity and identify the associated species in the area. The checklist contains the list of species arranged alphabetically with their conservation status available on the International Union for Conservation of Nature (IUCN) website. Plants of the World Online (POWO) and The International Plant Names Index (IPNI) were used for nomenclature.

Results

The Myristica swamp is located in Bhalandeshwar Sacred Grove at Kumbral Bagwadi (Image 1). The swamp is dominated by *Myristica magnifica*, which has prominent stilt roots (Image 1). The area of the grove and swamp is 8200 m² and 770 m², respectively. A total of 39 plant species were documented (Table 1, Images 3 & 4). Around 70 individuals of *Myristica magnifica* were recorded, out of which 19 individuals with a girth of ≥30 cm and 51 individuals with a girth of <30 cm. Given that 51 out of 70 individuals were <30 cm indicating regeneration of the *Myristica magnifica*. The size class plot for girth and height is given in Figures 1 & 2, respectively. The rank abundance curve shows

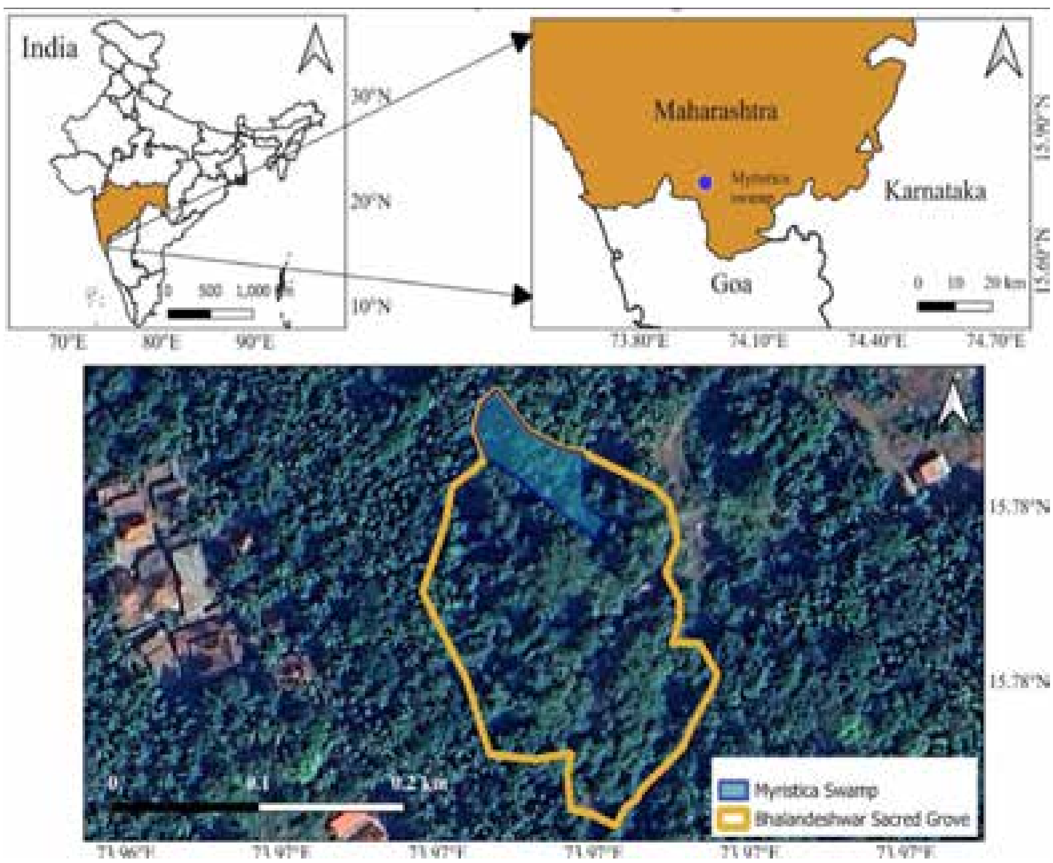

Image 1. Map showing the location of Bhalandeshwar Sacred Grove and the Myristica swamp as of 16 December 2023.

Table 1. Checklist of plants documented in the Myristica swamp of Bhalandeshwar.

	Species name	Family	Habit	IUCN Red List status
1	*Actephila excelsa* (Dalzell) Müll.Arg.	Phyllanthaceae	Small tree	Least Concern
2	*Allophylus cobbe* (L.) Forsyth f.	Sapindaceae	Liana	NA
3	*Anamirta cocculus* (L.) Wight & Arn.	Menispermaceae	Liana	NA
4	*Antidesma nigricans* Tul.	Phyllanthaceae	Shrub	NA
5	*Aporosa cardiosperma* (Gaertn.) Merr.	Phyllanthaceae	Tree	Vulnerable
6	*Artocarpus heterophyllus*	Moraceae	Tree	NA
7	*Artocarpus hirsutus* Lam.	Moraceae	Tree	Least Concern
8	*Bolbitis presiliana* (T.Moore) Ching.	Dryopteridaceae	Fern	Least Concern
9	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae	Tree	Least Concern
10	*Bridelia scandens* (Roxb.) Willd.	Phyllanthaceae	Scandent shrubs	Least Concern
11	*Calophyllum apetalum* Willd.	Calophyllaceae	Tree	Vulnerable
12	*Capparis* sp.	Capparaceae	Climber	NA
13	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	Tree	Least Concern
14	*Caryota urens* L.	Arecaceae	Tree	Least Concern
15	*Chassalia curviflora* (Wall.) Thwaites	Rubiaceae	Shrub	NA
16	*Cleodendron* sp.	Lamiaceae	Shrub	NA
17	*Combretum* sp.	Combretaceae	Herb	NA
18	*Diospyros candolleana* Wight	Ebenaceae	Tree	Vulnerable
19	*Dracaena elliptica* Thunb. & Dalm.	Asparagaceae	Herb	Least Concern
20	*Entada rheedei* Spreng	Fabaceae	Liana	NA
21	*Ficus hispida* L.f.	Moraceae	Tree	Least Concern
22	*Ficus nervosa* Roth	Moraceae	Tree	Least Concern
23	*Flacourtia montana* J.Graham	Salicaceae	Tree	NA
24	*Garcinia indica* (Thouars) Choisy	Clusiaceae	Tree	Vulnerable
25	*Gymnosporia rothiana* (Walp.) M.A.Lawson	Celastraceae	Shrub	NA
26	*Holigarna arnottiana* Hook.f.	Anacardiaceae	Tree	Endemic
27	*Ipomoea campanulata* L.	Convolvulaceae	Climber	NA
28	*Ixora coccinea* L.	Rubiaceae	Shrub	NA
29	*Ixora nigricans* R.Br. ex Wight & Arn.	Rubiaceae	Small tree	NA
30	*Ixora brachiata* Rox.	Rubiaceae	Tree	NA
31	*Lagenandra toxicaria* Dalzell	Araceae	Herb	Least Concern
32	*Leea indica* (Burm.f.) Merr.	Vitaceae	Small tree	Least Concern
33	*Lophopetalum wightianum* Arn.	Celastraceae	Tree	Least Concern
34	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	Tree	NA
35	*Machilus glaucescens* (Nees) Wight	Lauraceae	Tree	NA
36	*Mimusops elengi* L.	Sapotaceae	Tree	LC
37	*Myristica magnifca* Bedd.	Myristicaceae	Tree	Endangered/ Endemic
38	*Nothopegia castaneifolia* (Roth) Ding Hou	Anacardiaceae	Tree	Critically Endangered
39	*Pandanus furcatus* Roxb.	Pandanaceae	Shrub	NA
40	*Pothos scandens* L.	Araceae	Climber	NA
41	*Premna coriacea* C.B.Clarke	Lamiaceae	Climber	NA
42	*Pterospermum acerifolium* (L.) Willd.	Malvaceae	Tree	Least Concern
43	*Sterculia guttata* Roxb.	Malvaceae	Tree	NA
44	*Tabernaemontana alternifolia* L.	Apocynaceae	Tree	NA
45	*Tetrastigma leucostaphylum* (Dennst.) Alston	Vitaceae	Liana	NA
46	*Thottea siliquosa* E.S.S.Kumar, A.E.S.Khan & Binu	Aristolochiacea	Shrub	NA

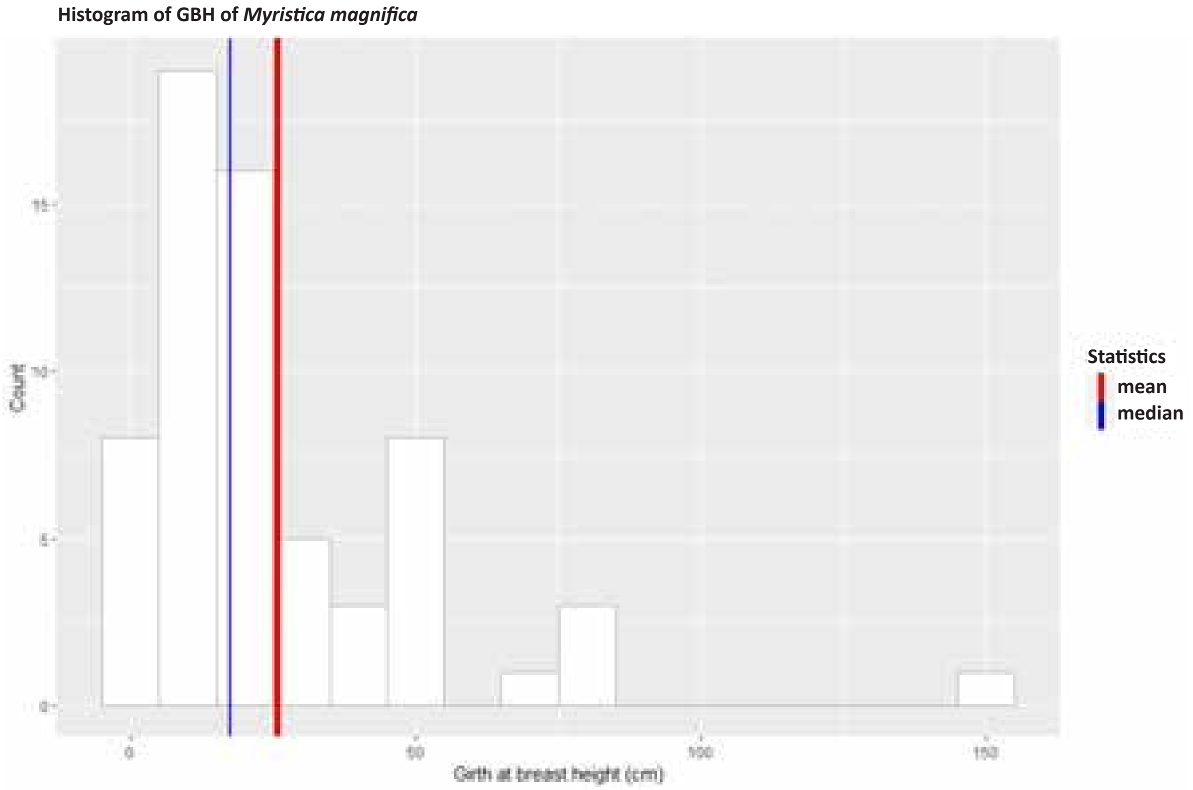

Figure 1. Histogram of girth at breast height of *Myristica magnifica* individuals that were >1.3 cm in height.

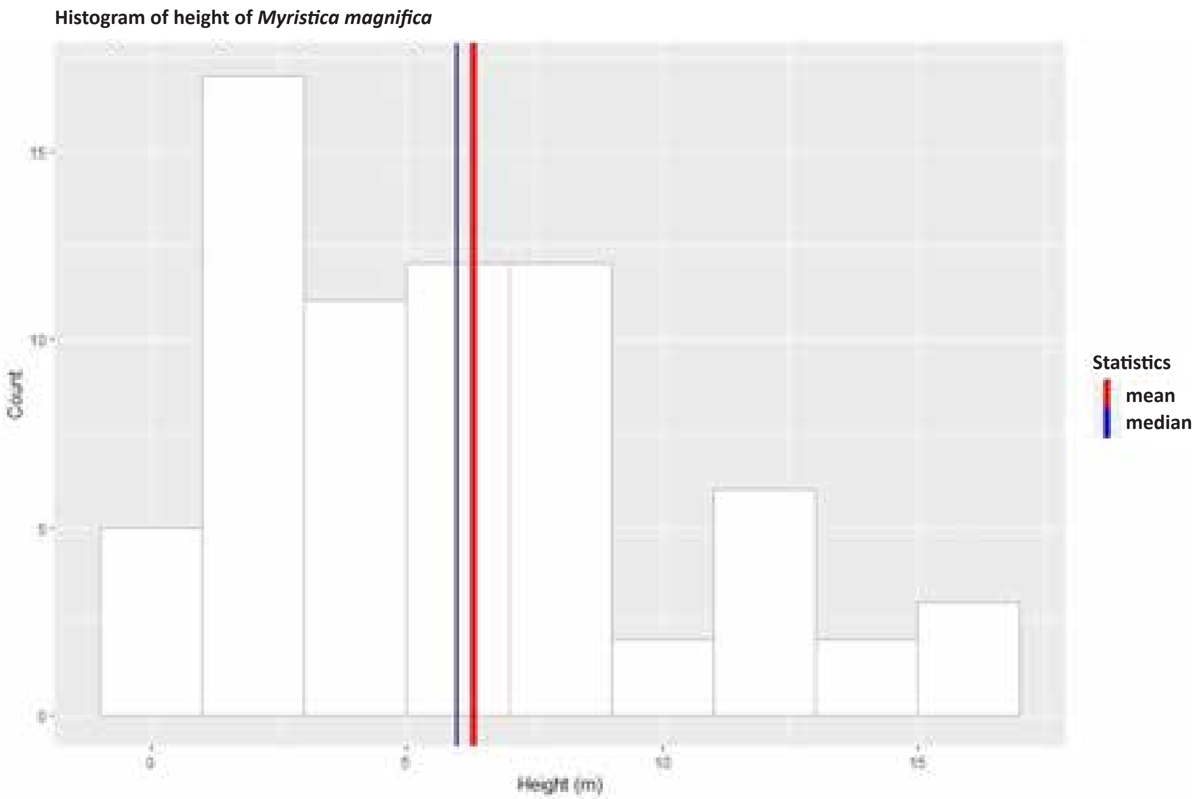

Figure 2. Histogram showing *Myristica magnifica* tree height distributions in the swamp. There is a greater representation of saplings indicating the regeneration of trees in the swamp.

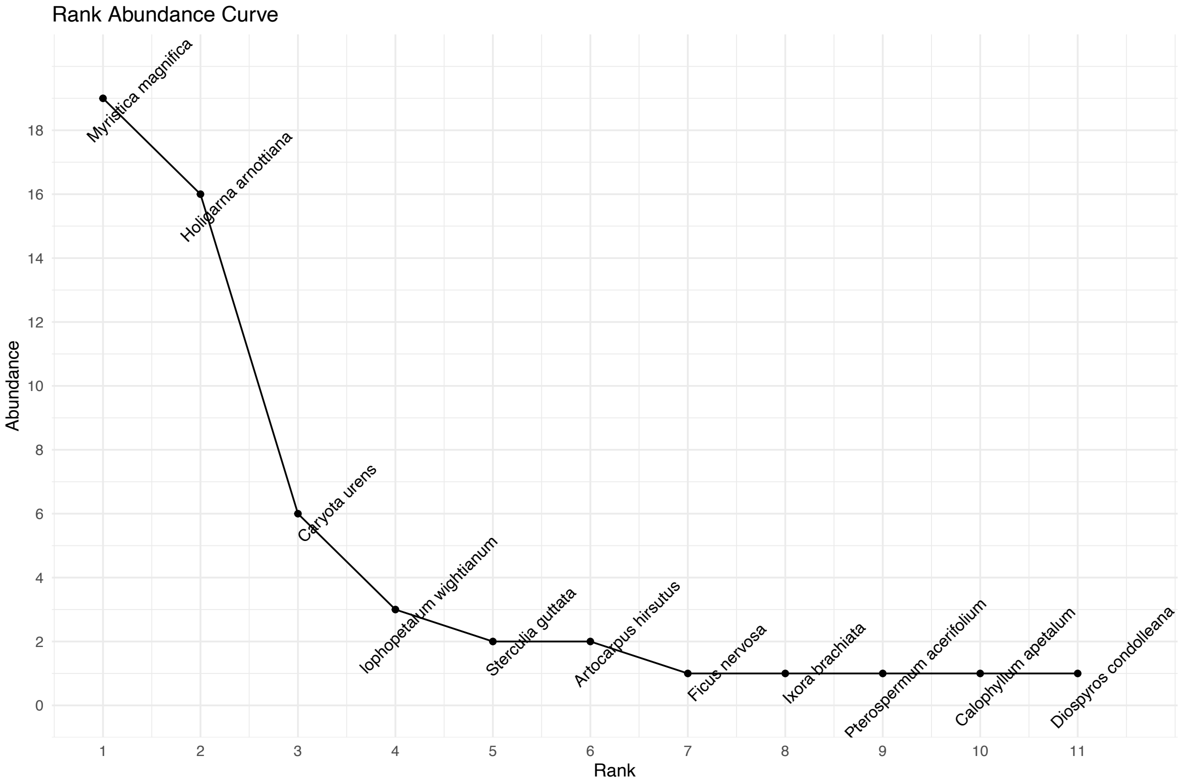

Figure 3. Rank abundance curve for all individual woody plant tree species in the Myristica swamp. Only those individuals with ≥30 cm girth at breast height were included in this plot.

Image 2. A—*Myristica magnifica* with undergrowth of fern, *Bolbitis presiliana*, and edge vegetation | B—Water inundation in the swamp and Stilt roots of *Myristica magnifica* | C—Source of water for the swamp | D—Idol being worshiped in the sacred grove. © Shital Desai.

Image 3. A—*Actephila excelsa* | B—*Allophylus cobbe* | C—*Anamirta cocculus* | D — *Antidesma nigricans* | E— *Aporosa cardiosperma* | F—*Artocarpus heterophyllus* | G—*Artocarpus hirsutus* | H—*Bolbitis presiliana* | I—*Bridelia retusa* | J—*Bridelia scandens* | K—*Calophyllum apetalum* | L—*Capparis* sp. | M—*Carallia brachiata* | N—*Caryota urens* | O—*Chassalia curviflora* | P—*Cleodendron* sp. | Q—*Combretum* sp. | R—*Diospyros candolleana* | S—*Dracaena elliptica* | T — *Entada rheedei* | U—Ficus hispida | V—*Ficus nervosa* | W—*Flacourtia montana* | X—*Garcinia indica*. © Shital Desai.

that the swamp species exhibit low species evenness, with *Myristica magnifica* being the dominant species in the swamp (Figure 3). The undergrowth in the swamp is dominated by the fern *Bolbitis presiliana* (T.Moore) Ching and *Pandanus furcatus* Roxb (Image 2).

Discussion

The local communities worship the deity Bhalandeshwar, who is believed to be an avatar of Lord Shiva and they have been performing religious rituals since the 16th century. The local people practice the ritual of 'Kaul' to seek permission or answers to their

Image 4. A—*Gymnosporia rothiana* | B— *Holigarna arnottiana* | *C—Ipomoea campanulata* | D—*Ixora coccinea* | E—*Ixora nigricans* | F—*Ixora brachiata* | G—*Lagenandra toxicaria* | H—*Leea indica* | I—*Lophopetalum wightianum* | J—*Macaranga peltata* | K—*Machilus glaucescens* | L—*Mimusops elengi* | M—*Myristica magnifca* | N—*Nothopegia castaneifolia* | O—*Pandanus furcatus* | P—*Pothos scandens* | Q—*Premna coriacea* | R—*Pterospermum acerifolium* | S—*Sterculia guttata* | T—*Tabernaemontana alternifolia* | U—*Tetrastigma leucostaphylum* | *V—Thottea siliquosa*. © Shital Desai.

questions. During the temple renovation, they sought permission from the deity Bhalandeshwar to cut and use the tree of *Myristica* for construction. However, they did not receive a positive Kaul from the deity, and thus, the swamp was protected. The spring that emerges at the temple, serves as a source of drinking water for local people. The swamps offer various ecological services, like groundwater recharge, carbon sequestration, natural barriers against floods, habitat, and food for many aquatic and aerial fauna. The fruits of *Myristica* are important food plants for threatened hornbills (Gopal et al. 2021). The occurrence and discovery of this second swamp in the northern Western Ghats of Maharashtra strongly point toward the possibility of more swamps in this region. Therefore, it is necessary to conduct a systematic survey to record the presence of marshes in various regions. The preservation of this swamp has been motivated by religious values and is imperative to utilise its water resources for several decades sustainably.

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NOTE

Ophioglossum jaykrishnae S.M.Patil et al. (Pteridophyta: Polypodiophyta: Ophioglossaceae): a new distribution record from Kanha National Park, Madhya Pradesh, India

Tarun Nayi [1], Mayur Bhagwat [2], Sanjay Saini [3], Soham Haldikar [4], Ishtayaque Patel [5], Shivaji Chavan [6], Nudrat Zawar Sayed [7] & Sunil Kumar Singh [8]

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The fern genus *Ophioglossum* L. belongs to the primitive family Ophioglossaceae, is diverse, and has about 52 species worldwide. Among these species, 23 are documented from India (Patil et al. 2018; Fraser-Jenkins et al. 2020). The genus was first studied in India by Beddome (1883). Since then, it has received significant attention from researchers such as Hope (1903), Blatter & d'Almeida (1922), Mahabale (1962), Panigrahi & Dixit (1969), Khandelwal (1987), Khullar (1994), Goswami (2007), Patil & Dongare (2014), and Kachhiyapatel et al. (2018). Recently, four new species of *Ophioglossum* were reported and described in Gujarat, India by Patil et al. (2018), Patel & Reddy (2018, 2019), and Patel et al. (2018), respectively.

The Kanha Tiger Reserve (KTR) spans across the Mandla and Balaghat districts of Madhya Pradesh and is situated in the Maikal hills of the Satpura range (Kanha Tiger Reserve 2024). During the floristic exploration of KTR, the authors collected an interesting specimen of *Ophioglossum* L. Upon critical examination, the specimen was identified as *O. jaykrishnae.* It was described by Patil et al. (2020) from Jambughoda Wildlife Sanctuary (WS), Gujarat. Currently, *O. jaykrishnae* is only known from Jambughoda Wildlife Sanctuary, Gujarat, and Koyna Wildlife Sanctuary, Maharashtra, India. Thus, the present collection from Kanha National Park accounts for a new addition to the flora of Madhya Pradesh, India. During the fieldwork, observations were made on species distribution, habitats, phenology, and the number of individuals in each population.

A floristic study was carried out for the Sondhar beat in the Kisli range of Kanha National Park, Madhya Pradesh, India during the months of October 2022 to December 2023. This area falls under the 22.366 N &

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80.543 E. During this study, an interesting species of *Ophioglossum* was collected. Collected specimens were prepared following the method of Forman & Bridson (1992). After a critical examination of the specimens with relevant literature (Beddome 1883; Fraser-Jenkins et al. 2020; Patil et al. 2020) it was identified as *O. jaykrishnae* S.M.Patil et al. Also, the species was confirmed by matching with the isotypes deposited at SUK herbaria (SMP & KSR 1082). The voucher specimens (TRN 101) were deposited in the Government Science College Herbarium Gandhinagar, Gujarat. The GeoCAT tool was used to estimate the extent of occurrence (EOO) and area of occupancy (AOO) (Figure 1).

Ophioglossum jaykrishnae S.M.Patil et al. is a terricolous species with a height of 4–10 cm, featuring a dark brown and pink colour palette. Its subterranean elements include rhizomorphs, tuberose – sub globose structures, and fibrous roots. Tropophylls with a brownish-pink hue emerge at a 30^0–60^0 angle to the fertile stalk. The lanceolate lamina showcases an acute apex and nearly truncate base with a smooth margin, pseudo-costa, and absence of a sheathing leaf base. The venation is simple with parallel areoles. The fertile segment is 3–8.5 cm long, dark brownish, and abaxially grooved. Strobili, measuring 0.5–2 cm, reveals an acute-acuminate apex in a dark brown-pink color. Sporangia are arranged in two alternate rows, with 4–8 pairs, and spores are 20–35 µm in diameter, featuring a trilete exine with tuberculate-varicose patterns. Overall, this plant exhibits intricate and unique characteristics in its morphology and reproductive structures (Image 1).

Reproductive period: July and August

Distribution: Jambughoda Wildlife Sanctuary, Gujarat (Patil et al. 2020), Koyna Wildlife Sanctuary, Maharashtra (Jadhav 2023), and Kanha Nation Park, Madhya Pradesh.

Ecology: *Ophioglossum jaykrishnae* grows in moist soil in open grasslands at altitudes up to 600 m. It is usually found in association with other species such as *Dimeria ornithopoda* Trin., *Cyperus triceps* (Rottb.) Endl., *Lindernia ciliata* (Colsm.) Pennell, *Lindernia crustacea* (L.) F. Muell., and other bryophyte species (Image 2).

Conservation status: The species was first recorded and described from Jambughoda WS located in Panchmahal district of Gujarat. It was subsequently reported from the Koyna WS in the Satara district of Maharashtra.
Recently, authors located this species in the Kanha Tiger Reserve. The population comprising 20–30 individuals is seen growing in a small area of roughly 1 km^2. The estimated extent of occurrence and area of occupancy of *Ophioglossum jaykrishnae* are 1,95,171.65 km^2 and 12 km^2, respectively (Figure 2).

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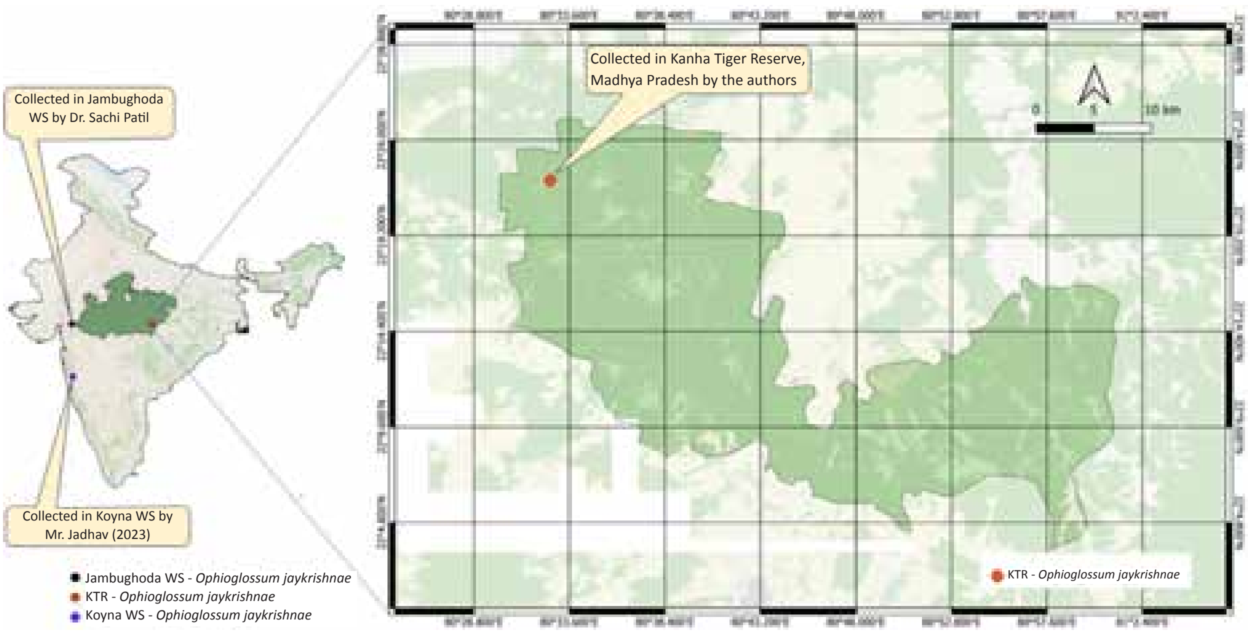

Figure 1. Depicting the location of *Ophioglossum jaykrishnae* S.M.Patil et al. (QGIS 2024)

Image 1. *Ophioglossum jaykrishnae* S.M.Patil, S.K.Patel, Raole & K.S.Rajput: a—habit | b—stem and leaves | c—fertile stalk-strobilus | d—fibrous root. © Tarun Nayi.

Image 2. Habitat of *Ophioglossum jaykrishnae*. © Tarun Nayi.

Figure 2. GeoCAT analysis showing distribution and analysis of extent of occurrence and area of occupancy (gsrid size 2km).

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