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Journal of Threatened Taxa

Open Access

10.11609/jott.2024.16.9.25791-25950
www.threatenedtaxa.org

26 September 2024 (Online & Print)
16(9): 25791–25950
ISSN 0974-79t07 (Online)
ISSN 0974-7893 (Print)

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25791–25801
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.9286.16.9.25791-25801
#9286 | Received 09 July 2024 | Final received 27 August 2024 | Finally accepted 07 September 2024

ARTICLE

Feeding dynamics of sympatric large carnivores in an anthropogenic landscape of the Indian Terai

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Abstract: An important challenge for large carnivore conservation is negative human-wildlife interaction. Livestock depredation by carnivores is one important aspect of this negative interaction. Hence, it is critical to understand the extent of livestock depredation by large carnivores through their diet profiles and feeding habits for managing and strategizing conservation measures. We investigated the food habits and dietary patterns of two large sympatric carnivores, the Tiger *Panthera tigris* and the Leopard *Panthera pardus* based on scat samples collected in wildlife corridors outside protected areas (PAs) in the Indo-Nepal transboundary and Corbett landscape in Uttarakhand, India. The frequency of occurrence of prey items in the scat samples was used to estimate the relative prey biomass and number of preys consumed by the Tigers and Leopards using a generalised biomass model. Scat analysis revealed the presence of mainly wild prey species, encompassing 12 species in tiger scat and 14 species in Leopard scat. The results show that Tigers and Leopards primarily depend on medium-sized prey, with relative prey biomass consumption of 53% and 60%, respectively. Tigers preyed most frequently on Wild Boar *Sus scrofa*, followed by Spotted Deer *Axis axis*, and Leopards preyed mostly on Spotted Deer, followed by Wild Boar. The relative biomass of livestock species in Tiger and Leopard diets is 14.2% and 15.7%, respectively. Dietary overlap between Tiger and Leopard was high, with the Leopard exhibiting a broader dietary niche breadth than the Tiger. Augmenting wild prey population through habitat improvement and protection outside PAs can significantly limit human-large carnivore conflict by decreasing livestock contribution in their diet. Studies on dietary habits need to expand to wildlife corridors and outside PAs in human-dominated landscapes to understand the ecological dynamics of human-wildlife negative interaction for future conservation strategies.

Keywords: Dietary profile, human-wildlife interaction, leopard, tiger, wildlife corridor.

Editor: Angie Appel, Wild Cat Network, Germany. **Date of publication:** 26 September 2024 (online & print)

Citation: Ranjan, V., S.A. Hussain, R. Badola, G. Vashistha & P.M. Dhakate (2024). Feeding dynamics of sympatric large carnivores in an anthropogenic landscape of the Indian Terai. *Journal of Threatened Taxa* 16(9): 25791–25801. https://doi.org/10.11609/jott.9286.16.9.25791-25801

Funding: The fieldwork was done under the project entitled “Dispersal, Communication and Conservation Strategies for Tiger (Panthera tigris tigris) in Kumaon Himalayas of Uttarakhand, India”, funded by National Mission on Himalayan Studies (Project Id: GBPNI/NMHS-2017-18/SGP-01).

Competing interests: The authors declare no competing interests.

Author details: See end of this article.

Author contributions: All authors contributed to the study conception and design. VR and GV did sample collection and fieldwork. Material preparation and data analysis were performed by VR. RB and SAH contributed to the intellectual review and supervision of the study. This study was supervised by RB, SAH and PMD. PMD acquired the necessary permissions and provided field support from the Uttarakhand Forest Department. The project under which this study was conducted was supervised by PMD. The first draft of the manuscript was written by VR and reviewed by GV. All authors reviewed the final draft and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgements: We thank the director and dean of the Wildlife Institute of India for research facilitation and support. We sincerely thank the Uttarakhand Forest Department for the necessary permissions, logistics, and field support. We extend our gratitude to the Haldwani Zoo and Safari staff for helping collect samples and necessary support during the fieldwork. We are thankful to the National Mission on Himalayan Studies for funding support for the project.

INTRODUCTION

Large carnivores are wide-ranging species inhabiting variable habitats and serving as flagship species for biodiversity conservation (Harihar et al. 2011). Although energy restrictions limit their population sizes in the wild, large predators significantly influence the organisation of communities through trophic cascades (Lamichhane et al. 2019). Predation is a phenomenon that connects trophic levels and is essential to many ecological and evolutionary processes (Fryxell et al. 2007). When sympatric species share a trophic level, niche differentiation and resource partitioning are evident (Schoener 1986). Differential use of food resources is an essential mode of resource partitioning in ecological communities (Karanth & Sunquist 2000) in addition to prey size (Gittleman 1985), activity patterns (Fedriani et al. 1999), space use patterns, and habitat use preference (Palomares et al. 1996; Shameer et al. 2021). Understanding the patterns of dietary niche overlap of sympatric carnivores is crucial for devising adequate conservation measures.

India harbours more than 75% of the world's wild Tiger population, with a population growth of 6.1% from 2006 to 2022 (Qureshi et al. 2023). The Tiger is distributed across India along with its co-predators Leopard and Dhole *Cuon alpinus* (Ramesh et al. 2012; Qureshi et al. 2023). These three large carnivores inhabit forests and coexist across various landscapes through spatio-temporal & dietary partitioning (Karanth & Sunquist 1995; Andheria et al. 2007; Ramesh et al. 2012; Selvan et al. 2013; Lamichhane et al. 2019; Mohan et al. 2021; Shameer et al. 2021). The distribution of the Dhole in the Indian Terai has declined extensively due to persecution in the past and is now restricted to a few protected areas (PAs) (Qureshi et al. 2023), including Nandhaur Wildlife Sanctuary, and adjoining wildlife corridors in the Terai of Uttarakhand (Ranjan & Dhakate 2021).

The dietary profile of animals can be studied easily with the most widely used non-invasive method of scat or faecal analysis (Ackerman et al. 1984; Karanth & Sunquist 1995; Klare et al. 2011). This method is very effective for large carnivores (Karanth & Sunquist 1995; Chakrabarti et al. 2016; Biswas et al. 2023). The dietary habits of the tiger and leopard have been studied extensively in India mainly in PAs (Andheria et al. 2007; Majumder 2011; Athreya et al. 2013; Basak et al. 2018; Biswas et al. 2023). Limited studies are available on the diet of the two species outside PAs in India, such as food habits and characteristics of livestock predation in human-dominated landscapes (Puri et al. 2020; Mohan et al. 2021; Dahya et al. 2023).

In tropical forests, the relative densities of various size classes of prey can vary naturally and due to human activity, affecting or influencing the community structures of large carnivores (Karanth & Sunquist 1995). The abundance and availability of prey species are critical to the sympatry of large carnivores (Andheria et al. 2007). Prey abundance does not necessarily affect prey selection (Bagchi et al. 2003; Lovari et al. 2015). The high density of wild prey limits or reduces livestock depredation and negative human-wildlife interactions (Basak et al. 2018; Upadhyaya et al. 2018; Puri et al. 2020). Sometimes, the human-large carnivore conflict scenarios are exaggerated due to political and social attributes of a specific region (Dickman 2010; Dickman et al. 2013; Nyhus 2016). Thus, the diet profile of large carnivores will also reveal the nature of conflict situations.

Our study focused on the feeding habits and dietary overlap of Tigers and Leopards in a multi-use landscape outside the PAs encompassing the critical wildlife corridors in the Terai-Bhabar region of northern India at the foothills of the Himalaya, a critical Tiger conservation landscape (Sanderson et al. 2006). We also explored the dependence of the large carnivores on livestock for food in areas outside PAs, where wild prey population is low and anthropogenic disturbances are high.

Study Area

Our study area is part of the Terai Arc Landscape, which lies in the Terai-Bhabar topography at the foothills of the Himalaya (Semwal 2005). The study area is located between Corbett Tiger Reserve (CTR) and the Indo-Nepal border in the eastern and southern parts of the state of Uttarakhand, bordering the Indian state of Uttar Pradesh. The study area is divided into two blocks (Image 1). Block 1 constitutes the Kosi corridor with adjoining areas of CTR, Ramnagar Forest Division (FD), and Almora FD of Uttarakhand. Block 2 encompasses the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridors with adjoining forest habitats of the Terai East FD, Haldwani FD, and Champawat FD of Uttarakhand. The Kosi corridor connects CTR with the Ramnagar FD and Pawalgarh Conservation Reserve along the Kosi River east of CTR in Uttarakhand (Johnsingh 2006; Anwar et al. 2014). The KKS corridor connects Nandhaur Wildlife Sanctuary (NWS) in Uttarakhand with Pilibhit Tiger Reserve (PTR) in Uttar Pradesh and the Indo-Nepal border in the Khatima forest range of the Terai East FD. The BB corridor connects NWS to the Kanchanpur

FD in Nepal, a transboundary landscape that expands to Shuklaphanta National Park in Nepal (Semwal 2005; Qureshi et al. 2014).

The study area lies in Tiger Habitat Block (THB) II and III (Johnsingh et al. 2004) and tiger conservation landscape (Sanderson et al. 2006; WWF & RESOLVE 2015). The large mammalian species in the region are Asiatic Elephant *Elephas maximus*, Tiger, Leopard, Sloth Bear *Melursus ursinus*, Sambar Deer *Rusa unicolor*, Spotted Deer *Axis axis*, Wild Boar *Sus scrofa*, and Northern Red Muntjac *Muntiacus vaginalis*. The study area falls in the 2B Himalaya – western Himalaya and 7A Gangetic Plain – upper Gangetic Plain biogeographic provinces of India (Rodgers et al. 2000).

Livestock grazing is common in the study area because it lies outside the PAs in a multi-use mosaic landscape where reserved forests are interspersed with human settlements and fragmented due to linear infrastructures (Johnsingh et al. 2004; Chanchani et al. 2014). Two important pastoralist community in the study area are ‘Bakarwal’ and ‘Van Gujjars’. The nomadic community of ‘Bakarwal’ migrates from the high-elevation Himalaya to lower elevations of the Terai-Bhabar during November to January with their large herds of sheep and goats camping for several days and months in the forest areas of the Himalayan foothills (Dangwal 2024). The ‘Van Gujjars’ is a pastoralist community residing in the study area’s forests with large herds of Water Buffalos *Bubalus bubalis* and Cattle *Bos taurus* (Sharma et al. 2012; Dangwal 2024).

MATERIALS AND METHODS

Scat Sample Collection

Scat samples of Tigers and Leopards were collected opportunistically in the study area during camera trapping and vegetation surveys on wildlife trails and

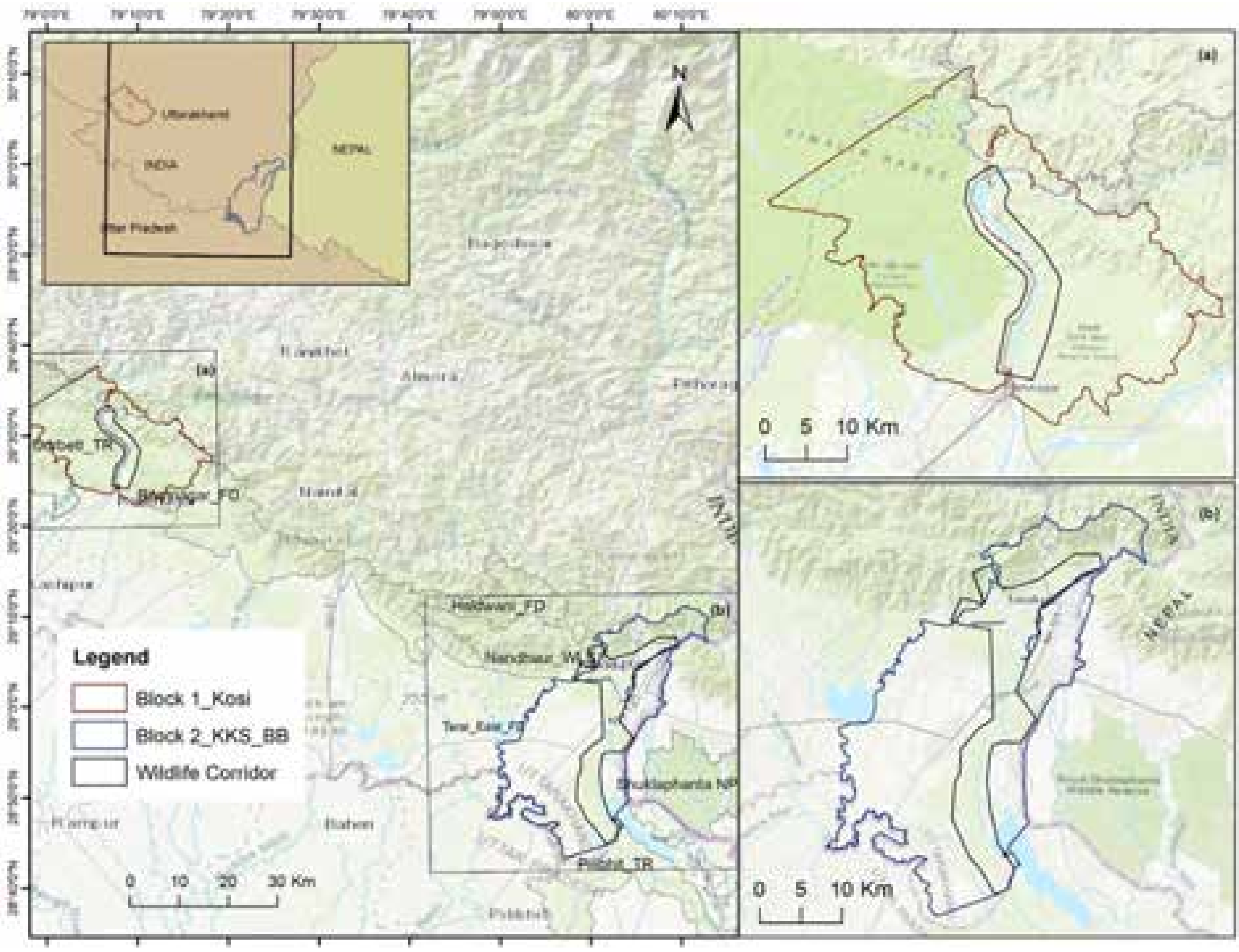

Image 1. Study area map with the two study blocks comprising of wildlife corridors: a—Block 1 with Kosi corridor connecting Corbett Tiger Reserve to Ramnagar forest division | b—Block 2 with Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridor in Indo-Nepal transboundary landscape.

forest roads. We collected scat in the summer season from March–June and in winter season from October–February. Scat collection was not possible during the monsoon season as forest areas were not accessible.

Tigers, Leopards, and other carnivores deposit scat on forest roads and wildlife trails as part of the communication mechanism (Smith et al. 1989; Karanth & Sunquist 1995; Andheria et al. 2007). The samples were collected from October 2019 to December 2021, stored in plastic zip lock bags, and predator species were identified based on ancillary signs and methods described in earlier studies based on visual and indirect signs (Karanth & Sunquist 1995; Andheria et al. 2007; Harihar et al. 2011; Lovari et al. 2015; Basak et al. 2018). Tiger scat has been observed to be less coiled with a more considerable distance between two successive constrictions (Johnsingh 1983; Mohan et al. 2021). The scat samples which were not identified for species based on ancillary signs were not analysed. After collection, the remaining scat samples were removed from the track to avoid repetitive sampling. We avoided collecting scat in village areas or metalled roads in forest habitats to avoid misidentification of species due to lack of indirect signs of species.

Sample processing and prey species identification

A substantial part of each sample was put in nylon stockings, a knot was tied and then soaked in water for 24 hours (Klare et al. 2011). After soaking, it was washed in running water in a sieve of <1 mm to remove debris and dirt (Ramesh et al. 2009; Upadhyaya et al. 2018). Then it was sun-dried for 72 hours (Andheria et al. 2007) before separating 20 random hairs per sample for identification of prey based on its general appearance, colour, relative length, width, cortex pigmentation, and medullary structures under a microscope (Mukherjee et al. 1994; Bahuguna et al. 2010; Dharaiya & Soni 2012).

Data analysis

We did not perform an analysis of vegetation, which we found in some scat samples of both species. We calculated the frequency of occurrence of each prey item in the scat samples, denoted as A, and expressed as a per cent of scat samples in which a particular prey item was found (Andheria et al. 2007). We calculated the corrected frequency of occurrence based on the number of prey items per scat; if two items were present in one scat, it was calculated as 1/2; if three items were present, then 1/3, and so on (Karanth & Sunquist 1995). However, when the body size of prey varies significantly, the frequency of occurrence can be misleading (Floyd et al. 1978; Ackerman et al. 1984). The non-linear models developed for the leopard (Lumetsberger et al. 2017) and the Tiger (Fàbregas et al. 2017) show better accuracy than linear models in assessment of biomass and number of prey consumed. The linear model is biased for tropical large carnivores and significantly underestimates the consumption of medium-sized prey (Chakrabarti et al. 2016). We used the nonlinear asymptotic generalised model developed by Chakrabarti et al. (2016) for carnivores in India based on the following formula:

$$Y_c = 0.033–0.025exp^{-4.284\ (X|Z)}$$

Y_c is biomass consumed per collectable scat/predator weight, X is the live weight of prey, and Z is the average live weight of predator. Y_c is used as a correction factor for estimating the relative prey biomass consumed by multiplying Y_c by the observed frequency of occurrence (A). The generalised biomass model is better suited for our study, where we want to assess the contribution of livestock to the food habits of Tigers and Leopards since this model does not overestimate large prey (Chakrabarti et al. 2016; Upadhyaya et al. 2018).

Our calculations are based on values for the average body weight of prey (Table 1), Tiger (140 kg) and Leopard (65 kg) (Harihar et al. 2011; Ahmed & Khan 2022). The relative prey biomass (D) and relative numbers of prey consumed (E) were calculated as per the equation below (expressed in percentage) described by Andheria et al. (2007).

$$D = \frac{A * Y}{\Sigma(A * Y)} * 100$$

$$E = \frac{D / X}{\Sigma(D / X)} * 100$$

To assess the dietary overlap between the Tigers and Leopards, we used the Pianka index (Pianka 1973) based on the frequency of occurrence, which ranges from 0 for no overlap to 1 for complete overlap.

$$Pianka\ index = \frac{\Sigma P_{ij} * P_{ik}}{\sqrt{\Sigma(P_{ij}^2 * \Sigma P_{ik}^2)}}$$

P_{ij} is the percentage of prey items i of predator j; P_{ik} is the percentage of prey items i of predator k

D_c and E_c denote the relative prey biomass and relative number of preys consumed using the Y_c correction factor based on the generalised biomass model, respectively. The D_c and E_c of Tigers and Leopards were statistically compared using the Kruskal-Wallis test statistic to understand the difference in diet profiles of the two large sympatric carnivores. We used Kruskal-Wallis as it is a non-parametric test, which does not assume that underlying data has a normal distribution (Xia 2020). We categorised the prey size into three classes based on their body weight: (i) large (above 50

Table 1. Frequency of occurrence (A) of different prey items, percent occurrence of each prey species (Po), live weight of prey (X), the number of scats with each type of prey (No.), Relative biomass consumed (D_c) and Relative number of prey consumed (E_c).

Prey species	X (kg)	Tiger						Leopard					
		No.	A (%)	Po	Y_c	D_c (%)	E_c (%)	No.	A (%)	Po	Y_c	D_c (%)	E_c (%)
Sambar Deer	185	23	15.9	14.29	0.033	19.54	4.91	8	9.0	7.08	0.033	10.83	1.60
Nilgai	184	12	8.5	7.45	0.033	10.38	2.62	5	5.6	4.42	0.033	6.77	1.01
Spotted Deer	50	32	20.4	19.88	0.028	20.95	19.49	17	17.4	15.04	0.032	20.39	11.18
Northern Red Muntjac	25	18	11.4	11.18	0.021	9.03	16.79	17	15.2	15.04	0.028	15.61	17.12
Wild Boar	35	36	24.0	22.36	0.024	21.82	29.00	18	16.3	15.93	0.031	18.14	14.21
Indian Hog Deer	25	4	1.6	2.48	0.021	1.26	2.34	5	4.5	4.42	0.028	4.62	5.07
Porcupine	8	8	3.2	4.97	0.013	1.58	9.18	5	3.4	4.42	0.018	2.24	7.69
Langur	10	4	1.7	2.48	0.015	0.94	4.35	8	5.1	7.08	0.020	3.70	10.15
Indian Hare	4	2	0.7	1.24	0.011	0.29	3.38	7	3.9	6.19	0.014	1.98	13.57
Cattle	175	14	7.8	8.70	0.033	9.50	2.52	6	6.2	5.31	0.033	7.44	1.17
Water Buffalo	250	4	3.0	2.48	0.033	3.70	0.69	2	1.1	1.77	0.033	1.35	0.15
Domestic goat	10	4	1.9	2.48	0.015	1.01	4.72	8	7.9	7.08	0.020	5.76	15.80
Domestic sheep	25	0	0	0	0.021	0	0	1	1.1	0.88	0.028	1.16	1.27
Bird (Unknown)	0	0	0	0		0	0	6	3.4	5.31		0	0

kg; Sambar Deer, Nilgai *Boselaphus tragocamelus*, cattle *Bos taurus*, Water Buffalo *Bubalus bubalis*; (ii) medium (20–50 kg; Spotted Deer, Northern Red Muntjac, Wild Boar, Indian Hog Deer *Axis porcinus*, Domestic Sheep *Ovis aries*); and (iii) small (below 20 kg; domestic goat *Capra hircus*, porcupine, langur, Indian Hare *Lepus nigricollis*) to understand the food habits and diet profiles of the two sympatric large carnivores (Harihar et al. 2011). The diet niche breadth of Tigers and Leopards was estimated using the Levins index (Levins 1968), standardised to a scale of 0–1 (Hurlbert 1978) based on the frequency of occurrence of different prey species. The standardised scale considers the proportional abundance of each resource state (Hurlbert 1978). The statistical tests were performed in PAST 4.03 and other analysis related to scat were performed in Microsoft Excel application. The map was prepared in ArcGIS 10.7, and graphs were prepared in PAST 4.03 and Ms-Excel.

RESULTS

From October 2019 to December 2021, we collected and analysed 116 Tiger and 89 Leopard scat samples in our study area. Our sample size was adequate for dietary profile investigation of Tigers and Leopards as the graph reached asymptote position for the number of preys detected with increasing number of samples (Figure 1).

Scat samples of tigers contained 12 prey species, with 64.7% of all consisting of one prey species, 31.9% of two species and 3.4% of three species. Tigers preyed most frequently upon Wild Boar (24%), followed by Spotted Deer (20.4%) (Table 1), and cattle (7.8%) constituted the most frequent prey amongst all livestock species. Three livestock species were observed in tiger scat, i.e., cattle, Water Buffalo (3%), and domestic goat (1.9%). All 12 prey items were observed in scat collected during the winter season. Scat collected in the summer contained 10 species except goat and Water Buffalo, and a higher contribution of cattle remains (14%) than in the winter (8%).

Scat samples of leopards contained 14 prey species, with 73% of all samples consisting of one species and 27% of two species. Leopards preyed most frequently upon Spotted Deer (17.4%), followed by Wild Boar (16.3%). Four livestock species were observed in Leopard scat, namely domestic goat (7.9%), cattle (6.2%), Water Buffalo (1%), and domestic sheep (1%). Unidentified remains like feather and beaks of birds (3.4%) were also found in leopard scat samples (Table 1). All 14 prey items were observed in leopard scat collected during the winter season and 10 prey species in scat collected during the summer except langur, Cattle, Water Buffalo, and sheep. The contribution of Wild Boar remains was higher in summer (23%) than in winter (14%).

The Wild Boar had the highest prey biomass contribution to the Tiger's diet with 21.82%, while Spotted Deer had the highest prey biomass contribution

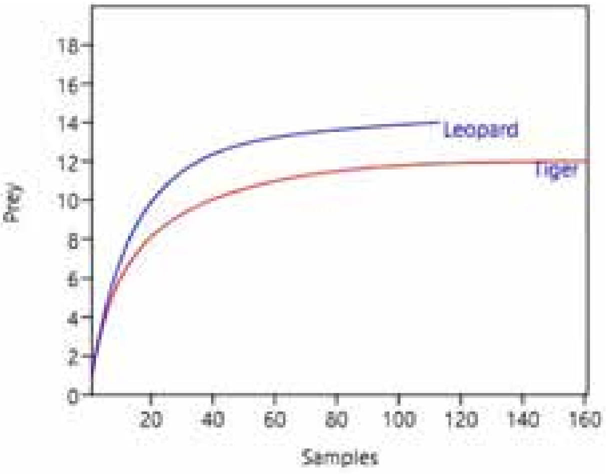

Figure 1. Graph showing number of preys in scat samples of Tiger and Leopard analysed for the study.

to the Leopard's diet with 20.39%. The cattle relative biomass contribution is the maximum among livestock species for both Tigers and Leopards. Overall, for all prey items, the diet composition showed no significant difference between relative prey biomass consumption (p = 0.53, χ^2 = 0.378) and relative number of preys consumed (p = 0.85, χ^2 = 0.032) by Tiger and Leopard.

Tiger and Leopard diets consist predominantly of medium-sized prey (Figure 2). Large prey constitutes 43.1%, medium prey ~53%, and small prey ~3.8% of biomass consumption in the Tiger diet profile. The leopard relative prey biomass consumption is highest for medium-sized prey (~60%), followed by large (26.4%) and small (13.7%) prey. The contribution of smaller prey is considerably higher in the diet of Leopards than of Tigers. Tiger relative prey biomass consumption primarily depends on wild prey (~85.8%), and around 14.2% on livestock. Relative prey biomass consumption of Leopards has a slightly higher share of livestock (~15.7%) than of Tigers (~14.2%). The relative number of medium-sized prey (67.6%) consumed by Tigers is substantially higher than that of large (10.8%) and small (21.6%) prey (Figure 2). However, the relative number of medium (48.9%) and small (47.2%) sized prey consumed by Leopards is equivalent but considerably higher than large prey (~3.9%) (Figure 2).

The relative prey biomass contribution of Wild Boar, Spotted Deer, and Sambar Deer is significant in the Tiger's diet. At the same time, Leopard food habits show a significant dependence on Spotted Deer, Wild Boar, and Northern Red Muntjak for biomass consumption (Figure 2). The dietary overlap between Tiger and Leopard in the study area is approximately 93% (Pianka Index = 0.928). The dietary niche breadth of Tiger and Leopard using the Levins index is 6.51 & 9.11, respectively, and the standardised diet niche breadth is 0.5 & 0.62 for Tiger and Leopard, respectively (Figure 3).

DISCUSSION

In the present conservation paradigm of large carnivores, it is essential to understand the feeding habits and prey-predator dynamics outside protected areas (Kshettry et al. 2018; Puri et al. 2020; Mohan et al. 2021; Dahya et al. 2023). Our study fills this gap in our understanding of the dietary habits of sympatric large carnivore species outside PAs in wildlife corridors of the Terai landscape of India. It is of paramount importance to understand the dependence on livestock, resource sharing, and diversity of food resources of sympatric large carnivores to address human-wildlife conflict in the landscape (Chakrabarti et al. 2016; Fàbregas et al. 2017; Lumetsberger et al. 2017; Puri et al. 2020; Dahya et al. 2023). Our results highlight that Tigers and Leopards prey largely on wild species, but they also indicate a substantial contribution of livestock to their diets, likely due to the lower abundance of wild species in wildlife corridors.

The higher dietary contribution of wild prey highlights that both Tiger and Leopard prefer wild prey over livestock. The lower share of livestock species in Tiger and Leopard diet even when the grazing is high can be attributed to the presence of a herder accompanying livestock herds, and the collection of a few scat samples from the inner areas of forest habitats with minimal disturbances. The contribution of livestock species is substantially lower in comparison to wild prey, still higher than inside PAs in the Terai landscape (Harihar et al. 2011; Basak et al. 2018; Upadhyaya et al. 2018). Studies in the mosaic landscape of PAs and non-PAs in the Terai Arc landscape also show a significant difference in livestock contribution in the diet of Tigers inside PAs and outside PAs (Harihar et al. 2011; Lamichhane et al. 2019; Biswas et al. 2023). Livestock depredation entails the loss of human property, and hence has a more pronounced effect on the conservation of large carnivores and human-wildlife negative interactions (Dickman et al. 2013; Nyhus 2016).

The number of stray cattle in forest habitats has increased in recent years due to government policies (Vivek Ranjan, pers. obs.; Governor of Himachal Pradesh 2014), which have an aggravated negative effect on large carnivore prey availability and feeding habits (Baker et al.

2008; Harihar et al. 2011; Pimenta et al. 2017). Moreover, the depredation of these stray livestock is not reported or recorded by the Forest Department. The maximum share of cattle in the diet of Tiger and Leopard amongst the livestock species can be attributed to its higher population than other livestock species and easier to hunt than Water Buffalo which is similar in other studies (Harihar et al. 2011; Lamichhane et al. 2019; Puri et al. 2020; Biswas et al. 2023). The Water Buffalo has also been observed in two Leopard scat samples from study block 2, which may be attributed to the Water Buffalo calf depredation or buffalo carcass. Carcass dumping was not observed in the Kosi corridor area; however, infrequent carcass dumping was observed in study block 2 areas. The presence of cattle and large livestock species in the forest habitats significantly affects the distribution of wild prey, especially large wild prey like Sambar Deer, which are more sensitive to (Gaynor et al. 2018; Upadhyaya et al. 2018; Habib et al. 2021). This also explains the higher dependence on medium-sized prey in the current study area.

The high dietary overlap of 93% between Tigers and Leopards in the current study area is consistent with findings in earlier studies from the Indian subcontinent (Wang & Macdonald 2009; Harihar et al. 2011; Mondal et al. 2012; Lamichhane et al. 2019). The high dietary overlap also indicates that these sympatric species do not base their coexistence on diet partitioning based on prey type, however, apparent partitioning may occur in prey selection based on body size, age class, and sex of the species (Ramesh et al. 2012; Lovari et al. 2015). The notions of optimal foraging theory preferring larger prey are invalid when the availability of prey is an important limiting factor other than ecological energetics, which supports hunting of prey with equivalent body size/weight and convenience of hunting, which optimises energy use (Gittleman 1985; Chakrabarti et al. 2016; Basak et al. 2018; Upadhyaya et al. 2018). The equivalence of relative number of medium and small prey consumed by leopards can be attributed to their agility and ability to climb trees easily for hunting smaller prey such as porcupines, Indian Hare, and langurs. The Tiger is a top predator, and its increasing population density affects the food habits of its co-predators inhabiting the same habitat by shifting their prey preference, selection of sex, age classes of prey, and hunting time (Andheria

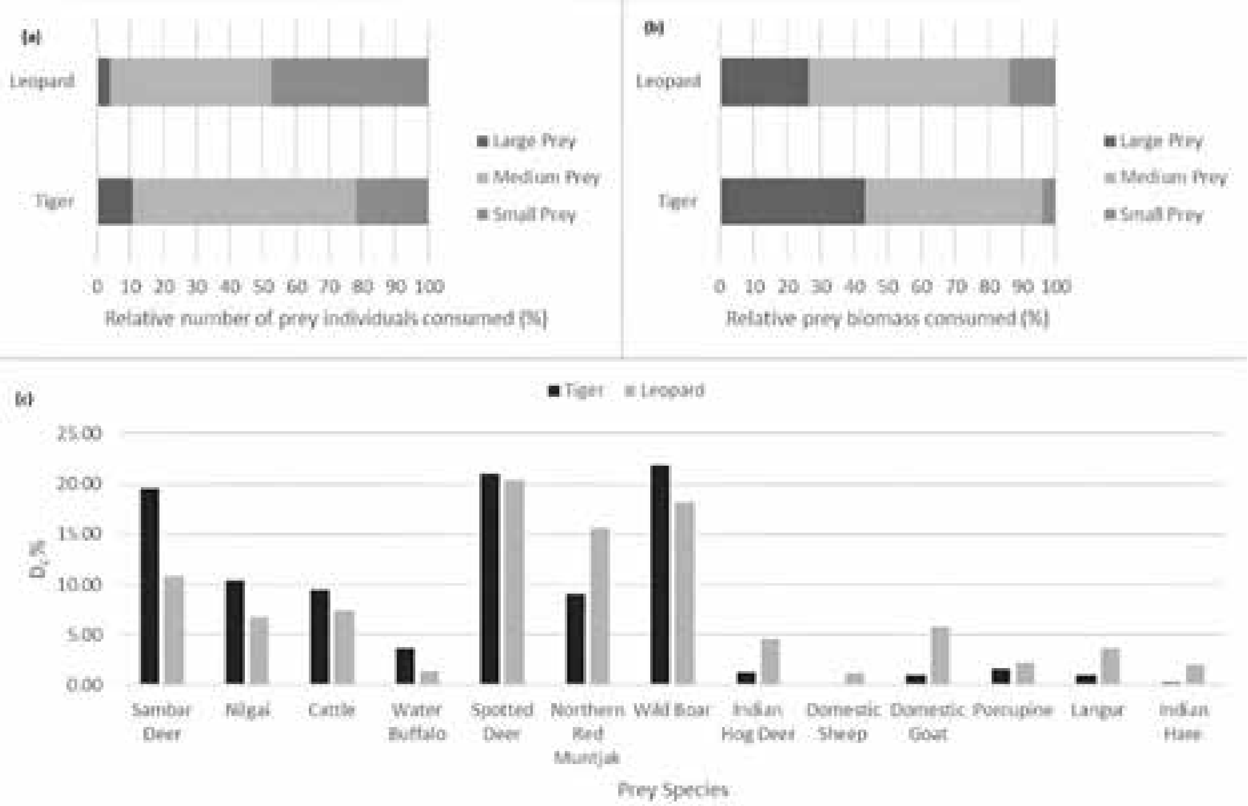

Figure 2. Diet profile of tiger and leopard in the study area: a—Relative prey biomass consumed (D_c) by the two sympatric large carnivores using a generalised biomass model for three categories of prey based on body size | b—Relative number of prey consumed (E_c) by two large carnivore species using a generalised biomass model | c—Contribution of different prey species in the prey biomass consumed by two sympatric carnivores. (Large prey >50 kg, Medium prey 20–50 kg, Small prey <20 kg)

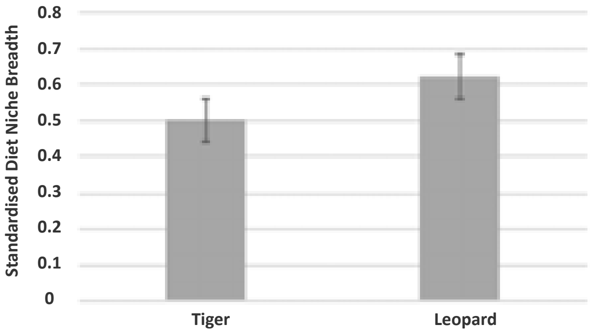

Figure 3. Standardised diet niche breadth of Tigers and Leopards in the study area with standard error using the Levins index.

et al. 2007; Harihar et al. 2011; Mondal et al. 2012; Shameer et al. 2021). It also explains the considerable difference in relative biomass and number of large prey consumption between Tiger (cumulative Dc = 43.1% and Ec = 10.8%) and leopard (cumulative Dc = 26.4% and Ec = 3.9%) in our study. This substantial difference in large prey relative consumption between Tiger and Leopard and the higher relative number of small prey in the Leopard diet indicates prey selection partitioning between the two sympatric species. The terrain of the habitat and prey behaviour also affect prey selection, causing spatiotemporal partitioning (Wang & Macdonald 2009).

The dietary specialisation of these two sympatric species is broad and suggests better adaptability to the existing environment and food availability. Both species exhibit a high dependence on medium body-size prey like Wild Boar and Spotted Deer, which could be attributed to their abundance in our study area. Similar trends and prey preferences have also been observed in other study areas of the Terai (Basak et al. 2018; Upadhyaya et al. 2018; Ahmed & Khan 2022). The broader dietary niche of Leopards observed in our study area indicates the generalist nature of prey selection and opportunistic feeding behaviour of Leopards (Puri et al. 2020; Mohan et al. 2021). Camera trap images obtained in the current study area have also shown evidence of poultry depredation by Leopards (Vivek Ranjan, unpub. data).

The absence of a wider variety of wild prey, high anthropogenic disturbance, and grazing pressure increase livestock depredation by large carnivores (Sankar et al. 2010; Basak et al. 2018). Our results show a higher livestock share in the Leopard diet with four livestock species compared to the Tiger diet with three species, which can be attributed to the varied habitat use patterns of these two sympatric predators. As the Tiger population density increases in the core forest habitats, the Leopard responds by spatially and temporally partitioning its habitat use, adapting to fringe habitats on the forest boundary, thereby increasing the chances of more frequent livestock depredation (Harihar et al. 2011; Bisht et al. 2019; Naha et al. 2020; Puri et al. 2022). Corbett Tiger Reserve (CTR), part of our study area, has the highest tiger population density among all the PAs in India (Bisht et al. 2019; Qureshi et al. 2023) and acts as a source population for the metapopulation of this landscape (Chanchani et al. 2014). The Tigers dispersing from the core habitats of CTR face a high risk of human-wildlife interactions outside PAs, mainly in the form of livestock depredation and human casualty in a few incidents (Bargali & Ahmed 2018; Bisht et al. 2019), as evident from compensation records of the Uttarakhand Forest Department (Uttarakhand Forest Department, unpub. data).

The seasonal migration of 'Bakarwal' disturbs the wild prey populations inhabiting those habitats and increases the probability of depredation by carnivores (Bisht et al. 2019; Qureshi et al. 2023), which is highlighted by the fact that all the scat samples of both the species with sheep hairs and all tiger scats with goat hairs were collected during winter. The large herds of Water Buffalo and cattle of 'Van Gujjars' negatively affects the wild prey population and disturbs the availability of pastures and foraging activity of wild prey species (Harihar et al. 2011). The livestock depredation of these pastoralist communities is also observed in the compensation records of the Uttarakhand Forest Department from the study area (Uttarakhand Forest Department, unpub. data).

Our study is based on a small sample size, but it highlights the importance of wild prey availability to contain conflict between people and large carnivores. Augmenting the wild prey population outside the PAs in wildlife corridors is vital to limit and reduce livestock depredation and improve habitat quality to accommodate wild prey populations in forest habitats. The wild prey population can be augmented by providing protection from hunting or poaching outside PAs. Additionally, improving habitat and heterogeneity in wildlife corridor areas and reducing anthropogenic disturbances are likely to provide a conducive environment for prey to naturally increase its population. The dietary profile of large carnivores of the study area provides information about the contribution of different prey species as food, which is crucial for understanding prey-predator dynamics in the landscape outside PAs. It will help develop a scientific management and mitigation plan for human-wildlife negative interaction and long-term conservation. More such studies with extensive sampling outside the PAs are needed to formulate long-term landscape conservation plans.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25802–25815

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8999.16.9.25802-25815

#8999 | Received 28 February 2024 | Final received 19 June 2024 | Finally accepted 01 July 2024

ARTICLE

Avifaunal diversity assessment and conservation significance of Therthangal Bird Sanctuary, Ramanathapuram, Tamil Nadu: insights about breeding waterbirds

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Abstract: The study offers a comprehensive avifaunal diversity assessment within the Therthanagal Bird Sanctuary (TBS) in the Ramanathapuram district of Tamil Nadu, India, conducted from April 2021 to March 2023, covering two breeding seasons. A total of 96 bird species from 18 orders and 44 families were recorded. The family representations by species included: Ardeidae with 10 species, Accipitridae and Rallidae with six species each, Anatidae with five species, Alcedinidae, Cuculidae, Columbidae, Threskiornithidae and Cisticolidae with four species each. Four globally "Near Threatened" species (IUCN Red List) were reported: Oriental Darter *Anhinga melanogaster*, Black-headed Ibis *Threskiornis melanocephalus,* Asian Woolly-necked Stork *Ciconia episcopus,* and Spot-billed Pelican *Pelecanus philippensis*. The observed frequencies of species classes were: common (n=58, 60%), uncommon (n=28, 29%), and rare (n=10, 10%). The majority of species were residents (n=83, 86%), followed by winter visitors (n=12, 12%), and a single passage migrant, (Rosy Starling *Pastor roseus*). Of conservation significance was the finding that 23 of 40 waterbird species recorded in the sanctuary were breeding on-site. Maximum numbers of birds and nests were recorded in the second year, which was presumed to be due to improved rainfall and water availability. The findings underscored the importance of the sanctuary in providing bird habitat, and emphasised the need for its conservation, particularly in safeguarding breeding waterbird habitat. This study provided essential baseline data for any management plan that the forest department may develop for the sanctuary.

Keywords: Breeding birds, conservation policy, Gulf of Mannar Biosphere, heronry, land birds, bird migration, Near Threatened, protected areas, waterbirds, wetlands.

Editor: Taej Mundkur, Good Earth Environmental, Arnhem, The Netherlands. **Date of publication:** 26 September 2024 (online & print)

Citation: Byju, H., H. Maitreyi, N. Raveendran & Reshmi Vijayan (2024). Avifaunal diversity assessment and conservation significance of Therthangal Bird Sanctuary, Ramanathapuram, Tamil Nadu: insights about breeding waterbirds. *Journal of Threatened Taxa* 16(9): 25802–25815. https://doi.org/10.11609/jott.8999.16.9.25802-25815

Funding: Partially funded by The Integrated Development of Wildlife Habitats in Wildlife Division, Ramanathapuram.

Competing interests: The authors declare no competing interests.

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

Acknowledgements: We sincerely thank the Gulf of Marine Biosphere Trust for funding the project as well as providing us with logistical and staff support during the work. We extend our gratitude to Mr. Bakan Jagdish Sudhakar, I.F.S., for his valuable suggestions and co-operation in implementing the Project. We also thank Melito Pinto in helping with the map and the APWs of TBS in kindly following the instructions and overseeing the monitoring process during each field visit.

INTRODUCTION

Wetlands in tropical and sub-tropical Asia provide essential life support systems for many local communities (Ranga 2006; Friend 2007), serving as centres of ecosystem services, resources, and recreational values (Maltby & Acreman 2011). This stresses the importance of wetland conservation (Sharma et al. 2019). Worldwide, wetlands continue to be degraded (Zedler & Kercher 2005), with the global area shrinking by 6% between 1993 and 2007 (Prigent et al. 2012) and by 54–87% over the past three centuries (Davidson 2014). Degradation due to human land use has raised serious concerns about many taxa dependent on wetlands (Prigent et al. 2012), including waterbirds (Beyersbergen et al. 2004; Bakker 2005).

Wetland ecosystems face significant pressures stemming from extensive land alterations and infrastructure development (Pramod et al. 2011). The intensification of agricultural and industrial activities contribute to further stress (Bassi et al. 2014). These factors collectively lead to a reduction in the extent of wetlands, consequently diminishing their hydrological, economic, and ecological functions (Bassi et al. 2014). The link between wetland degradation and loss of bird biodiversity is established in earlier studies (Wang et al. 2021; IUCN 2023), with losses being more pronounced than in terrestrial ecosystems (Millennium Ecosystem Assessment 2005; Dudgeon et al. 2006;). Wetlands provide essential breeding, feeding, and roosting grounds for numerous bird species. Human activities that destroy or degrade these habitats (Brook & Aramde 2012) have a direct impact on the availability of suitable habitats for these birds, leading to population declines (Rajpar & Zakaria 2010). It is estimated that 55% of wetland bird species have declined worldwide, except for some large herbivorous waterbirds, which are increasing (BirdLife International 2017; Pöysä et al. 2019). Birds serve as valuable indicators of the ecological health of ecosystems (Peron et al. 2013), and play crucial functions as seed dispersers and pollinators, highlighting their essential roles in maintaining ecosystem balance (Bibi & Ali 2013).

Wetlands play a crucial role in supporting biodiversity, and in India, they have been instrumental in providing a lifeline for various bird species. In India, wetlands encompass approximately 4.1 million hectares of land, excluding areas used for irrigated agriculture, rivers, and streams. Among these, 1.5 million hectares are natural, while 2.6 million hectares are man-made. In recent years, there has been a growing interest in promoting the sustainable utilization and adaptive management of these ecosystems. However, challenges persist, including insufficient data and disparities in management approaches applied to these ecologically significant areas (Shan et al. 2021).

Colonial nesting waterbirds are important indicators of changes in the environment (Roshnath & Sashikumar 2019), as they breed in limited locations (Kushlan et al. 2002). These birds breed in single-species or mixed-species colonies, known as heronries, where they maintain healthy ecosystems by providing nutrients (Green & Elmberg 2014). Numerous heronries have disappeared in the last century across India (Subramanya 1996).

Studies on avian distribution in the Ramanathapuram district and the Gulf of Mannar Biosphere Reserve (GoM) in Tamil Nadu, India reported numerous additional birding hotspots (Byju et al. 2023 a, b, c), including the discovery of rare vagrant Light-Mantled Albatross *Phoebetria palpebrata* (Byju & Raveendran 2022), and additional breeding records of the newly described taxon Hanuman Plover *Charadrius seebohmi* (Byju et al. 2023 d). These findings underscored the importance of continuous monitoring in GoM, an Important Bird and Biodiversity Area (IBA) of the Central Asian Flyway (CAF).

This study on the avifaunal distribution of the Therthangal Bird Sanctuary (TBS) in the Ramanathapuram district was undertaken because the rainfed sanctuary faced problems of tree wilting due to anthropogenic pressures like water removal from the tank for agriculture and other related activities. An additional objective was to focus on the conservation importance of breeding waterbirds, including colonial nesters. This study aims to contribute to the management plan of the forest department for the well-being and conservation of this wetland and its breeding waterbird species.

METHODS

Study area

The Therthangal Bird Sanctuary (9.4566 N, 78.7719 E) with an estimated area of 29.295 hectares in Therthangal village (Image 1) was designated as a bird sanctuary in 2010 (Byju & Raveendran, 2024).

The dominant vegetation in this sanctuary is Babul trees, *Acacia nilotica,* which were planted by the Tamil Nadu state forest department as part of the social forestry scheme which started in 1960 (Wilson 1979). The sanctuary is mostly rainfed. It has, in general, one to three metres deep tank embankments. Between the

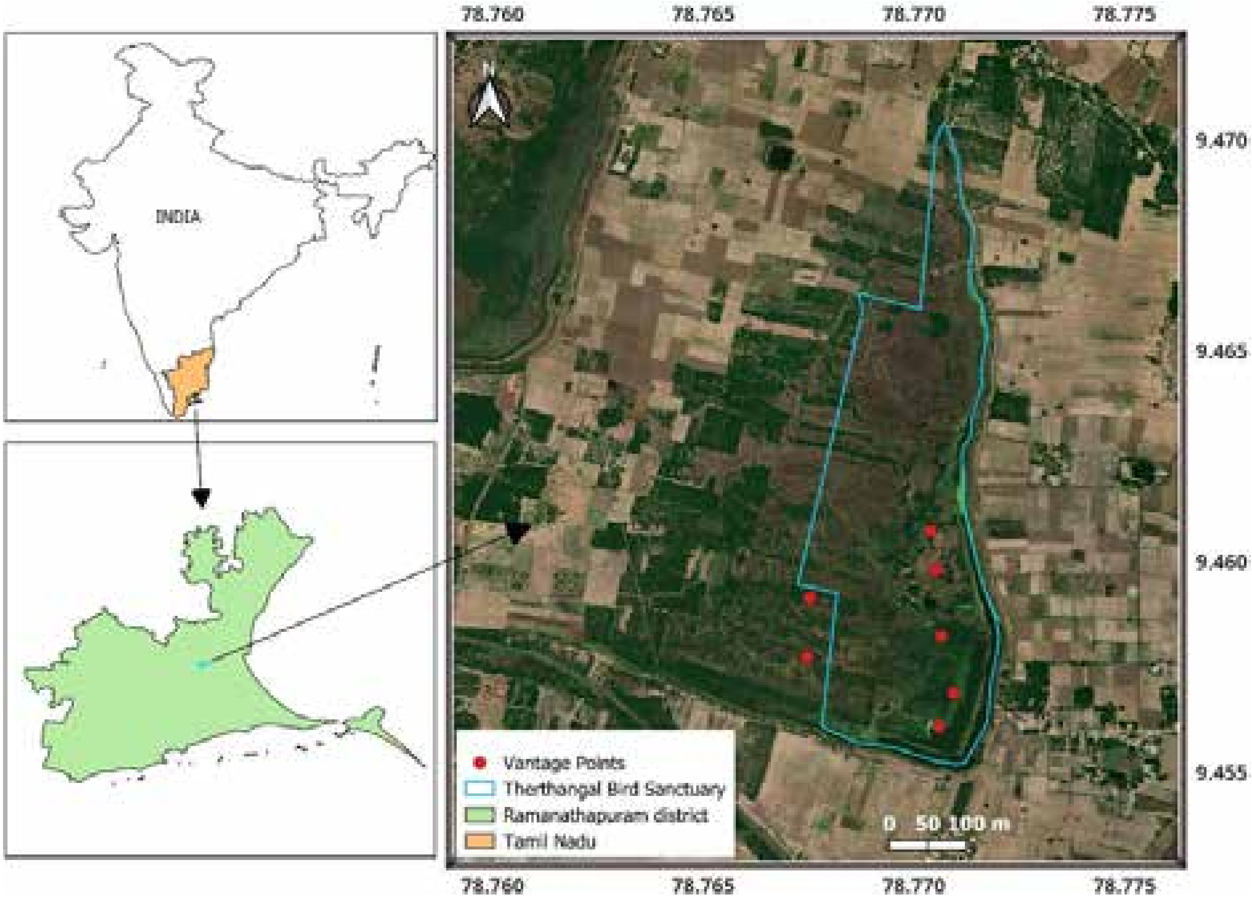

Image 1. Location map of Therthangal Bird Sanctuary with scanning points.

vegetation and the embankments, there is a wide water-holding region (~30m). The area receives an average rainfall of 503–1000 mm annually. The lowest and the highest temperature in Therthangal Bird Sanctuary ranges from 26–36 ^{0}C. Agricultural lands surrounded the sanctuary and marked the northern boundary (Images 2 & 3). The main habitat types observed in the sanctuary are: 1. Open-water habitat (WL=Wetland), 2. Agricultural land (AL), 3. Trees (Tr) like *Babul,* Mesquite *Prosopis juliflora*, Palmyra *Borassus flabellifer,* and Tamarind *Tamarindus indica* trees on the bund bordering the wetland, 4. Grassland (GL) on the wetland area, and 5. Shrub habitat (OS=open scrub type). Three distinct seasons were northern Winter (December–February), northern Summer (March–June) and Monsoon (September–November).

Monitoring methods

This study was carried out between April 2021 and March 2023. Field visits were conducted once every two weeks to observe the status, breeding activity, number, and diversity of birds. The field surveys were conducted in the morning (07.00–10.00 hrs) and the evening (16.00 – 19.00 hrs), depending on the season when birds were most active. Data were collected following direct count and block count methods (Bibby et al. 2000; Howes & Bakewell 1989). Waterbirds were counted at seven scanning points separated by 100–200 meters (Image 1), depending on the landscape and visibility of the birds. We stopped at each point for five minutes before the actual count so that the birds could get acclimated to us. Observations recorded while moving from one scanning point to another were entered as incidental records. Birds were observed using Nikon binoculars (10x50) and identified with the help of a field guide (Grimmett et al. 2011). This communication follows the species nomenclature of Praveen & Jayapal (2023).

Species residential status was determined as Resident (R), Passage Migrant (PM), or Winter Visitor (WV) depending on the temporal patterns and duration of occurrence (Grimmett et al. 2011). Species were listed as per their global Red List status (IUCN 2023). We also documented any potential threats to the birds. The data collected in each survey were later analysed for the relative abundance of families. Species were classified based on observation frequencies as: Common (C) - frequently observed in the study area (encountered on 6-8/10 visits); Uncommon (UC) - spotted on 3-5/10 visits; Rare (R) - encountered on 1-2/10 visits) (Mackinnon & Philips 1993). Relative diversity (RDi) was calculated with the following formula (Koli 2014):

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

We also documented the breeding activities of waterbirds within the sanctuary. Active nests were identified by fortnightly surveys and by monitoring the flights of adult birds commuting between nests and foraging areas. We visited the sanctuary twice a month during the breeding season to estimate the total number of nests, employing standard techniques such as ground counts or using binoculars and spotting scopes for nests, as the counts were less than 100 (Gibbs et al. 1988; Dodd & Murphy 1995). For sites with few nests or those that were completely inaccessible, we utilized perimeter counts (Dodd & Murphy 1995) based on visible nests and observed foraging flights from the colony edge, as other techniques were impractical.

RESULTS AND DISCUSSION

Avian community structure

A total of 96 species, representing 44 families across 18 orders, were documented in the study area; a comprehensive checklist is provided (Table 1). Of the 96 species, waterbirds were predominant with 40 species from 14 families (Figure 2). Notably, our observations highlighted the prevalence of families such as Ardeidae (10 species), followed by Accipitridae and Rallidae (6 species each), Anatidae (5 species), and Alcedinidae, Cuculidae, Columbidae, Threskiornithidae, and Cisticolidae (4 species each), representing the bird species of the region (Figure 2 & 3). The most speciose order was Passeriformes comprising 18 families and 29 species. Relative Diversity (RDi) analysis (Table 2) indicated that the most prevalent family in the Therthangal Bird Sanctuary was Ardeidae with a relative diversity of 10% (n=10 species). This was followed by the families Rallidae and Accipitridae with 6.2% (n=6 species each) and the Anatidae family with 5.2% (n=5 species). The families Cuculidae, Columbidae, Threskiornithidae, and Cisticolidae represented 4.1% (n=4 species each), while the families Coraciidae, Ciconiidae, Corvidae, Muscicapidae, and Phalacrocoracidae reported 3.1% (n=3 species each). The families that represented 2.0% (n=2 species each) were Phasianidae, Meropidae, Scolopacidae, Laniidae, Nectariniidae, and Motacillidae. The rest of the families had a single species each.

Within the sanctuary, the avian community was categorised based on the observed frequency, revealing that 58 species (60%) were Common (C); 28 species (29%) were Uncommon (UC), and the remaining ten (10%) were rare (R). Regarding residency status, the majority of species within TBS were Resident (R), accounting for 83 species (86%), while 12 species (13%) were Winter Visitors (WV) and the remaining one was a Passage Migrant (PM) Rosy Starling *Pastor roseus*. Common residents included the Peafowl *Pavo cristatus*, Indian Robin *Copsychus fulicatus*, Asian Koel *Eudynamys scolopaceus* and White-throated Kingfisher *Halcyon smyrnensis.* Our study documented seven diurnal and nocturnal raptors, including the Black-winged Kite *Elanus caeruleus*, Western Marsh Harrier *Circus aeruginosus*, Booted Eagle *Hieraaetus pennatus,* Shikra *Accipiter badius,* Oriental Honey Buzzard *Pernis ptilorhynchus,* Brahminy Kite *Haliastur indus* and Spotted Owlet *Athene brama*.

The distribution of waterbird species across families is graphically represented in Figure 1. Numerous wetland factors influenced waterbird abundance and diversity, including wetland area, water depth and quality, trophic level structure, and the availability of suitable roosting and breeding sites for birds (Wiens 1989; Mukherjee et al. 2002; Ma et al. 2010). Notably, migratory duck species such as Garganey *Spatula querquedula* and Northern Shoveler *Spatula clypeata* along with shorebirds like the Wood Sandpiper *Tringa glareola* and Common Sandpiper *Actitis hypoleucos* were recorded. The presence of these migratory bird species in reasonable numbers during both the migratory seasons of the study highlighted the importance of sanctuary in providing critical wintering grounds during their migration (see Figure 2 & 3).

During the observation period, the sanctuary recorded five major waterbird species: Asian Openbill *Anastomus oscitans* (n 1324), Spot-billed Pelican *Pelecanus philippensis* (n 785), Glossy Ibis *Plegadis falcinellus* (n 411), Black-headed Ibis *Threskiornis melanocephalus* (n 289) and Painted Stork *Mycteria leucocephala* (n 226). Additionally, the five major land bird species recorded included the passage migrant Rosy Starling (n 2200), Barn Swallow *Hirundo rustica* (n 200), Rose-ringed Parakeet *Psittacula krameri* (n 170), Baya Weaver *Ploceus philippinus* (n 120) and Common Myna *Acridotheres tristis* (n 82). TBS also supported four Near-Threatened waterbirds – Black-headed Ibis,

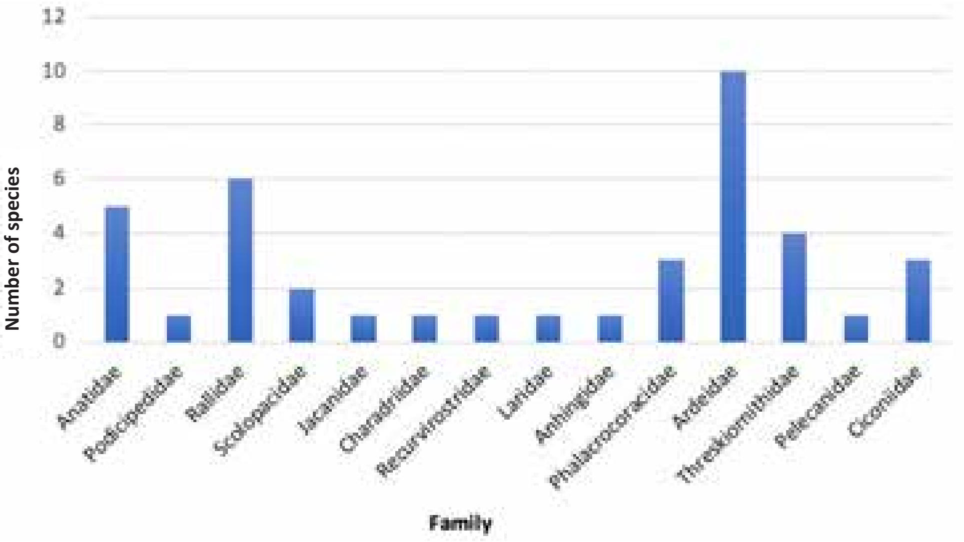

Figure 1. Family-wise species count of waterbirds from Therthangal Bird Sanctuary.

Figure 2. Mean monthly number of total land bird species in Therthangal Bird Sanctuary.

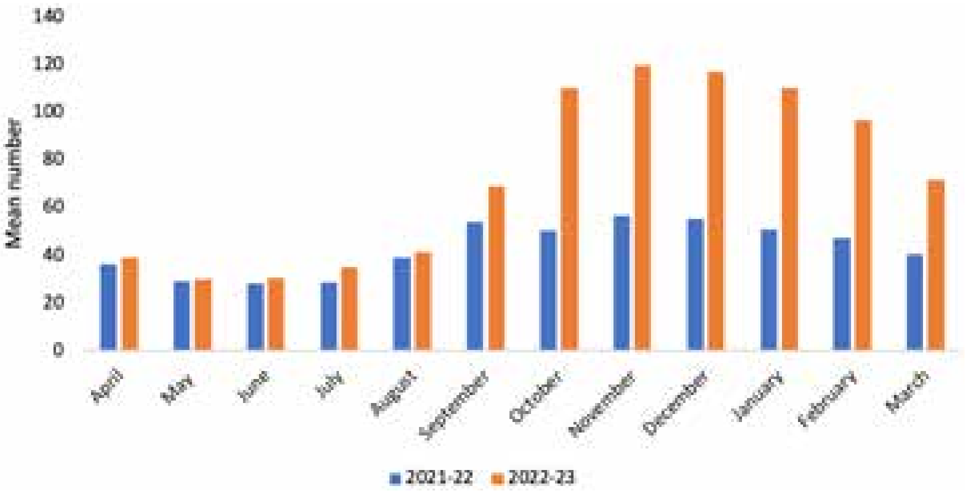

Figure 3. Mean monthly number of total waterbird species in Therthangal Bird Sanctuary.

Table 1. Checklist of avifauna recorded from Therthangal Bird Sanctuary, Tamil Nadu.

Scientific name	Common name	Migratory status	IUCN Red List status	Frequency of observation	Habitat type
Order: Galliformes					
Family: Phasianidae					
Pavo cristatus	Indian Peafowl	R	LC	C	AL/OS
Francolinus pondicerianus	Grey Francolin	R	LC	C	GL/OS
Order: Anseriformes					
Family: Anatidae					
Sarkidiornis melanotos	Comb Duck	R	LC	C	WL
Anas poecilorhyncha	Indian Spot-billed Duck	R	LC	C	WL
Spatula querquedula	Garganey	WV	LC	UC	WL
Spatula clypeata	Northern Shoveler	WV	LC	R	WL
Dendrocygna javanica	Lesser Whistling-Duck	R	LC	UC	WL
Order: Podicipediformes					
Family: Podicipedidae					
Tachybaptus ruficollis	Little Grebe	R	LC	C	WL
Order: Piciformes					
Family: Picidae					
Dinopium benghalense	Black-rumped Flameback	R	LC	C	Tr
Family: Megalaimidae					
Psilopogon haemacephalus	Coppersmith Barbet	R	LC	UC	Tr
Order: Bucerotiformes					
Family: Upupidae					
Upupa epops	Common Hoopoe	R	LC	UC	AL/GL
Order: Coraciiformes					
Family: Coraciidae					
Coracias benghalensis	Indian Roller	R	LC	C	OS/AL
Halcyon smyrnensis	White-throated Kingfisher	R	LC	C	WL
Alcedo atthis	Common Kingfisher	R	LC	C	WL
Family: Meropidae					
Merops orientalis	Green Bee-eater	R	LC	C	OS/AL
Merops philippinus	Blue-tailed Bee- eater	WV	LC	C	OS/AL
Order: Cuculiformes					
Family: Cuculidae					
Centropus sinensis	Greater Coucal	R	LC	C	OS
Eudynamys scolopaceus	Asian Koel	R	LC	C	OS
Clamator jacobinus	Pied Cuckoo	R	LC	UC	OS
Hierrococcyx varius	Common Hawk Cuckoo	R	LC	UC	OS
Order: Psittaciformes					
Family: Psittacidae					
Psittacula krameri	Rose-ringed Parakeet	R	LC	C	Tr
Order: Strigiformes					
Family: Strigidae					
Athene brama	Spotted Owlet	R	LC	UC	OS/AL/Tr

Scientific name	Common name	Migratory status	IUCN Red List status	Frequency of observation	Habitat type
Order: Columbiformes					
Family: Columbidae					
Columba livia	Rock Pigeon	R	LC	C	AL/OS/GL
Streptopelia decaocto	Eurasian Collared-Dove	R	LC	C	AL/OS/GL
Spilopelia senegalensis	Laughing Dove	R	LC	C	AL/OS/GL
Spilopelia chinensis	Spotted Dove	R	LC	C	AL/OS/GL
Order: Apodiformes					
Family: Apodidae					
Cypsiurus balasiensis	Asian Palm- swift	R	LC	C	Tr
Order: Gruiformes					
Family: Rallidae					
Gallinula chloropus	Common Moorhen	R	LC	UC	WL
Porphyrio porphyrio	Grey-headed Swamphen	R	LC	UC	WL
Amaurornis phoenicurus	White-breasted Waterhen	R	LC	C	WL
Fulica atra	Eurasian Coot	R	LC	C	WL
Zapornia pusilla	Baillon's Crake	WV	LC	R	WL
Gallicrex cinerea	Watercock	R	LC	R	WL
Order: Charadriiformes					
Family: Scolopacidae					
Tringa glareola	Wood Sandpiper	WV	LC	UC	WL
Actitis hypoleucos	Common Sandpiper	WV	LC	UC	WL
Family: Jacanidae					
Hydrophasianus chirurgus	Pheasant-tailed Jacana	R	LC	UC	WL
Family: Charadriidae					
Vanellus indicus	Red-wattled Lapwing	R	LC	C	WL
Family: Recurvirostridae					
Himantopus himantopus	Black-winged Stilt	R	LC	C	WL
Family: Laridae					
Chlidonias hybrida	Whiskered Tern	WV	LC	R	WL
Order: Accipitriformes					
Family: Accipitridae					
Circus aeruginosus	Western Marsh Harrier	WV	LC	R	OS/GL
Elanus caeruleus	Black-winged Kite	R	LC	C	AL/OS
Hieraaetus pennatus	Booted Eagle	WV	LC	R	OS/Tr
Accipiter badius	Shikra	R	LC	UC	AL/GL/Tr/OS
Pernis ptilorhynchus	Oriental Honey Buzzard	R	LC	R	Tr
Haliastur indus	Brahminy Kite	R	LC	C	WL/GL
Order: Suliformes					
Family: Anhingidae					
Anhinga melanogaster	Oriental Darter	R	NT	UC	WL
Family: Phalacrocoracidae					
Microcarbo niger	Little Cormorant	R	LC	C	WL
Phalacrocorax carbo	Great Cormorant	R	LC	UC	WL
Phalacrocorax fuscicollis	Indian Cormorant	R	LC	C	WL

Scientific name	Common name	Migratory status	IUCN Red List status	Frequency of observation	Habitat type
Order: Pelicaniformes					
Family: Ardeidae					
Ixobrychus sinensis	Yellow Bittern	R	LC	UC	WL
Ardea cinerea	Grey Heron	R	LC	UC	WL
Ardea purpurea	Purple Heron	R	LC	UC	WL
Egretta garzetta	Little Egret	R	LC	C	WL
Bubulcus ibis	Cattle Egret	R	LC	C	WL
Ardea alba	Great Egret	R	LC	C	WL
Ardea intermedia	Intermediate Egret	R	LC	C	WL
Ardeola grayii	Indian Pond Heron	R	LC	C	WL
Nycticorax nycticorax	Black-crowned Night Heron	R	LC	C	WL
Butorides striata	Striated Heron	R	LC	UC	WL
Family: Threskiornithidae					
Threskiornis melanocephalus	Black-headed Ibis	R	NT	C	WL
Plegadis falcinellus	Glossy Ibis	R	LC	C	WL
Pseudibis papillosa	Red-naped Ibis	R	LC	C	WL
Platalea leucorodia	Eurasian Spoonbill	R	LC	C	WL
Family: Pelecanidae					
Pelecanus philippensis	Spot-billed Pelican	R	NT	C	WL
Order: Ciconiiformes					
Family: Ciconiidae					
Anastomus oscitans	Asian Openbill	R	LC	C	WL
Mycteria leucocephala	Painted Stork	R	LC	C	WL
Ciconia episcopus	Asian Woolly-necked Stork	R	NT	R	WL
Order: Passeriformes					
Family: Artamidae					
Artamus fuscus	Ashy Woodswallow	R	LC	C	OS/AL
Family: Laniidae					
Lanius schach	Long-tailed Shrike	R	LC	R	OS
Lanius cristatus	Brown Shrike	WV	LC	UC	OS
Family: Dicruridae					
Dicrurus macrocercus	Black Drongo	R	LC	C	GL/AL/OS
Family: Corvidae					
Dendrocitta vagabunda	Rufous Treepie	R	LC	UC	OS
Corvus macrorhynchos	Indian Jungle Crow	R	LC	C	OS/GL/WL
Corvus splendens	House Crow	R	LC	C	AL/OS/WL/GL
Family: Sturnidae					
Acridotheres tristis	Common Myna	R	LC	C	AL/OS/GL
Pastor roseus	Rosy Starling	PM	LC	UC	AL/OS/GL
Family: Hirundinidae					
Hirundo rustica	Barn Swallow	WV	LC	UC	AL/WL
Family: Pycnonotidae					
Pycnonotus cafer	Red-vented Bulbul	R	LC	C	OS/AL/GL

Scientific name	Common name	Migratory status	IUCN Red List status	Frequency of observation	Habitat type
Family: Timaliidae					
Turdoides affinis	Yellow-billed Babbler	R	LC	C	OS/AL
Family: Cisticolidae					
Prinia socialis	Ashy Prinia	R	LC	C	AL/OS/GL
Prinia inornata	Plain Prinia	R	LC	C	AL/OS/GL
Orthotomus sutorius	Common Tailorbird	R	LC	C	AL/OS/GL
Cisticola juncidis	Zitting Cisticola	R	LC	UC	AL/OS/GL
Family: Acrocephalidae					
Acrocephalus dumetorum	Blyth's Reed Warbler	WV	LC	R	OS
Family: Alaudidae					
Galerida cristata	Jerdon's Bushlark	R	LC	UC	AL/OS/GL
Family: Muscicapidae					
Saxicola caprata	Pied Bushchat	R	LC	C	OS
Copsychus fulicatus	Indian Robin	R	LC	C	AL/OS
Copsychus saularis	Oriental Magpie Robin	R	LC	C	AL/OS
Family: Nectariniidae					
Cinnyris asiaticus	Purple-rumped Sunbird	R	LC	C	OS/GL
Cinnyris asiaticus	Purple Sunbird	R	LC	C	OS/GL
Family: Ploceidae					
Ploceus philippinus	Baya Weaver	R	LC	UC	OS
Family: Estrildidae					
Euodice malabarica	Indian Silverbill	R	LC	UC	AL/GL/OS
Family: Dicaeidae					
Dicaeum concolor	Pale-billed Flowerpecker	R	LC	C	OS
Family: Passeridae					
Passer domesticus	House Sparrow	R	LC	C	AL/GL
Family: Motacillidae					
Motacilla maderaspatensis	White-browed Wagtail	R	LC	C	WL
Anthus rufulus	Paddy-field Pipit	R	LC	UC	GL/AL

Migratory status: R—Resident | WV—Winter visitor | PM—Passage migrant | IUCN Status: CR—Critically Endangered | EN—Endangered | LC—Least Concern | NT—Near Threatened | VU—Vulnerable | WPA Frequency of observation: R—Rare | C—Common | UC—Uncommon | Habitat type: WL—Wetland | GL—Grass land | OS—Open scrub | AL—Agricultural land | Tr—Trees on the bund adjoining the wetland and agricultural lands.

Asian Woolly-necked Stork *Ciconia eniscopus,* Oriental Darter *Anhinga melanogaster*, and Spot-billed Pelican - highlighting the sanctuary's critical role in conserving near-threatened species.

The habitat changes observed in the study area support different groups of waterbirds and terrestrial birds, each with distinct habitat preferences for activities like foraging, nesting, and roosting (Hattori & Mae 2001). Waterbirds, in particular, utilised various habitat changes in the region for different activities throughout the year (Kularatne et al. 2021). As many of the trees began to wilt and decay, the stronger trees were preferred by colonial nesters during the second breeding season.

Breeding waterbird population and diversity

Of the 40 species of waterbirds recorded, 23 were observed breeding in the sanctuary (Table 3). This heronry had partially submerged trees within the waterbody as the preferred habitat for nesting birds. The Spot-billed Pelicans and Painted Storks occupied the *Acacia nilotica* trees (Images 3 & 4). The predominant nesters were Asian Openbills closely followed by Spot-billed Pelicans. The maximum number of nests and birds were recorded in year 2. It could be inferred that an

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Image 2. Aerial view of TBS with surrounding agriculture lands.

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Image 3. Livestock grazing amongst invasive plants on the water and bank at TBS.

increase in rainfall in the second year compared to the previous year may have enabled the increase in nesting attempts (Frank et al. 2021). Oriental Darters, Eurasian Spoonbills, and Asian Openbills nested in the medium-sized trees like *Prosopis juliflora*, Black-headed Ibises nested in the canopy, and Cormorants, Egrets, and Pond Herons occupied the lower strata of the habitat of the trees. Most of the nesting materials were collected from the nearby agricultural fields.

Conservation status of avian fauna

Understanding the importance of a site requires an examination of its significance in relation to its species richness (Bruford 2002). The TBS supports four 'Near Threatened' species, such as the Black-headed Ibis, Oriental Darter, Asian Woolly-necked Stork, and Spot-bellied Pelican (IUCN 2023); the remaining 92 are 'Least Concern' (LC) species (Table 1). Previously, no proper

Table 2. Relative diversity (RDi) of various avifaunal families at Therthangal Bird Sanctuary.

Family	Number of species observed	Relative diversity (%)
Phasianidae	2	2.08
Anatidae	5	5.20
Podicipedidae	1	1.04
Picidae	1	1.04
Megalaimidae	1	1.04
Upupidae	1	1.04
Coraciidae	3	3.12
Meropidae	2	2.08
Cuculidae	4	4.16
Psittacidae	1	1.04
Strigidae	1	1.04
Columbidae	4	4.16
Apodidae	1	1.04
Rallidae	6	6.25
Scolopacidae	2	2.08
Jacanidae	1	1.04
Charadriidae	1	1.04
Recurvirostridae	1	1.04
Laridae	1	1.04
Accipitridae	6	6.25
Anhingidae	1	1.04
Phalacrocoracidae	3	3.12
Ardeidae	10	10.4
Threskiornithidae	4	4.16
Pelecanidae	1	1.04
Ciconiidae	3	3.12
Artamidae	1	1.04
Laniidae	2	2.08
Dicruridae	1	1.04
Corvidae	3	3.12
Sturnidae	2	2.08
Hirundinidae	1	1.04
Pycnonotidae	1	1.04
Timaliidae	1	1.04
Cisticolidae	4	4.16
Acrocephalidae	1	1.04
Alaudidae	1	1.04
Muscicapidae	3	3.12
Nectariniidae	2	2.08
Ploceidae	1	1.04
Estrildidae	1	1.04
Dicaeidae	1	1.04
Passeridae	1	1.04
Motacillidae	2	2.08

Table 3. Breeding waterbirds of Therthangal Bird Sanctuary.

Common name	Scientific name	Maximum nest count during the study		Maximum bird count during the study	
		Year 1	Year 2	Year 1	Year 2
Spot-billed Pelican	*Pelecanus philippensis*	54	182	335	785
Little Cormorant	*Microcarbo niger*	10	65	106	264
Indian Cormorant	*Phalacrocorax fuscicollis*	15	45	62	155
Oriental Darter	*Anhinga melanogaster*	9	30	40	90
Great Egret	*Ardea alba*	5	8	15	32
Intermediate Egret	*Ardea intermedia*	4	11	13	42
Little Egret	*Egretta garzetta*	3	8	20	63
Cattle Egret	*Bubulcus ibis*	6	18	50	126
Grey Heron	*Ardea cinerea*	5	15	18	40
Purple Heron	*Ardea purpurea*	2	5	9	15
Indian Pond Heron	*Ardeola grayii*	2	11	45	45
Black-crowned Night Heron	*Nycticorax nycticorax*	13	41	50	124
Painted Stork	*Mycteria leucocephala*	18	61	92	226
Red-naped Ibis	*Pseudibis papillosa*	2	2	5	8
Asian Openbill Stork	*Anastomus oscitans*	80	264	556	1324
Glossy Ibis	*Plegadis falcinellus*	4	12	167	411
Black-headed Ibis	*Threskiornis melanocephalus*	22	72	117	289
Eurasian Spoonbill	*Platalea leucorodia*	6	12	20	42
Spot-billed Duck	*Anas poecilorhyncha*	1	4	9	23
Comb Duck	*Sarkidiornis sylvicola*	1	2	8	20
Black-winged Stilt	*Himantopus himantopus*	2	4	20	46
Red wattled Lapwing	*Vanellus indicus*	1	2	16	42
Lesser Whistling Duck	*Dendrocygna javanica*	1	1	18	38

Image 4. Nesting of Asian Open-billed Storks.

Image 5. Nesting of Spot-billed Pelican on top of trees.

scientific studies had been conducted in this sanctuary, and 96 species, including 40 waterbirds, were recorded during the present study. The number of breeding waterbirds supported in the sanctuary is dependent on various factors mentioned earlier. This data provides fundamental information for future studies aimed at shaping management plans to enhance wetland conservation, supporting both resident and migratory bird populations.

Potential management issues

Wetlands account for 24% of invasive species globally (Zedler & Kercher, 2004; Kaushik & Gupta 2014), including invasive trees like *Prosopis,* which support breeding birds. The invasive *Prosopis* were being removed to prevent water loss, destruction of habitat and hindrance to native trees without a proper plan for their replacement which impacted birds like Asian Openbill and cormorants as they currently prefer to nest in these trees. The native *Acacia nilotica* was the main species on which the birds roosted in the sanctuary. Recently, some trees wilted and died due to changes in monsoon patterns. The removal of *Prosopis* coupled with drought driven wilting of *Acacia* trees reduced the number of potential nesting sites for the birds and also resulting in the abandonment of nests by waterbirds, affecting their nesting behaviour (Roshnath & Sinu 2017). Therefore, it is very important that the new trees planted are native and have greater adaptability to survive drought as well as excess water, to support the breeding population of waterbirds. The two-year nesting observations highlighted the difference in nesting preferences (Table 3) and the impact of irregular monsoons (Jabaraj & Gopi 2020) due to climate change affecting the habitats of waterbirds (Wormworth & Mallon 2006). *Ipomea carnea* was another invasive species that rapidly replaced the native vegetation at the site, with the potential to affect ground-nesting birds. Hence, we suggest long-term monitoring of nesting locations and breeding seasons (Urfi 2011; Pavon-Jordan et al. 2020).

During the study, we observed a few minor threats that affected the sanctuary. One such threat was the grazing of cattle during the drought seasons, which led to the destruction of trees. Cattle, in search of food, climbed the trees and ate the bark due to the scarcity of leaves, causing the trees to slowly die. Additionally, the adjacent agricultural lands were sprayed with pesticides during cultivation. The impact of these chemicals on breeding birds needs to be ascertained for future studies. Furthermore, the local caste dynamics played a significant role among villagers surrounding the sanctuary. Conflict arose over water usage rights and the lack of clear boundary markings between the sanctuary and the villagers' lands, leading to disputes with the forest department. Consequently, the officials and staff needed to be proactive to prevent any acts of retaliation against the birds and trees by the aggrieved parties.

CONCLUSIONS

Therthangal Bird Sanctuary serves as a suitable habitat for a wide variety of bird species, both resident and migratory. This is a testament to the ecological richness and conservation value of the sanctuary. Conservation strategies for these ecological indicator species (Ogden et al. 2014) necessitates a comprehensive approach that addresses threats to wetland habitats and waterbird populations, as they have high site fidelity. Conserving a wetland like the TBS and its associated waterbird populations requires a collaborative effort involving diverse stakeholders to ensure sustained management interventions, education, and advocacy programmes. The local villagers are dependent on the water for household activities, agriculture, and grazing their cattle during drought periods. Conservation efforts should focus on habitat preservation, restoration, and sustainable management to ensure the long-term survival of these species. Habitat destruction, pollution, and anthropogenic activities in the surrounding areas pose serious challenges. Conservation strategies must address these threats to safeguard the sanctuary and its avifauna.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25816–25830

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.7832.16.9.25816-25830

#7832 | Received 16 January 2022 | Final received 15 August 2024 | Finally accepted 17 August 2024

ARTICLE

Habitat heterogeneity and taxonomic diversity of fish fauna in estuaries: a study from southern Sri Lanka

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Abstract: A survey was conducted to identify fish fauna related to the dominant habitats, viz., (i) Honduwa Lake (stagnate water), (ii) estuarine area with mangroves, (iii) freshwater marshy area with floating aquatic vegetation, (iv) canals, and (v) river, in the Dedduwa estuary of southern Sri Lanka. Thirty-nine species of fish including two endemics (to the island) were identified, including members of major migratory families such as Anguillidae and Megalopidae. Based on the abundance of species, the Bray-Curtis similarity index indicated a clear separation of the canal and freshwater marsh, with other studied areas. Similarly, the taxonomic diversity of the canal and freshwater marsh was high, indicating high variation and diversity of the species and genera. Protection of mangroves and related habitats is important to maintain the stability and long-term existence of fish fauna in the estuary. Effective monitoring is proposed for detecting and eliminating illegal encroachments, mangrove clearance, and illegal fishing activities. Moreover, improving the knowledge and awareness among members of the local community, politicians, and environment officers about the importance of the region's biodiversity implementing strong policies, and creating a strong responsible stakeholder bond are required to ensure the long-term sustainability of the estuary.

Keywords: Brackishwater, catadromy, conservation, fish diversity, fish migration, mangroves, taxonomic distinctness.

Editor: Mandar Paingankar, Government Science College Gadchiroli, Maharashtra, India.

Date of publication: 26 September 2024 (online & print)

Citation: Bandara, K.S.N. (2024). Habitat heterogeneity and taxonomic diversity of fish fauna in estuaries: a study from southern Sri Lanka. *Journal of Threatened Taxa* 16(9): 25816–25830. https://doi.org/10.11609/jott.7832.16.9.25816-25830

Funding: This study was funded by the Environment Foundation (Guarantee) Limited, Sri Lanka under the fauna and flora study for Dedduwa development project.

Competing interests: The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Acknowledgements: I would like to acknowledge Ms. Zaineb Akbarally and Ms. Chaturangi Wickramaratne of the Environment Foundation (Guarantee) Limited for their cooperation and support extended to this study. I am also thankful to Prof. U. S. Amarasinghe, Prof. Sevvandi Jayakody, Dr. Suranjan Fernando, Dr. Kumudu P. Kopiyawattage and Ms. Achini Wathsala for their valuable comments in preparing this manuscript.

INTRODUCTION

Estuaries are considered one of the most productive coastal ecosystems in the tropics (Whittaker & Likens 1975; Whitfield & Elliott 2011; Sreekanth et al. 2017). Ecologically, estuaries are highly significant as they provide critical ecosystem services including coastal protection (Barbier 2020), carbon sequestration (Douglas et al. 2022; Das et al. 2023), sediment filtration (Schubel & Carter 1984; Teuchies et al. 2013), and habitat enrichment (Cardoso 2021; Denis et al. 2022). These ecosystem services are essential in sustaining the coastal biodiversity and well-being of aquatic taxa (Cardoso 2021). Among the various ecological services, the most significant is habitat provisioning and maintaining ecosystem integrity in coastal environments (Blaber et al. 1989; Sreekanth et al. 2020). Estuaries form a transition zone between river and maritime environments and are hence always influenced by tidal fluctuation and freshwater fluxes (Potter et al. 2010). These heterogenous physico-chemical changes featured unique and variable habitat formations such as mangroves, shallow open waters, freshwater and saltwater marshes, swamps, sandy beaches, mud and sand flats, rocky shores, river deltas, tidal pools, and seagrass beds enhancing the habitat complexity and species composition in estuaries (Hagan & Able 2003). The diversified habitats in the estuaries are known to provide nurseries and feeding grounds for fish essentially for larval stages (Potter et al., 2013; Guerreiro et al. 2021). Therefore, estuaries provide refuges for a wide variety of fishes including both marine and freshwater species to complete their life cycles (Blaber et al. 1989; Whitfield & Elliott 2002; Elliott et al. 2007).

Distribution of fishes in an estuary is fundamentally determined by habitat heterogeneity, prey predator relationship, and water chemistry (Jackson et al. 2001; Maes et al. 2005; Kadye et al. 2008; Sreekanth et al. 2020). The productivity of the habitats is equally important to determine the dietary compositions of fishes (Hagan & Able 2003). The climatic fluctuations and changes in precipitation determine the level of productivity (e.g., accumulation of autochthonous and allochthonous nutrients) and trophic relationship among fishes (Gillanders et al. 2011; Sreekanth et al. 2019). The lowland reaches of rivers are characterized by high levels of suspended solids inducing high turbidity (Cyrus & Blaber 1987). Hence, productivity is largely determined by the nutrient loads from the upper reaches of the river. In the freshwater–seawater transition zone, these particles are effectively ‘trapped’ due to flocculation and converging suspended sediment fluxes (Kranck 1981). River mouths, estuaries, or transitional waters represent the transition between freshwater and marine environments and are influenced by both aquatic realms (Robinson et al. 1999). This makes estuaries unique ecosystems with a range of salinity gradients, from freshwater to seawater in addition to lentic and lotic habitats (Ruhl 2013). Fish species with the ability to tolerate huge salinity gradients can be identified in these various habitats and microhabitats (Barletta et al. 2005; Breine et al. 2011). Hence, species richness in estuaries is commonly dominated by marine species (Whitfield 1999; Franco et al. 2008). Moreover, fishes show migration between estuaries and other ecosystems and are also benefited by the estuaries markedly in larval development and predator avoidance (Dando 1984; Leggett 1984).

Estuaries in Sri Lanka are highly characterized by the variability in size, shape, configuration, ecohydrology, and tidal fluxes (Miththapala 2013). These wetlands cover approximately 93,075 ha in Sri Lanka’s coastal zone (Department of Coast Conservation and Coastal Resource Management 2018). Though these ecosystems provide important habitats for fish taxa, proper ecological studies are scarce to determine the pattern of fish assemblages associated with the various habitats. Ministry of Forestry and Environment (1999) reported 53 fish species in mangrove ecosystems in Sri Lanka. Estuaries a highly dynamic ecosystems, and these facts provide essential evidence to determine conservation priorities in coastal environment management. These mangrove and estuarine areas are increasingly subjected to degradation due to anthropic interventions including tourism, sewage disposal, the introduction of exotic species, and river diversions (Samarakoon & Samarawickrama 2012; Miththapala 2013). Therefore, these ecosystems are particularly important for integrating sound ecological management with sustainable economics (Meire et al. 2005). Hence, the current study was conducted to understand the common characteristics of habitat heterogeneity and fish faunal assemblages associated with estuarine ecosystems.

MATERIALS AND METHODS

Study area

Dedduwa estuary is fed by the Bentota River and is situated in the southwestern part of Sri Lanka. Ecologically, the Dedduwa estuary is remarkably important as it comprises diversified mangroves and related estuarine habitats, which provide essential living environments for assemblages of fauna and flora. The study area is approximately 8 km^2 (Figure 1) and consists of five different types of habitats, viz.: (i) ‘Honduwa’ Lake (lentic), (ii) marshy area with associate aquatic vegetation, (iii) mangroves, (iv) canals, and (v) river. The Honduwa area is characterized by stagnant saline water (approximately 0.95 km^2). There are two major canals connected to Honduwa; one runs through the inland and connects to the estuary and the other is from the estuary to the sea. Therefore, the Honduwa Lake often experiences the gradients of salinity fluctuation. The maximum depth is approximately 2.1 m. *Sonneratia caseolaris* and *Rhizophora apiculata* are the most dominant mangroves in the area with other associates such as *Dillenia suffruticosa*, *Derris trifoliate*, and *Acrostichum aureum*. The marshy area is approximately 0.1 km^2. This area contains open water with floating aquatic vegetation. Most of the open water area is covered by aquatic vegetation such as *Aponogeton crispus, Pistia stratiotes*, *Ceratophyllum demersum*, *Ipomoea aquatica*, *Hydrilla verticillata*,

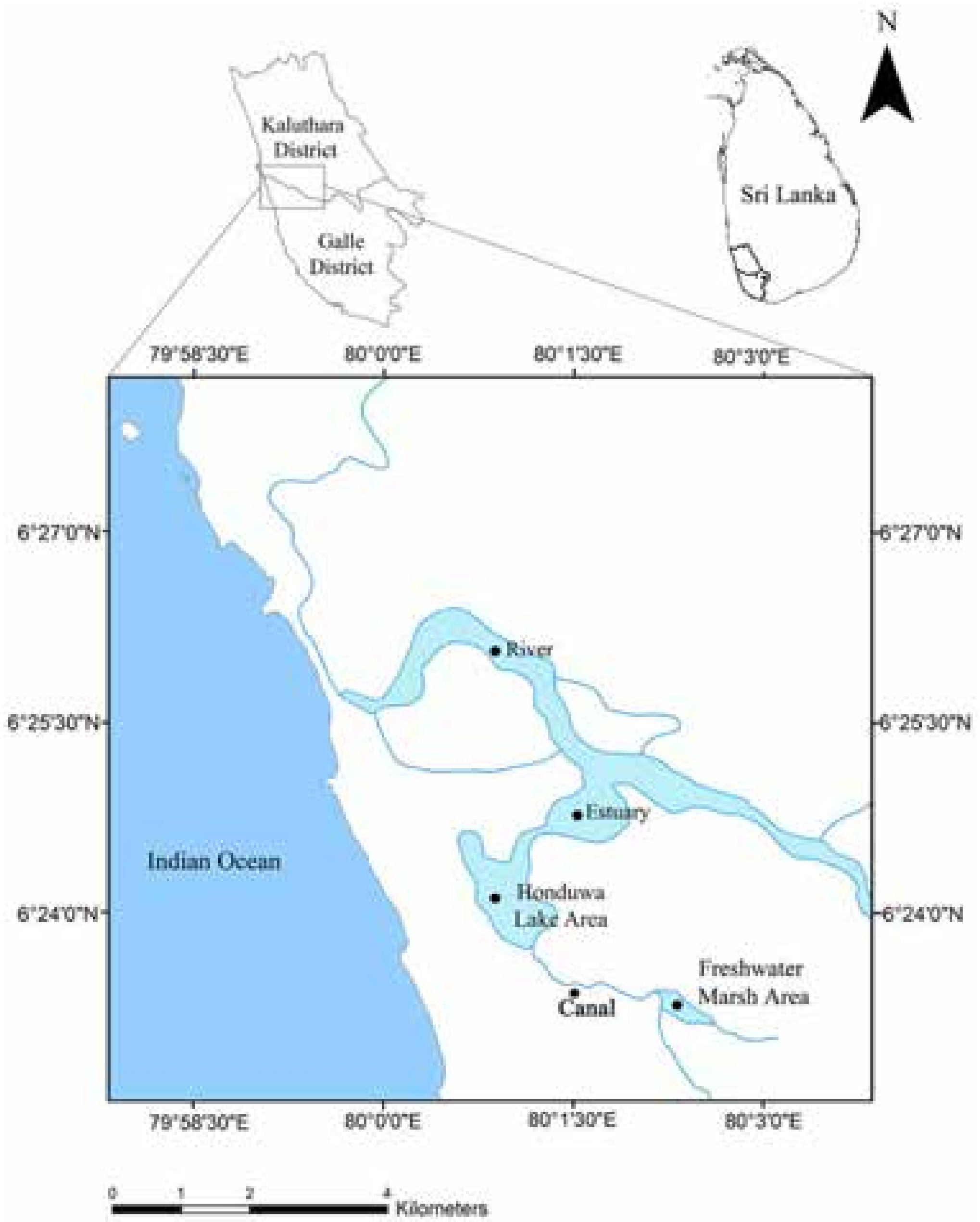

Figure 1. Location of Dedduwa estuary, Sri Lanka. The different sites surveyed for the fish fauna are also marked.

Utricularia aurea, *Nympoides* spp., *Nymphaea* spp., *Eichhornia crassipes*, and *Salvinia molesta*. The floating and marginal vegetation provide vital refugees for aquatic invertebrates. Hence, this marshy area is rich with wetland ichthyofauna. Some areas are entirely infested with invasive aquatic plants like *Salvinia molesta* and submerged during the rainy period. Therefore, the abundance of aquatic fauna possibly shows great fluctuations year-round. Water pools with aquatic weeds provide good nursery grounds for small fishes. This area is highly influenced by human alterations. Hence, associated vegetation has been invaded by invasive plants such as *Annona glabra* and *Typha angustifolia*. The marsh located next to Honduwa Lake (see Figure 1) is approximately 0.86 km^2 in extent. This area contains mixed vegetation of mangroves and freshwater aquatic plants. Most of the area has open water and is probably ideal for euryhaline fish species. Much of the riparian vegetation is densely covered by alien *D. suffriticosa* which provides a shady environment for aquatic fauna. A patchy distribution of mangroves can be seen in the marginal areas and provide nursery grounds for various fish species. The canal contains slow-moving water. Due to less salinity compared to the estuary or river mouth and high turbulence, this water may provide proper living environments for rheophilic freshwater species and anadromous fishes. The canal extends for 2.19 km and most of the area is covered by mangroves. This is an important migratory pathway for both marine and brackish water fish species and is highly influenced by tidal fluctuations. Mixed vegetation with several species of mangrove (e.g., the considerable distribution of *Nypa fruticans*) and mangrove associates can be seen in the area.

Data collection

Fish samples were collected from September to October 2019 in each of the five sites using a dragnet of the dimension of 1.5 x 1.5 m with a 2 mm mesh size. Although some other sampling methods such as gillnets cast nets and traps were also used, the data collected from those sampling methods were excluded from analysis due to the inconsistency of the samplings. Every accessible location with different biological (e.g., different vegetation types) and physical characteristics (e.g., in different water depths and flow rates) was surveyed, and data were collected for the analysis. Altogether 117 samples were collected for the analysis covering all the habitat types (Table 1). The number of individuals of different species caught in every sampling effort was recorded separately. The anthropogenic activities that were carried out at each sampling site were observed such as disposal of sewage and fishing activities. Also, the abundance of microhabitat types was noted in different segments of the river and estuary (see Table 5 in the results section).

Diversity indices

The diversity of fish in each site was estimated using the following different methods in Primer V.5.2.2 software (Clark & Warwick 2001).

i. Shannon-Wiener index (H') (Shannon 1948)

$$H = -\sum pi . \ln pi$$

where p_i = the proportion of species *i* relative to the total number of species

ii. Margalef diversity index (*d*) (Margalef 1958)

$$d = \frac{S-1}{\ln N}$$

where S is the number of species, and N is the total number of individuals in the sample.

iii. Brillouin index (Brillouin 1956), *HB*, was calculated using:

$$HB = \frac{\ln N! - \sum_{i=1}^{s} \ln ni!}{N}$$

where *N* is the total number of individuals in the sample, *ni* is the number of individuals belonging to the i^{th} species, and *s* is the species number. The Brillouin index measures the diversity of a collection, as opposed to the Shannon index which measures a sample.

iv. Fisher's alpha, *S* (Fisher et al. 1943)

This is a parametric index of diversity given below assumes that the abundance of species follows the ln series distribution:

$$\frac{S}{N} = \frac{(1-x)}{x[-\ln(1-x)]}$$

where *S* is the number of taxa, *N* is the number of individuals

$$\alpha = \frac{N(1-x)}{x}$$

where α the diversity index

v. Simpson index, *D* (Simpson 1949)

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

where N is the total number of individuals in the sample, and n is the number of individuals belonging to a certain species. It measures the 'evenness' of the community ranging from 0 to 1.

vi. Pielou's evenness index (J) (Pielou 1969, 1975)

$$J = H/\log(S)$$

If H is the observed Shannon-Wiener index, the maximum value this could take is log(S), where S is the total number of species in the habitat.

Table 1. Summary of the sampling efforts of five different aquatic habitats in the Dedduwa estuary, Sri Lanka.

Habitat	Total number of samples
Honduwa Lake area	27
Estuarine area	24
Canal area	32
Rivermouth	15
Mashy area with floating aquatic vegetation	19

Taxonomic distinctness tests

To determine the taxonomic distance the following approach was adopted. Species were classified to all major taxonomic levels in a Linnean classification following the taxonomy of the fauna (Beesley et al. 1998). A constant path length (ω = 1) between levels was used to calculate the taxonomic distance between species pairs (Warwick & Clarke 1995). Average Taxonomic Distance (AvTD) was calculated using presence/absence data from each site. Using each separate dataset, taxonomic distinctness was quantified using the TAXDTEST procedure in the PRIMER-V.5.2.2 software package (Clarke & Warwick 2001). The 'variation in taxonomic distinctness' [VarTD, Lambda (+)] between every pair of species recorded in a study. It matches the previously defined 'average taxonomic distinctness' [AvTD, Delta (+)], which is the mean path length through the taxonomic tree connecting every pair of species in the list. VarTD is simply the variance of these pairwise path lengths and reflects the unevenness of the taxonomic tree. Samples from the master list were used to generate an expected distribution of values, including a mean and 95% confidence interval. The expected distribution was represented visually as a funnel plot, showing values for different numbers of species, and the observed values were overlaid on the plot. This was used to test the null hypothesis that each observed value had the same value as one predicted using the master list, rejected at the 5% significance level (Clarke & Warwick 2001; Smith & Rule 2002), i.e., sites falling outside the 95% confidence limits were interpreted as having an AvTD value significantly lower (or higher) than expected.

Comparative analysis of ichthyofaunal diversity and abundance

To compare the diversity and abundance of fish in each habitat type, the mean abundance data of each species were used. The similarities of fish communities among sampling sites were determined by the Bray-Curtis similarity coefficient (Bray & Curtis 1957). The ln (x+1) transformation was used before analysis due to the presence of zero values. The ordination of non-metric Multidimensional Scaling (MDS) of sampling sites was determined based on the Bray-Curtis similarity matrix (Clarke & Warwick 2001) using the PRIMER-5 software package (Version 5.2.2). Bray-Curtis similarity analysis was done by using two different approaches. One approach was the analysis performed by separating abundance data for the different species into the five habitat types identified (Table 1) and the second approach was considering all the sampling locations as a single data set and freely clustered it according to the similarity of species composition in each location.

RESULTS

Altogether 41 species of fish were identified including marine, true estuarine, and freshwater species (Table 2). A higher number of species was recorded at the Honduwa Lake and the estuary (18 species in each habitat) while the lowest (12 species) was recorded associated with the river (Table 4). Of these, *Clarias brachysoma* and *Horadandia atukorali* were the endemic freshwater species identified. Species namely *Oryzias dancena, Etroplus suratensis, Ambassis ambassis, Butis butis,* and *Bhava vittatus* were identified in all five different habitat types (Table 2). The results of the present study did not show any dominant group in the assemblage. In Honduwa Lake, estuary, and river the most dominant species were *Ambassis ambassis, Butis butis, O. dancena,* and *Etroplus suratensis* contributing 88.4%, 77.9%, and 74.5 % in abundance respectively (Figure 2). The most abundant species in freshwater marsh habitats were *Horadandia atukorali* (42.3%) and in the canal area was *Ehirava fluviatilis* (29%) (Figure 2). The occurrence of dominant species in saline waters (e.g., estuarine area and Honduwa Lake) showed approximately a similar pattern in abundance. Comparing saline habitats with freshwater habitats (e.g. marsh with aquatic vegetation) a remarkable difference in patterns of species dominance was observed (Figure 2).

When the Bray-Curtis similarity index based on the abundance of fish species is considered, the freshwater marshy habitat was separated from other sampling sites at about the 28.9% level of similarity (Figure 3). The similarity level of fish abundance in the canal area with Honduwa Lake is approximately 51.2% (Figure 3). Also, the canal area with Honduwa Lake further separated from the rest of the sampling sites in the MDS ordination

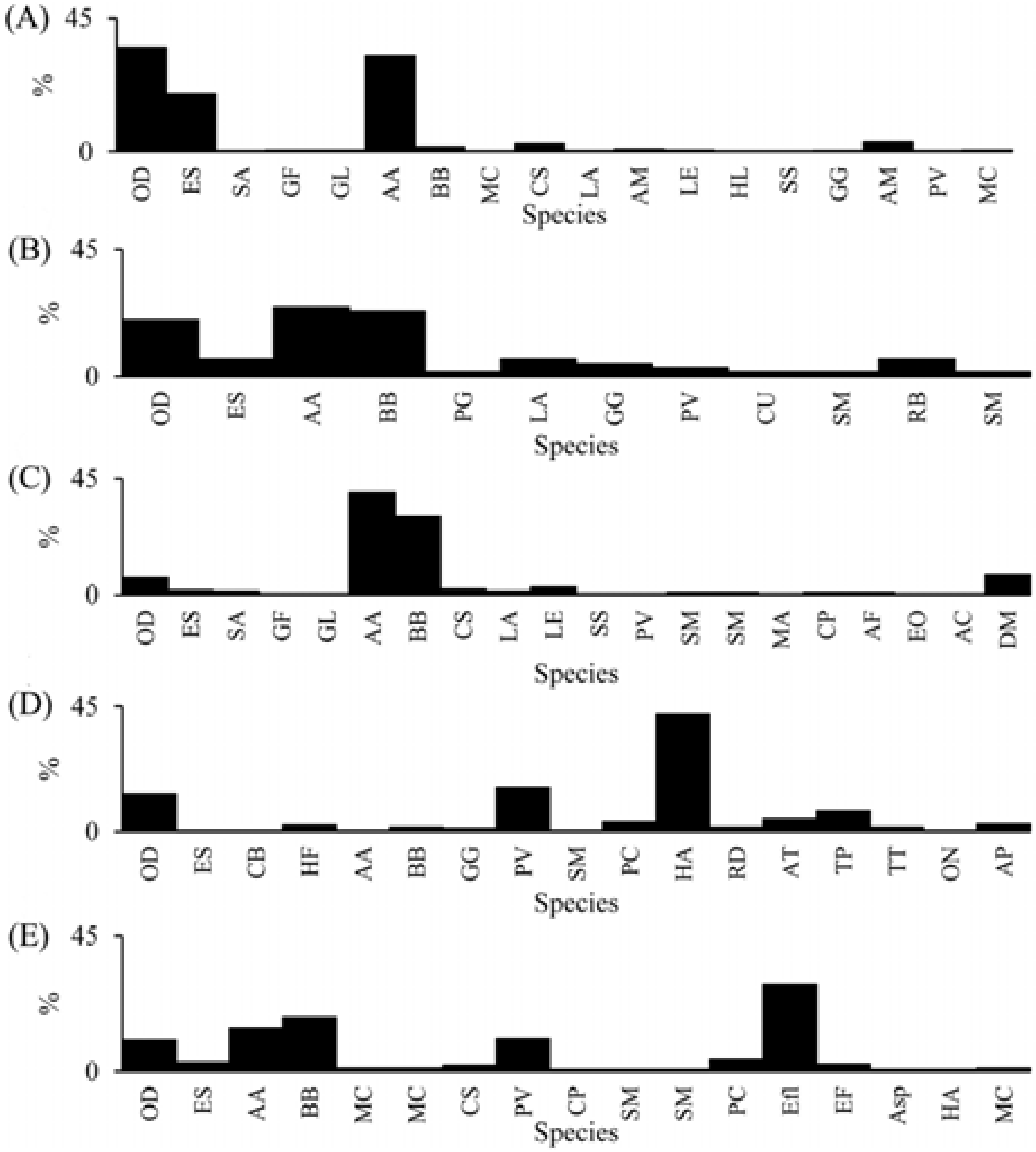

Figure 2. Relative abundance of identified fish species in five habitats studied in the Dedduwa Estuary, Sri Lanka: A—Honduwa Lake | B—River | C—Estuarine area | D—Freshwater Marshy habitat | E—Canal. Abbreviations of the species are given in Table 2.

(Figure 4). The diversity indices Shanon, Brillouin, and Simpson showed the highest diversity in river and canal habitats. Margelef index showed the highest species richness in estuarine habitats. The evenness of the species is approximately high in estuary and canal (Table 3).

The Bray Curtis similarity analysis for the species abundance of different habitats indicated five distinct clusters in a 25% similarity level (Figure 5). It differentiates the freshwater marsh and the canal into a single cluster (I) possibly due to the similarity of habitat choices of freshwater fishes associated with the two areas (e.g., low salinity). Honduwa Lake, canal, estuary, and some sampling locations in the river are grouped into a single cluster at 20% similarity level. As majority of the species in these four habitats are common except a

Table 2. Checklist of ichthyofauna recorded from the different habitats in the Dedduwa estuary, Sri Lanka. Endemic species are mentioned in bold letters. The migratory habit of relevant fishes is also mentioned as superscripted abbreviations after the scientific name. All the abbreviations are explained after the table.

	Family	Scientific name (abbreviation)	Common name	Conservation status		Habitats					Salinity range	Source
				NCS	GCS	HLH	ES	RI	FWM	CN		
1.	Adrianichthyidae	*Oryzias dancena* (OD)	Rice fish	NE	LC	+	+	+	+	+	Polyhaline	Roberts 1998
2.	Ambassidae	*Ambassis ambassis* $^{\text{Oce.}}$ (AA)	Commerson's glassy	NE	LC	+	+	+	+	+	Polyhaline	Fricke 1999
3.	Anabantidae	*Anabas testudineus* $^{\text{Pot.}}$ (AT)	Climbing perch	LC	LC				+		Mesohaline	Talwar and Jhingran 1991
4.	Anguillidae	*Anguilla* spp.$^{\text{Cat.}}$ (AS)	Eel							+	Polyhaline	Kottelat 2013
5.	Aplocheilidae	*Aplocheilus parvus* (AP)	Dwarf panchax	LC	LC				+		Mesohaline	Seegers 1997
6.	Ariidae	*Arius maculatus* $^{\text{Pot.}}$ (AM)	Spotted catfish	NE	NE	+					Polyhaline	Kailola 1999
7.	Carangidae	*Caranx sexfasciatus* $^{\text{Amp.}}$ (CS)	Bigeye trevally	NE	LC	+	+	+		+	Polyhaline	Paxton 1989
8.	Channidae	*Channa punctata* $^{\text{Pot.}}$ (CP)	Spotted snakehead	LC	LC				+		Mesohaline	Pethiyagoda 1991
9.	Channidae	*Channa striata* $^{\text{Pot.}}$ (CS)	Striped snakehead	LC	LC				+	+	Mesohaline	Pethiyagoda 1991
10.	Cichlidae	*Etroplus suratensis* (ES)	Pearl spot	LC	LC	+	+	+	+	+	Mesohaline	Pethiyagoda 1991
11.	Cichlidae	*Oreochromis niloticus* $^{\text{Pot.}}$ (ON)	Nile tilapia	EX	LC			+			Mesohaline	Trewavas 1983
12.	**Clariidae**	***Clarias brachysoma**** **(**CB)	**Walking catfish**	**VU**	**NE**				**+**		Oligohaline	Pethiyagoda 1991
13.	Clupeidae	*Anodontostoma chacunda* $^{\text{Ana.}}$ (AC)	Chacunda gizzard shad	NE	LC		+				Polyhaline	Whitehead 1985
14.	Clupeidae	*Dayella malabarica* $^{\text{Amp.}}$ (DM)	Day's round herring	NE	LC		+				Polyhaline	Whitehead 1985
15.	Clupeidae	*Ehirava fluviatilis* $^{\text{Amp.}}$ (EF)	Malabar sprat	NE	LC					+	Polyhaline	Whitehead 1985
16.	Cyprinidae	*Plesiopuntius bimaculatus* (PB)	Redside barb	LC	LC				+		Oligohaline	Pethiyagoda 1991
17.	Cyprinidae	*Bhava vittatus* (PV)	Silver barb	LC	LC	+	+	+	+	+	Mesohaline	Pethiyagoda 1991
18.	Cyprinidae	*Rasbora dandia* (RD)	Broadline striped rasbora	LC	LC				+		Oligohaline	Silva et al. 2010
19.	Cyprinidae	***Horadandia atukorali**** (HA)	**Green carplet**	**VU**					+	+	Mesohaline	Pethiyagoda 1991
20.	Eleotridae	*Butis butis* $^{\text{Amp.}}$ (BB)	Duckbill sleeper	NE	LC	+	+	+	+	+	Polyhaline	Hoese 1986
21.	Eleotridae	*Eleotris fusca* $^{\text{Amp.}}$ (EF)	Dusky sleeper	NE	LC					+	Polyhaline	Maugé 1986a
22.	Gerreidae	*Gerres filamentosus* $^{\text{Amp.}}$ (GF)	Whipfin silver-biddy	NE	LC	+	+				Polyhaline	Woodland 1984
23.	Gerreidae	*Gerres limbatus* $^{\text{Amp.}}$ (GL)	Saddleback silver-biddy	NE	LC	+	+				Polyhaline	Iwatsuki et al. 2001
24.	Gobiidae	*Glossogobius giuris* $^{\text{Amp.}}$ (GG)	Tank goby	LC	LC	+		+	+		Polyhaline	Maugé 1986b
25.	Gobiidae	*Caragobius urolepis* $^{\text{Amp.}}$ (CU)	Scaleless worm goby	NE	LC			+			Mesohaline	Kottelat et al. 1993
26.	Gobiidae	*Oligolepis* cf. *acutipennis* $^{\text{Amp.}}$ (OA)	Sharptail goby	NE	LC			+			Polyhaline	Maugé 1986b
27.	Gobiidae	*Gobius malabaricus* $^{\text{Amp.}}$ (GM)	Malabar goby	NE	LC		+	+			Polyhaline	Maugé 1986b
28.	Hemiramphidae	*Hyporhamphus limbatus* $^{\text{Pot.}}$ (HL)	Congaturi halfbeak	NE	LC	+					Polyhaline	Collette and Su 1986
29.	Heteropneustidae	*Heteropneustes fossilis* (HF)	Asian stinging catfish	LC	LC				+		Mesohaline	Rainboth 1994

	Family	Scientific name (abbreviation)	Common name	Conservation status		Habitats					Salinity range	Source
				NCS	GCS	HLH	ES	RI	FWM	CN		
30.	Leiognathidae	*Leiognathus equulus* $^{\text{Amp.}}$ (LE)	Common ponyfish	NE	LC	+	+				Polyhaline	James 1984
31.	Lutjanidae	*Lutjanus argentimaculatus* $^{\text{Oce.}}$ (LA)	Mangrove red snapper	NE	LC	+	+	+			Polyhaline	Allen 1985
32.	Megalopidae	*Megalops cyprinoides* $^{\text{Amp.}}$ (MC)	Indo-Pacific tarpon	NE	DD	+				+	Polyhaline	Whitehead 1984
33.	Monodactylidae	*Monodactylus argenteus* (MA)	Silver moony	NE	LC		+				Polyhaline	Heemstra 1984
34.	Mugilidae	*Mugil cephalus* $^{\text{Cat.}}$ (MC)	Flathead grey mullet	NE	LC	+				+	Polyhaline	Harrison 1995
35.	Osphronemidae	*Pseudosphromenus cupanus* (PC)	Spiketail parasidefish	LC	LC				+	+	Mesohaline	Pethiyagoda 1991
36.	Osphronemidae	*Trichopodus trichopterus* (TT)	Three spot gourami	EX	LC				+		Oligohaline	Rainboth 1996
37.	Osphronemidae	*Trichopodus pectoralis* (TP)	Snakeskin gourami	EX	LC				+		Oligohaline	Rainboth 1996
38.	Scatophagidae	*Scatophagus argus* $^{\text{Amp.}}$ (SA)	Spotted scat	NE	LC	+					Polyhaline	Schofield 2021
39.	Sillaginidae	*Sillago sihama* $^{\text{Amp.}}$ (SS)	Silver sillago	NE	LC	+	+				Polyhaline	McKay 1992
40.	Soleidae	*Brachirus orientalis* $^{\text{Ana.}}$ (BO)	Oriental sole	NE	NE		+				Polyhaline	Munroe 2001
41.	Tetraodontidae	*Chelonodon patoca* $^{\text{Ana.}}$ (CP)	Milk spotted puffer	NE	LC		+			+	Polyhaline	Kottelat et al 1993

Amp.—Amphidromous | Ana.—Anadromous | Cat.—Catadromous | CN—Canal | DD—Data deficiency | E—English | ES—Estuary | EX—Exotics | FWM—Freshwater marshy area | GCS—Global conservation standards | HLH—Honduwa Lake habitat | LC—Least concern | NCS—National conservation standards | Oce.—Oceanodromous | Pot—Potamodromous | RI—River | S—Sinhala | VU—Vulnerable; */**bold**—Endemic

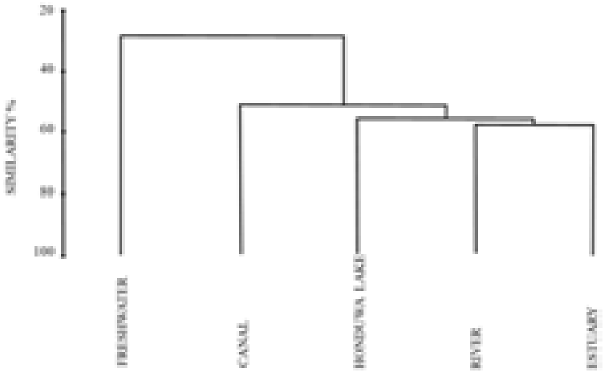

Figure 3. Bray-Curtis similarity of the sampling sites of Dedduwa Estuary, Sri Lanka based on the relative abundance of fish species.

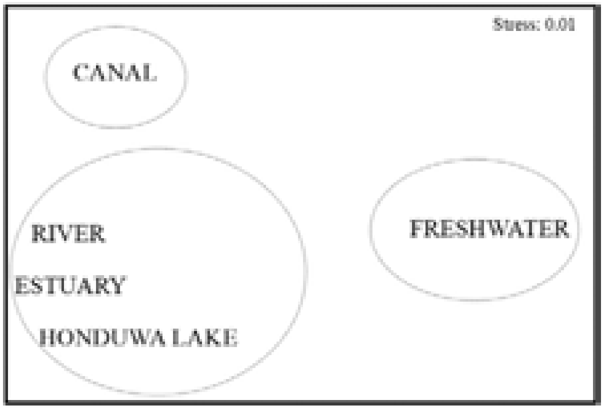

Figure 4. Two-dimensional MDS ordination of sampling sites of Dedduwa Estuary, Sri Lanka according to the relative abundance of fish species.

few species such as *Megalops cyprinoides, Scatophargus argus, Monodactylus argentius*. These four habitats were somewhat similar due to the presence of mangroves. *B. butis* and *A. Ambassis*, are almost equally distributed among canal, estuary, river, and Honduwa Lake, indicating approximately a similar species composition among sites. At the 25% similarity level, this cluster split into two distinct clusters, possibly due to the higher number of *A. ambassis* and *B. butis* caught in cluster V compared to cluster IV. Cluster II and III contained different species whereas Cluster III contained *O. dancena* and *E. suratensis* which were not observed in Cluster II. The Margelef species richness index was higher in clusters I and IV which were associated with freshwater/canal habitat and a combination of canal, estuary, Honduwa Lake, and river respectively. Simpson index was high in clusters I, II, and V (Table 4). The values of Fisher and Pielou's indices are comparatively higher in clusters I, II and V. Similarly, Shannon and Brillouin

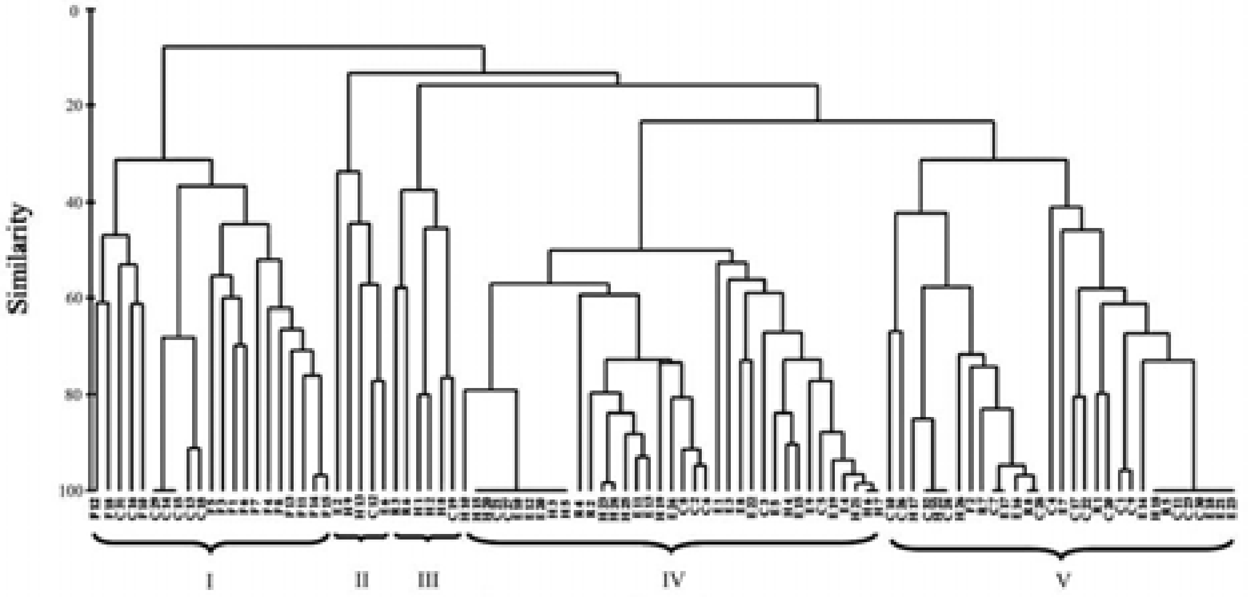

Figure 5. Bray-Curtis similarity of the sampling sites of Dedduwa Estuary, Sri Lanka based on the relative abundance of fish species in different sampling efforts. Five different clusters with a 25% similarity level are marked separately. C—Canal | E—Estuarine area | F—Freshwater marsh | H—Honduwa Lake | R—River.

indices indicate high species richness and evenness in clusters I, II, and V (Table 4).

The taxonomic diversity of the area is within the expected diversity (see Figure 6A). The taxonomic diversity is expressed as observed average taxonomic distinctions (Figure 6A) and variation of taxonomic distinctions (Figure 6B). Honduwa Lake and the estuary are occupied by nearly similar species. Therefore, taxonomic diversity shows an approximately similar variation (Figure 6A). The canal includes species in different genera such as *Anguilla, Eleotris,* and *Channa* and therefore, the canal is different from the other four habitats with taxonomic diversity (Figure 6A). Freshwater habitat was occupied by distinctive genera such as *Rasbora, Anabas, Horadandia, Channa, Clarias, Heteropneustes,* and *Puntius*. Therefore, freshwater habitats also showed high and distinctive taxonomic diversity beyond the expected taxonomic variation compared to other habitats (Figure 6B). The overall taxonomic diversity is shown in Fig. 7 indicating probability contours (back-transformed ellipses) between AvTD and VarTD with a range of sublist sizes.

The fish fauna seems influenced by the various fishing activities of the fishers. Though commercial fishing activities are uncommon, artisanal fishers operate their vessels in every accessible area. Brush piles were found in Honduwa Lake in the northern part of the estuary. Encircling nets were operated in the river, Honduwa Lake, and the estuarine area. No operation of encircling nets was observed in the canal segment (Table 5).

DISCUSSION

The fish fauna of estuarine systems has long been regarded as dominated by estuarine-dependent or estuarine-opportunistic marine species, with the movement of fishes among different salinity gradients being largely determined by the distribution of various habitats and tidal influences (Vieira & Musick 1994). The current finding of 41 fish species from the estuary and related habitats provides insight into the importance of habitat assessment and biodiversity conservation. The fish assemblage in the area is highly vulnerable to being threatened due to the proposed future development activities. Some species have a wide distribution and are found in several habitats while others show a more confined distribution restricted to specialized habitats (see Figure 2). The current study reveals that the distribution of fish species in Honduwa Lake, the Dedduwa Estuary, and the river shows a closely similar pattern. The distribution of species in the canal and freshwater marsh area is different from Honduwa Lake, estuarine area, and river (Figure 4). The variation of salinity could be the major limiting factor for the species distribution among these habitats. The major difference among the three systems is that the Honduwa and the estuarine area act as a lentic ecosystem while the

Table 3. Different diversity indices and related diversity values were calculated to represent the fish diversity of studied habitats in the Dedduwa Estuary, Sri Lanka.

	S	N	Margelef index	Pielou's evenness	Fisher evenness	Brillouin	Shanon	Simpson index
Honduwa	18	576	2.67	0.55	3.52	1.54	1.59	0.74
River	12	213	2.04	0.81	2.72	1.90	2.03	0.84
Estuary	18	164	3.06	0.59	4.41	1.60	1.72	0.74
Canal	15	377	2.74	0.74	4.01	1.89	2.02	0.84
Freshwater	16	253	2.52	0.68	3.38	1.79	1.90	0.77
S—Total number of species or species richness | N—Number of individuals tested for the analysis.								

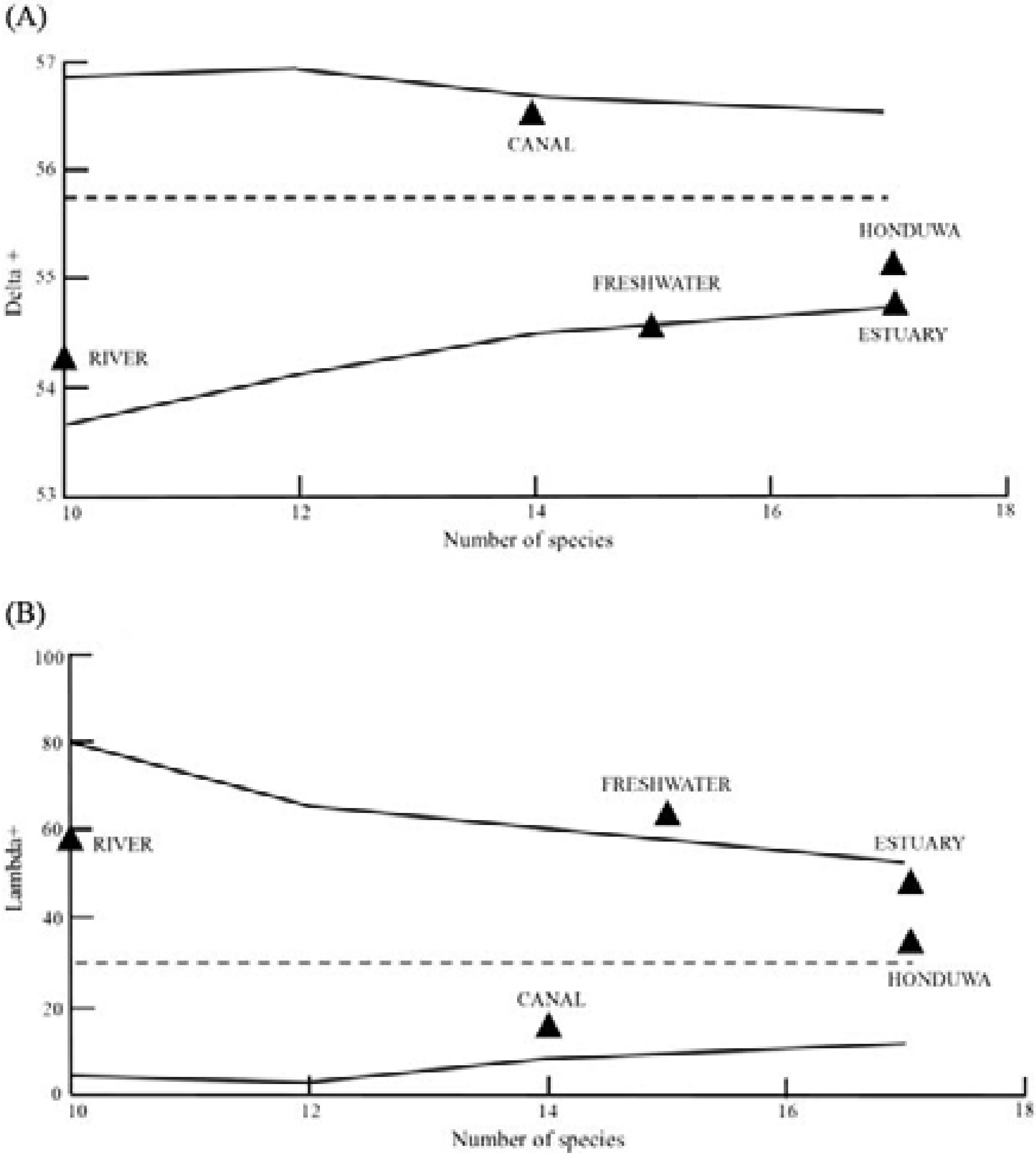

Figure 6. Confidence funnels showing values of (A) observed average taxonomic distinctness (AvTD, Δ+) and (B) variation in taxonomic distinctness (VarTD, Λ+) of fish diversity of Dedduwa estuary, Sri Lanka overlaid on the predicted mean and its 95% confidence interval related.

Table 4. Different diversity indices and related diversity values were calculated to represent the fish diversity of the Dedduwa Estuary, Sri Lanka, for different given clusters in Bray-Curtis similarity analysis in Figure 6.

Cluster	S	N	Margelef index	Pielou's evenness	Fisher evenness	Brillouin	Shanon	Simpson index
I	18	346	2.91	0.67	4.03	1.86	1.94	0.78
II	13	403	2.00	0.78	2.56	1.96	2.02	0.79
III	11	747	1.51	0.46	1.82	1.07	1.09	0.51
IV	18	406	2.83	0.51	3.85	1.40	1.47	0.68
V	14	227	2.40	0.80	3.29	1.80	1.91	0.81

S—Total number of species or species richness | N—Number of individuals tested for the analysis.

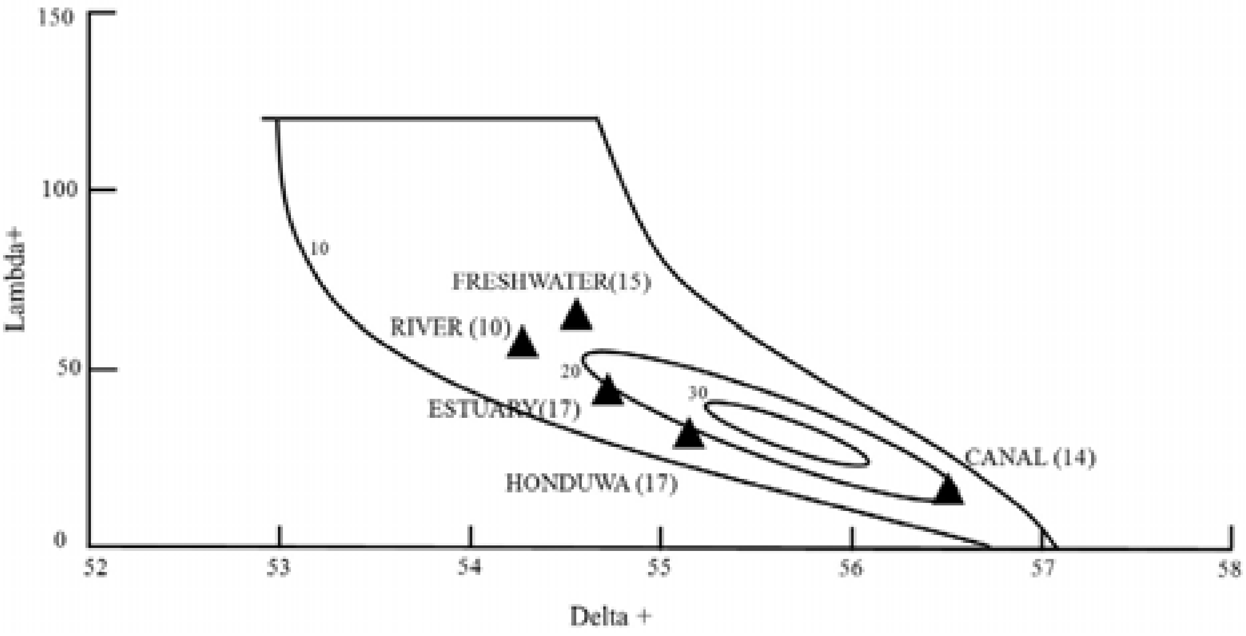

Figure 7. Probability contours (back-transformed ellipses) between AvTD and VarTD with a range of sublist sizes: m = 10, 20, and 30; Plot is based on 1,000 simulations. Simulated fish assemblages were generated from a total species list representing all fishes collected over all surveys.

river is a lotic ecosystem. This difference may have also brought about differences in ichthyofaunal diversity and distribution among habitats.

According to the results presented in this study, the species distribution in the two different salinity gradients in freshwater and brackish water habitats is comparatively different (Figure 3). The species with a wide range of distribution probably are euryhaline (Bulger et al. 1993). Majority of the species recognized as the juvenile stage which denoted mangroves of the riparian habitat provide proper feeding and nursery ground for juvenile stages. The glass eels of *Anguilla* spp. found from the canal area provides evidence of the breeding migration of the catadromous species (Table 2). IUCN (2011), describes the breeding migration of *Anguilla bicolor* (Level fin eel) in the Kala Oya River basin of Sri Lanka and further explains the importance of seagrass beds as refuges of the glass eels. The current finding of glass eels associated with canals and estuaries is particularly important because it explains the eel migration and probably a good indicator of future conservation actions. Nevertheless, the presence of fishes with different migration types such as Amphidromous, Anadromous, Potadromous, and Oceanodromous highlights the importance of the estuary for stabilizing the community structure of fishes (Table 2).

The results show the freshwater habitats (e.g. canal and marsh) are clearly distinguished from brackish water habitats according to the species composition (Figure 6). These canals in more inland areas are connected with freshwater habitats and provide perfect habitats

Table 5. The presence of aquatic vegetation and related anthropogenic activities at the five sampling sites of the Dedduwa Estuary, Sri Lanka.

	Presence of aquatic vegetation		**Anthropogenic activities**		
	Presence of mangroves	Presence of aquatic weeds	Encircling nets	Disposal of waste	Brush park
Honduwa Lake habitat	H	-	+	-	+
Estuary	H	-	+	-	-
River	H	-	+	+	-
Canal	L	+	-	-	-
Freshwater marsh	-	+	-	+	-

H—high | L—Low | +/-—Presence/Absence.

for Polyhaline (conditions ranging from a salinity of 18 –30 ppt), Mesohaline (waters with a salinity between 5 and 18 ppt), and Oligohaline (waters with salinity from 0.5–5 ppt) species (Karleskint 1998) because with high salinity influx, those species probably migrate towards the headwaters of the canal and streams probing for fewer salinity areas (Table 2).

In this analysis, different indices were used to describe the diversity of fish fauna in different habitats in the estuarine area. Because different diversity indices give results in different integrity. The Shannon index is based on percentage composition by species (Magurran 1988). When the randomness of the sampling cannot be guaranteed, the Brillouin index was used to calculate the heterogeneity (Southwood & Henderson 2000). This is because several sampling locations were inaccessible, due to the abundance of crocodiles, snags, and high water depth. Shannon index gives similar results where proportional abundance and number of species in the sample remain constant (Magurran 1988). The Brillouin index measures diversity as opposed to the sample. Both Shanon and Brillouin indices have given approximately similar results as indicated by Magurran (2004). Simpson index is more biased towards the most abundant species rather than species richness (May 1975). Pielou's evenness is an index that measures diversity along with species richness. Compared with indices such as Simpson's index or Shannon's index, a more thorough description of a community structure can be interpreted using Pielou's evenness (Heip & Herman 2001). Margalef's diversity index is a species richness index (Gamito 2010). Many species richness measures suffer from the problem that they are strongly dependent on sampling effort. The greater the sampling effort potentially the higher the index value. Thus, comparing metrics from samples collected with differing levels of sampling effort can be difficult and possibly misleading (Gamito 2010). As mentioned above (see methodology section) data generated from the alternative sampling efforts were excluded from the analysis, and the analysis may have been affected due to insufficient representation of fish species in the samples. Further considering the diversity measurements, Fisher's Alpha (α) is widely used as a diversity index to compare communities varying in the number of individuals (N), because theoretically independent of sample size. This is highly dependent on the sample size and the total number of species (Magurran 1988). Hence, Honduwa Lake habitat and estuarine area (Table 3) and Cluster I and IV (Table 4) show higher Fisher's alpha indices.

The average taxonomic distinctness index (AvTD, Δ+) measures the average taxonomic distance between species at a site, or the average path length joining every pair of individuals in a sample, using a standard Linnean classification, i.e. species, genus, family, order, class etc. (Warwick & Clarke 1995). The variation in taxonomic distinctness index (VarTD, Λ+) measures the variation in the average distance between species pairs (Clarke & Warwick 2001). The taxonomic diversity of the fish fauna observed in the area is within the expected range (Figure 6) confirming the high accuracy of the sampling. Except for migratory species, the distribution of the fish fauna in the estuarine areas is location-specific (Bruno et al. 2013). This specifies the ecological significance and conservation needs of the different types of habitats to conserve different species. Results show the freshwater habitats are unique to several endemic species, especially around marshes including *Horadandia atukorali* and *Clarias brachysoma*. These two species are highly localized for aquatic habitats with submerged vegetation (Pethiyagoda 1991).

The area is extremely popular for the tourism industry. The high visitor pressure and pollution of the freshwater systems seem to be a major threat to the freshwater fish fauna. The loss of riparian habitats was also observed during the field observations. Freshwater species abundance was higher in inland marshes and canals where there is less tidal effect. Though, mesohaline freshwater species like *Channa* spp. and *Puntius* spp. (Table 2) were observed in these freshwater segments, those species were not detected in the brackish water areas. The abundance and distribution of freshwater species increased notably with rainfall. These abiotic factors are important to explain the range expansion of the freshwater species in estuarine systems (Drinkwater & Frank 1994).

CONCLUSIONS

Fish fauna in the Dedduwa estuary provides insight into habitat preference and fish assemblages. The mutualistic relationship between fishes and habitats promotes the stability and functionality of this wetland habitat. The presence of the two endemic and vulnerable species—*Horadandia atukorali* and *Clarias brachysoma*—in marshy freshwater habitat and catadromous migration of *Anguilla* spp. highlights the conservation importance. In the current study freshwater systems are associated with canals where water quality is often vulnerable due to anthropogenic inputs such as sewage and solid waste and are likely to have noticeable impacts on the freshwater and amphidromous fishes. Though the species richness in the studied habitat was approximately similar, higher variations were observed in the abundance of different species. This demonstrates the habitat-orientated species distribution and ontogenetic habitat shifting of different species in the study area. The presence of fish species with different migratory habits denoted the importance of the estuary as a refuge and feeding ground for juvenile fish during their critical development stages. Therefore, current habitat alterations and pollution loads from different sources would affect the movement of the fishes and must be kept to be minimum.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25831–25842

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9078.16.9.25831-25842

#9078 | Received 07 April 2024 | Final received 11 July 2024 | Finally accepted 28 August 2024

ARTICLE

Successful establishment of a coral nursery for active reef restoration in Kavaratti Island, Lakshadweep archipelago

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Abstract: The achievements in successfully establishing coral nurseries using asexually reproduced transplants in Kavaratti Island, Lakshadweep archipelago are presented. During the present study, the survival and growth of 180 fragments of corals fixed on concrete blocks with iron frames laid over a 40 m^2 area near reefs inside the lagoon of Kavaratti atoll were assessed. Significant differences in growth were observed between acroporid and non-acroporid corals after two years of transplantation. *Acropora muricata* (31.1 ± 0.4 cm) and *Isopora palifera* (15.9 ± 3.4 cm) displayed the highest and lowest growth rates among acroporid corals and *Pocillopora damicornis* (481.9 ± 68.4 cm^3) and *Hydnophora microconos* (33.4 ± 15.7 cm^3) had the highest and lowest rates, among non-acroporid corals. A diverse fish assemblage comprising 21 species belonging to 10 families was observed at the transplantation site, with *Chromis viridis* and *Dascyllus aruanus* being the dominant species. The success achieved in this study makes it an ideal approach to be used elsewhere in the Lakshadweep archipelago and the wider Indian Ocean region to develop underwater tourism and promote science-based management and restoration of coral reefs.

Keywords: Acropora, Arabian Sea, artificial substrate, atoll, coral fragments, coral nursery, coral reef, Indian Ocean, lagoon, transplantation.

Editor: M. Nithyanandan, Kuwait Institute for Scientific Research (KISR), Salmiya, Kuwait. **Date of publication:** 26 September 2024 (online & print)

Citation: Riyas, C.A., K.K. Idreesbabu, R. Raghavan & S. Sureshkumar (2024). Successful establishment of a coral nursery for active reef restoration in Kavaratti Island, Lakshadweep archipelago. *Journal of Threatened Taxa* 16(9): 25831–25842. https://doi.org/10.11609/jott.9078.16.9.25831-25842

Funding: Department of Science and Technology, Lakshadweep Administration, Government of India,
and a grant (Grant-In-Aid General-40). No additional funding specific to this work has been availed from other sources.

Competing interests: The authors declare no known competing financial interests or personal relationships that have appeared to influence the work reported in this paper.

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Author contributions: SS and KKI – conceptualisation, design of work and supervision. CAR – Field work, coordination, data collection and manuscript writing. RR, KKI and SS manuscript review, editing and comments.

Acknowledgements: The authors gratefully acknowledge the Department of Environment and Forest, Lakshadweep Administration, for necessary permissions during the study period. Ms Raziya Beegum M.K (Technical Officer), Mr C.N. Mueenudheen, Mr B. Mohammed Nowshad, Ms Mariyambi P.C and Ms Sabeena M for their support in the field; research dive team, Mr Syed Abdullakoya, Mr Abdu Raheem, Mr Sharafudheen, Mr Ilthuthmish Nasarulla, Mr Saheerali, Mr Kaleel, and Mr Thabsheer of DST, without whom this work could not have been possible.

INTRODUCTION

Despite being of the most spectacular, productive, and biologically diverse marine ecosystems (Odum & Odum 1955; Connell 1978; Moberg & Folke 1999), coral reefs face unprecedented threats from various natural and anthropogenic stressors (Wilkinson 1998; Obura et al. 2022), including deteriorating water quality, destructive fishing methods, over-exploitation of reef fauna, emerging diseases, and climate change (Hoegh-Guldberg 1999; Bellwood et al. 2004; Halpern et al. 2019; Schartup et al. 2019; Issifu et al. 2021). Almost half of the world's coral reef ecosystems are now degraded (IPBES 2019), many reefs in southern Asia, and the Pacific region continue to decline steadily (Burke et al. 2011), and others like the western Indian Ocean region are predicted to have high risk of collapse within the next 50 years (Obura et al. 2022). Additionally, the catch-per-unit effort of coral reef-associated fishes has been declining by 60% since the 1950s, and the capacity of reefs to provide critical ecosystem service declined by 50% during the same period (Eddy et al. 2021). The prospects for coral reef ecosystems and their resources appear bleak in the coming future.

Around the world, damaged coral reef communities recover very slowly, particularly when there are changes in benthic morphology or chronic degradation in prevailing environmental conditions (Roth et al. 2018). The complete recovery of the reef to pre-existing ecological community structure and ecosystem services may extend to hundreds or even thousands of years without active intervention by resource managers (Hein et al. 2020). Despite its limitations and reservations (Omori 2019; Boström-Einarsson et al. 2020), coral reef restoration efforts are accelerating worldwide to offset the rate of reef health declines (Boström-Einarsson et al. 2020; Suggett & van Oppen 2022). The primary objective of coral restoration is to transplant fast-growing and healthy coral fragments, to rebuild dead reefs to their original state, or as nearly as possible to the original state, and thus increase the live coral coverage (Ramesh et al. 2020). Massive corals are also recommended for transplantation due to their lower susceptibility to damage and mortality, which can ultimately produce the habitat required for fish and other coral morphologies (Ammar et al. 2013). While fast-growing corals are ideal candidates for active reef restoration, they are highly susceptible to bleaching-related impacts and mortality. Therefore, any active restoration should focus on both branching and non-branching corals to achieve fruitful results (Ramesh et al. 2020).

The Lakshadweep archipelago, part of the Laccadive-Maldives-Chagos group of islands, comprise 12 atolls, three reefs, five submerged banks, and ten inhabited islands (Kaladharan & Anasukoya 2020). Lakshadweep reefs are the only atolls among the Indian reefs. The coral reefs of this archipelago have been threatened and destroyed by a range of stressors, including regular bleaching events, cyclonic disturbance, and anthropogenic interventions (Riyas et al. 2020). These threats necessitate the development and implementation of active coral restoration programs. In the Lakshadweep archipelago, transplantation of corals can help create habitats that provide alternative livelihoods for the fishing community and, in particular, serve as an ideal management strategy for aquarium fish collectors without damaging prime coral colonies in the reef. The present study aims to develop an effective transplantation method for establishing a coral nursery in the Kavaratti lagoon of the Lakshadweep archipelago, focusing on the use of fast-growing coral species to facilitate the rapid restoration of degraded reefs. Also, it aims to understand the composition and abundance of reef fish assemblages that colonize near the transplantation site based on the growth and survival of transplanted fragments.

MATERIALS AND METHODS

Study site

Kavaratti Island (10.558°N 72.623°E), part of the Lakshadweep archipelago, is located off the southwestern coast of India (Image 1). The area of Kavaratti lagoon is approximately 3.63 km^2, and most parts of its seabed are covered by coral sand, dead corals, and rubbles, together with well-developed live coral communities near the inner reef slope adjacent to the restoration site. The total cover of the live coral community at Kavaratti Atoll was estimated to be 21.7% (Idreesbabu et al. 2017). The selected location for attempting the restoration experiments is a 2.5-m-deep area within the lagoon of the Kavaratti Atoll, consisting of a sandy bottom (Image 2). The coral fragments were collected from different donor sites or locations of the lagoon including the intertidal zone, inner reef lagoon, and reef crest of the atoll, to obtain different fragments grown in different conditions and locations in the lagoon. The donor sites were approximately 500 m to 2.5 km away from the transplantation site.

Selection of the donor and recipient sites

This restoration effort focused on using indigenous healthy corals found in the shallow lagoons of Kavaratti islands because of their natural resilience to the local environment. The long-term success and resilience of transplanted corals rely heavily on genetic diversity. Accordingly, using donor sites with high genetic diversity is preferable to enable transplanted corals to adjust to changing environmental conditions. Coral species were chosen from the donor site because of their rapid growth and abundance.

The recipient site chosen for the transplantation had environmental conditions with minimal signs of stressors, such as pollution, sedimentation, or overfishing to maximize the survival and growth of the transplanted corals. In the same way, a nearby site that has been damaged by coral fragmentation was also taken into consideration as a potential donor site.

Artificial substrate

Coral nursery units were made of angle bars and iron mesh (2 × 2 × 0.5 m). Concrete blocks (25 x 20 cm) were used as the artificial substrate for coral fixing (Image 3a). To increase the durability of the coral nursery unit and prevent the early onset of rust and corrosion, food-grade epoxy paint was applied and allowed to dry for three days before deployment. A total of 10 iron frames (4 m^2) were arranged at the restoration site.

Coral transplantation

Coral fragments available around the lagoon were used for transplantation, as they were grown in the local environment. Branches of acroporid and non-acroporid corals that naturally grew on artificial substrates, such as concrete structures and buoys in the lagoon, were pruned to obtain coral fragments. Collected coral fragments were transferred underwater using plastic baskets by scuba diving. They were identified up to the species level using an underwater coral finder following Kelley (2009). Selected and sized nubbins were then fixed on rectangular cement blocks using plastic cable ties and these blocks were fixed into the deployed iron

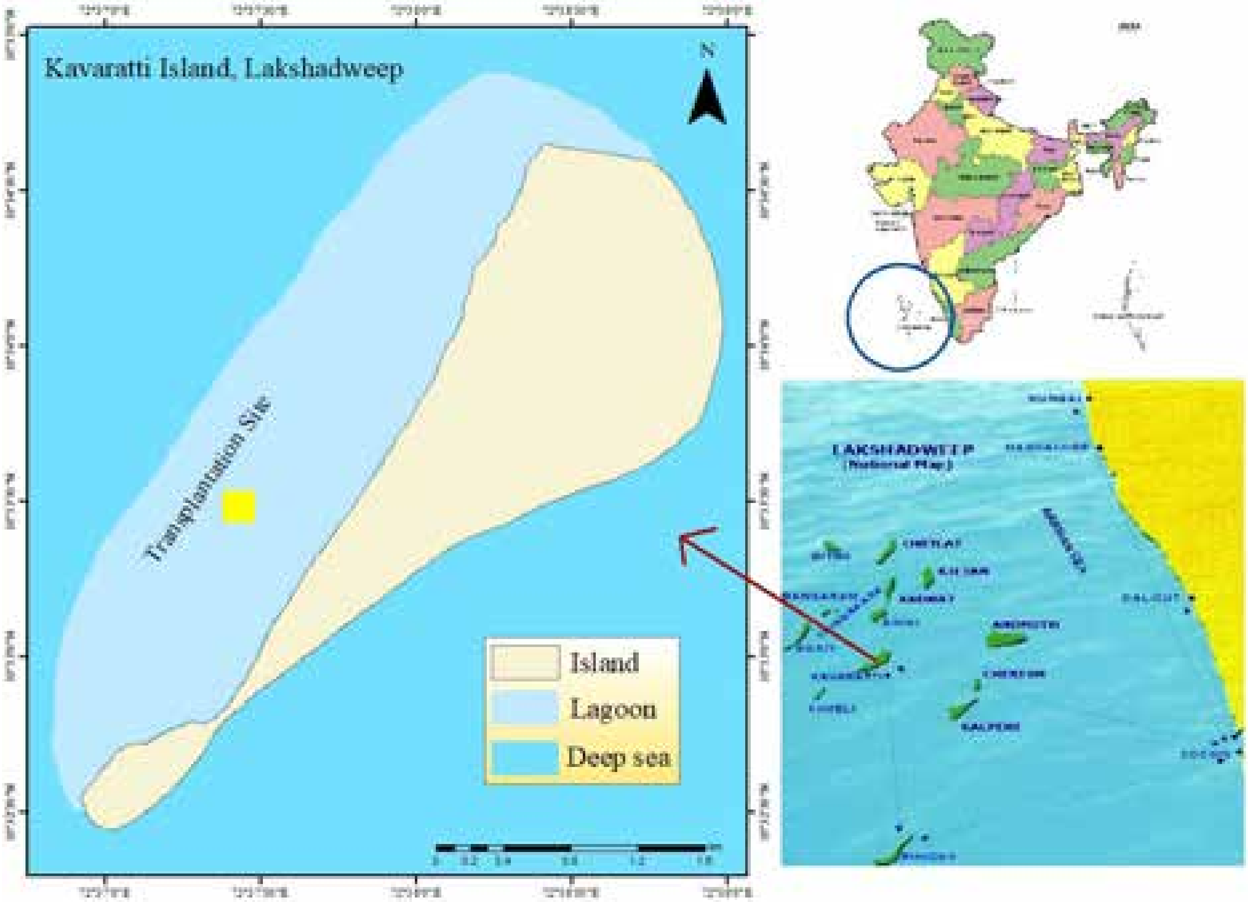

Image 1. Map of the lagoon off Kavaratti Island, Lakshadweep archipelago, India, showing the location (marked in yellow) of the transplantation site.

Image 2. Site selected for coral transplantation in the Kavaratti lagoon, Lakshadweep archipelago (before restoration).

mesh frame. Twenty coral fragments each measuring 7–11 cm in length were fixed in each iron mesh frame. The number of coral fragments, species, and size used at the beginning are provided in Tables 1 and 2. The debris, algae, and sand particles deposited on the transplanted fragments were removed weekly for the first two months and fortnightly thereafter using a soft brush. Survival and growth rates were monitored monthly from January 2016 until January 2018.

Data collection and analysis

The growth rate of the massive corals was reported as colony height (h) in centimeters (cm) and approximate colony volume (V), calculated using a formula $V = r^2h$, of which ‘r’ was calculated from length (l) and width (w) as (l⍰w) /4 (Yucharoen et al. 2013). The total growth rate of acroporid coral was measured to the nearest centimeter and compared between species. Seawater temperature was recorded using a Hobo data logger (HOBO Pendant UA-002-64) and the turbidity data was obtained from a data buoy deployed in Kavaratti, as part of a joint initiative by the Department of Science and Technology and the National Institute of Oceanography, Goa. The survival rate was calculated based on the percentage of corals that survived the initial fixing. Survival of coral transplants (expressed as the percentage of the live individuals which survived the initial fixed) was recorded monthly. Belt transects (Brock 1954) measuring 10 x 5 m which were placed horizontally to the coral restoration site were used to quantify the density of associated fish species. Fish species were identified primarily using Kuiter (2014) and Allen & Steene (2007). Further, the fishes were identified to species-level taxonomy following Fricke et al. (2023).

RESULTS

Growth rates of transplanted corals monitored for two years revealed higher annual values for acroporid, than non-acroporid corals. Growth rate varied widely between species (Tables 1 & 2), with the highest growth rates observed in *Acropora muricata* (31.1 ± 0.4 cm, n = 25), *A. hyacinthus* (21.7 ± 1.5 cm, n = 14) and, *A. gemmifera* (17.5 ± 2.8 cm, n = 10) (Table 1, Figure 1), and lowest growth rates in *Pocillopora damicornis* (481.9 ± 68.4 cm^3, n = 12), *P. grandis* (273.12 ± 36.1 cm^3, n = 12), and *Echinopora lamellosa* (95.1 ± 21.3 cm^3, n = 8) (Table 2, Figure 2). A comparison of the mean initial lengths of the acroporid fragments showed no significant variation ($F = 2.75$; $P > 0.01$) however the final growth showed a significant variation ($F = 162.91$; $P < 0.01$). This denotes variation in the growth of different species selected for the study even though the initial sizes are uniform. In

Table 1. Size (Mean ± SD) of transplanted acroporid corals in Kavaratti lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

Coral species	Number of fragments (N)	Initial size (cm)	Size after two years (cm)	Growth rate (cm/2years)
Acropora austera	15	7.64 ± 1.2	24.7 ± 0.9	17.08 ± 1.04
Acropora digitifera	15	7.3 ± 0.9	23.9 ± 0.8	16.6 ± 1.3
Acropora gemmifera	10	7.7 ± 2.9	25.2 ± 2.8	17.5 ± 2.8
Acropora hyacinthus	14	9 ± 1.5	30.6 ± 1.6	21.7 ± 1.5
Acropora muricata	25	8.2 ± 2.6	39.3 ± 2.7	31.1 ± 0.45
Acropora tenuis	11	6.53 ± 0.7	22.6 ± 0.5	16.22 ± 0.6
Isopora palifera	10	9.4 ± 2.5	25.3 ± 3	15.9 ± 3.4

Table 2. Volume (Mean ± SD) of transplanted non-acroporid corals in Kavaratti Lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

Coral species	Number of fragments (N)	Initial volume (cm^3)	Volume after 2 years (cm^3)	Growth rate (cm^3/2years)
Echinopora lamellosa	8	18.6 ± 8.9	113.7 ± 50.5	95.1 ± 21.3
Gardineroseris planulata	8	8.8 ± 1.2	42.5 ± 29.3	33.7 ± 11.5
Hydnophora microconos	8	29.5 ± 8.6	62.9 ± 27.7	33.4 ± 15.7
Lobophyllia hemprichii	10	33.6 ± 19.8	68.8 ± 29.1	35.2 ± 9.5
Platygyra daedalea	12	24.1 ± 9.9	61.99 ± 31.2	37.89 ± 14.9
Pocillopora damicornis	12	20.04 ± 11.5	502.008 ± 115.9	481.9 ± 68.4
Pocillopora grandis	12	29.2 ± 13.8	302.321 ± 53.36	273.12 ± 36.1
Porites lobata	10	15.7 ± 11.9	49.2 ± 36.2	33.5 ± 23.5

non-acroporids, the initial nubbins taken significantly varied in volume (F = 6.06; P <0.01), and the final growth of the fragments also varied significantly (F = 372.82; P <0.01).

During the study period, water temperature (Figure 3) varied between 25.9^{0}C (in August 2018) and 31.6^{0}C (in May 2016), and turbidity (Figure 4) between 0.6 NTU (in February 2018) and 6.3 NTU (in July 2018).

The underwater visual census showed the presence of a diverse fish assemblage at the transplantation site, with around 21 species belonging to 10 families. The major families of fish represented at the transplantation site included Acanthuridae, Balistidae, Chaetodontidae, Holocentridae, Labridae, Monacanthidae, Pomacentridae, Scorpaenidae, Serranidae, and Zanclidae (Table 3). The numbers of *Chromis viridis* and *Dascyllus aruanus* were higher than other species, suggesting that the transplantation site acts as a good spawning ground, as *Pocillopora* sp. and *Acropora* sp. were preferred as a breeding space. The health of the transplanted corals could also be ascertained from the occurrence of coral-feeding fishes of the genus *Chaetodon* and herbivorous fishes such as those belonging to the family Acanthuridae. The results indicated that fish diversity varied based on the nature of the benthic substrate at the transplantation site, the species composition of the corals, as well as the dietary preferences of the fish.

DISCUSSION

Scientific transplantation, the most expensive and effective method for coral rehabilitation, has been extensively applied as a management option in many countries of the world (Rinkevich 2005; Ferse 2010; Garrison & Ward 2012), while research on coral restoration have been carried out in more than 56 countries (Boström-Einarsson et al. 2020). Most projects on coral restoration are conducted in the USA, Philippines, Indonesia and Thailand, with the majority of these involving coral fragmentation, or transplantation of coral fragments (Boström-Einarsson et al. 2020). These restoration programs have successfully accelerated the recovery of degraded coral reefs due to natural and anthropogenic disturbances. However, they are limited to particular environmental conditions such as substrate type, sexual recruits and sheltered zones (Edwards & Gomez 2007; Edwards 2010; Rinkevich 2014). Different

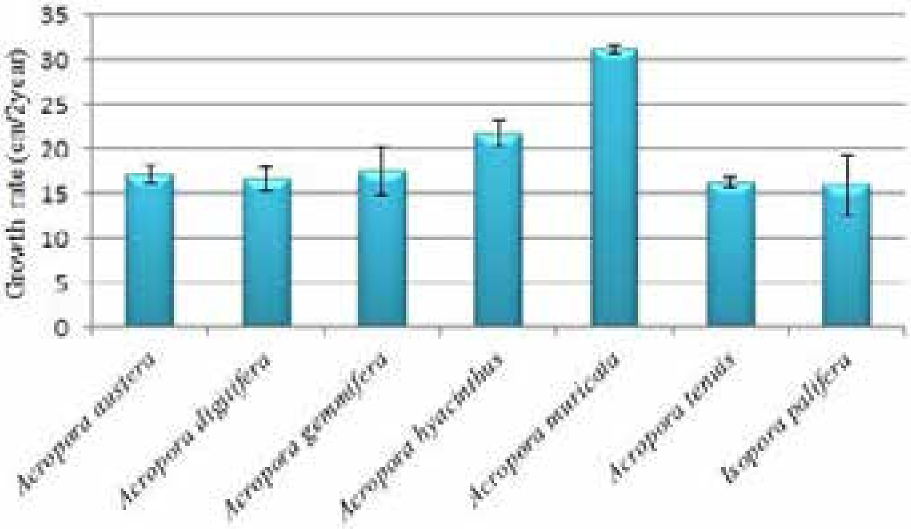

Figure 1. Growth rates observed in transplanted acroporid corals in the Kavaratti lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

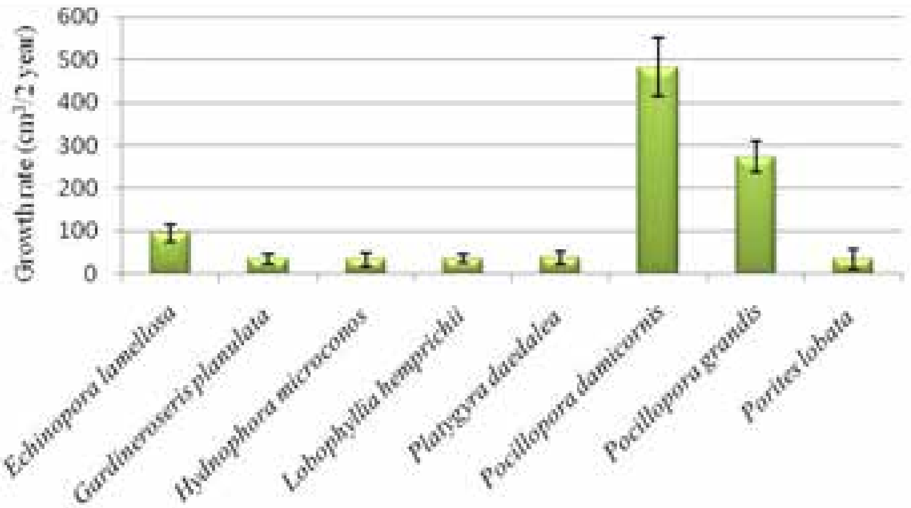

Figure 2. Growth rates observed in transplanted non-acroporid corals in the Kavaratti Lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

countries have developed many alternative techniques over the last few decades, which involve directly fixing coral colonies and fragments onto a reef substrate, which is the most commonly practiced technique (Boström-Einarsson et al. 2020). Although the coral fragment technique used for coral restoration is common worldwide, this study is unique in that it has used such a large number of coral nubbins with long-term monitoring for the first time through the Department of Science and Technology, Lakshadweep Administration.

All transplanted coral species in the present study showed reasonable growth rates, and an ability to self-attach to concrete blocks and augmented polyps within the lagoon. Between the groups, acroporid corals displayed a faster growth rate than non-acroporid corals, suggesting that fast-growing acroporid corals are more favourable for providing quick coral reef ecosystem services. The structural morphology of *Acropora* facilitates the provision of food, shelter, and breeding sites for many organisms in the marine ecosystem, and plays a critical overall role in creating a healthy ecosystem in the sea, as well as in the formations of islands, and for coastal protection (Bruckner 2002). It is for these reasons that most global restoration projects focus on fast-growing, branching, acroporid corals (Boström-Einarsson et al. 2020).

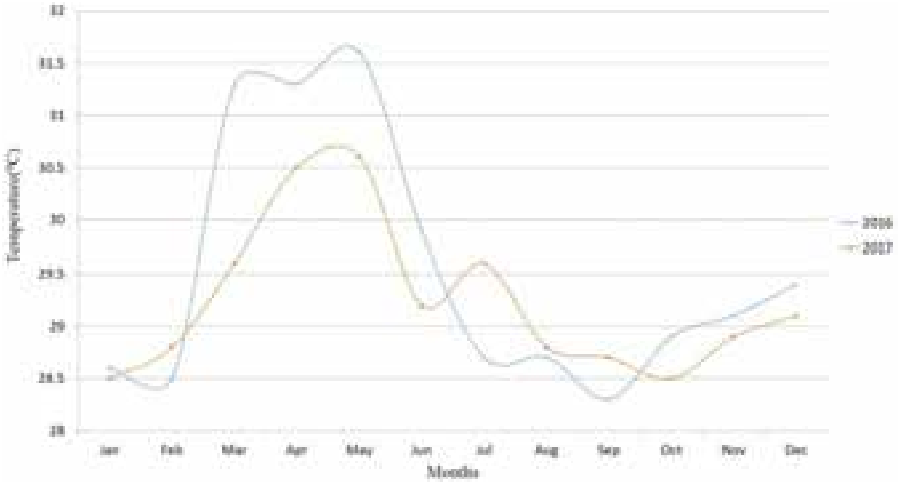

Figure 3. Sea water temperature (°C) around the transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, from January 2016 until December 2018

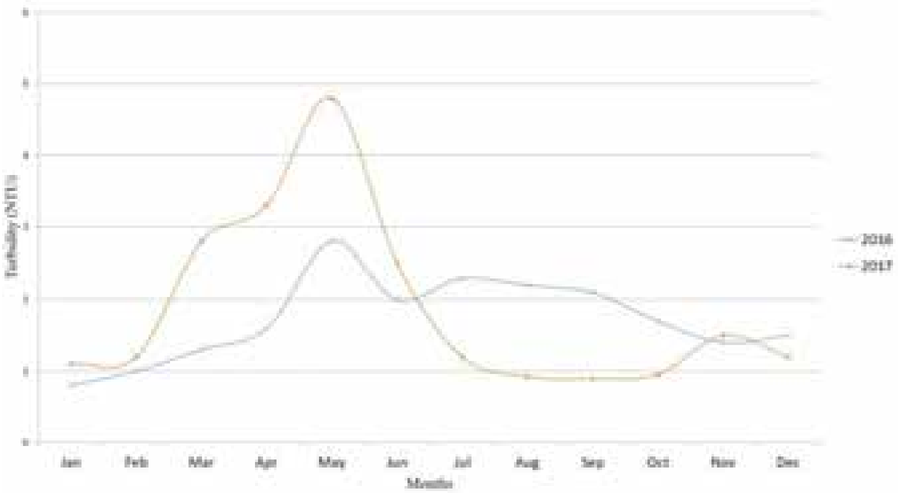

Figure 4. Turbidity around the transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, from January 2016 until December 2018

Growth rates of coral in the present study are considered high compared to those observed in the Red Sea, and Pacific (Lizcano-Sandoval et al. 2018; Mahmoud et al. 2019). Varying growth rates have been reported for corals from many parts of the world, for example, coral Davis reef (0.67 cm/month; Oliver et al. 1983), Solitary Islands (0.80 mm/month; Harriott 1999), Thailand (0.28 cm/month; Putchim et al. 2008), Maldives (0.48 cm/month, Clark & Edwards 1995), and Gulf of Kachchh, India (0.33 cm/month; Kumar et al. 2016, Gulf of Mannar, India (0.79 cm/month; Ramesh et al. 2020). Idreesbabu et al. (2017) first studied the restoration of corals in the Lakshadweep archipelago and observed a mean growth of 14.85 cm/year for *Acropora muricata*, which was relatively lower than those observed in the present study (i.e., 15.55 cm/year). The comparatively higher growth rate obtained during the present study could be due to the better management and conducive physicochemical parameters prevalent in the region (Davidson et al. 2019).

The global mean survival rate of restored corals is 66% (Boström-Einarsson et al. 2020), with survival depending on various factors. Survival rates across all nursery fragments in our study ranged from 64% to 99%. Acroporid corals showed higher survival rates (between 90% and 99%) compared to non-acroporid corals (between 64% and 89%) indicating an improved survival rate compared to the global average (Figure 5). Our results reveal a higher success rate of transplantation efforts and good health of transplanted corals even after two years. This high survival is likely due to the size of coral fragments and coral species capable of

Image 3. A—Iron mesh with transplanted coral fragments deployed in the lagoon bed at Kavaratti, Lakshadweep archipelago | B—Secretion and deposition of $CaCO_3$ by *Acropora muricata* on cement slabs | C—Fish aggregation in the transplantation site | D—Well-developed coral colonies in the transplantation site after two years.

resisting environmental factors used for transplantation. Fragment size is a critical parameter to consider in reef restoration, as it influences the survival and growth of a coral transplant in the new environment (Sam et al. 2021). The initial size of the coral fragments used in our study ranged from 7 cm to 11 cm. Perhaps, the high survival rate obtained in this study indicates that we have used the optimal size of coral fragments for transplantation, as observed previously (Shafir et al. 2010).

Our study also highlights that successful coral transplantation depends on the selected species, and other key environmental factors, such as temperature and turbidity at the study site. In the Lakshadweep archipelago, the sea surface temperature usually increases between the summer months of March and May (Shenoi et al. 1999). In our study, the water temperature showed an increasing trend from March to May, with a gradual decline from the last week of May, due to the onset of the monsoon showers (Figure 3). Turbidity rates at the study sites increased from April and extended till August, mostly due to high wave action, high precipitation and water runoff during the monsoon. The data obtained from the ongoing coral reef monitoring program of Department of Science and Technology, shows that salinity, pH and dissolved oxygen (DO) in Kavaratti Island ranged 31.44–37.81 psu, 7.90–8.40, 3.02–4.88 ppm with average values of 35.14 psu, 8.18, and 3.94 ppm, respectively, which may also have influenced the coral transplantation. Physical parameters such as temperature, salinity, water motion, sedimentation and turbidity also influence the survival of transplanted coral, and reef health (Yap et al. 1998; Ferrier-Pages et al. 1999; Mohamed & Mohamed 2005; Ramesh et al. 2019; Howlett et al. 2021)

The diverse fish population at the transplantation site indicates that the 'site' mimics conditions on a natural reef (Rilov & Benayahu 2000), and offers a habitat which not only constitutes a shelter, but also acts as a potential breeding ground for fishes and other marine

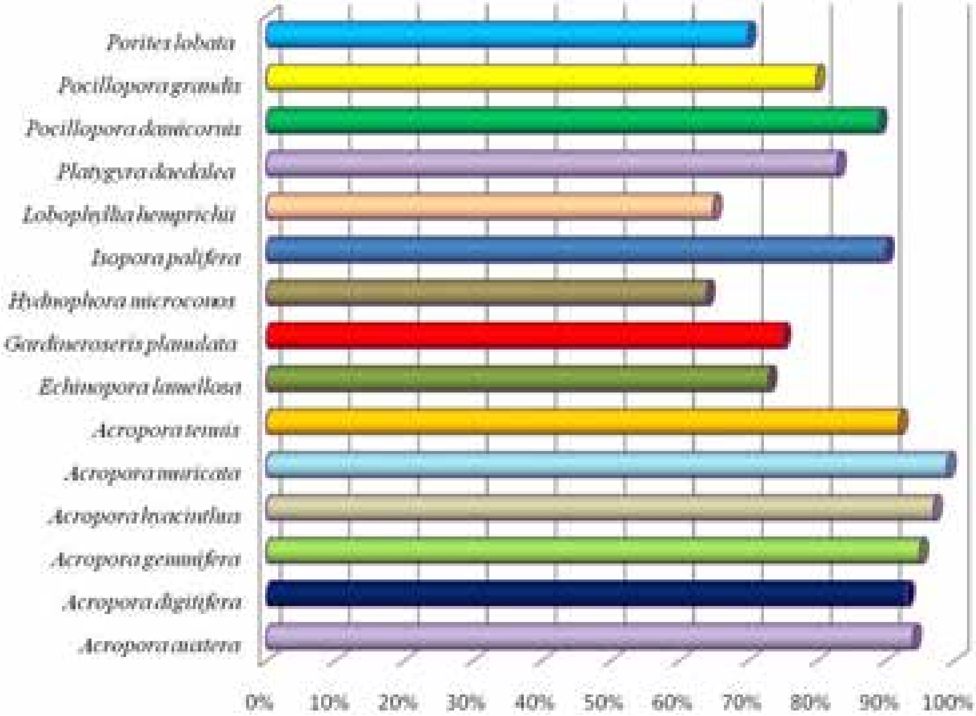

Figure 5. Percentage survival of various coral species in the transplantation site in Kavaratti lagoon, Lakshadweep archipelago, after two years.

Table 3. List of fish species observed at the coral transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, and their numbers.

Family	Species	Number of fishes
Acanthuridae	*Acanthurus triostegus*	5
	Ctenochaetus striatus	20
Balistidae	*Rhinecanthus aculeatus*	2
Chaetodontidae	*Chaetodon trifascialis*	4
	Chaetodon auriga	2
	Chaetodon trifasciatus	10
	Chaetodon falcula	2
Holocentridae	*Sargocentron diadema*	3
	Neoniphon sammara	6
Labridae	*Thalassoma lunare*	2
	Halichoeres scapularis	5
	Gomphosus varius	2
	Labroides dimidiatus	2
Monacanthidae	*Oxymonacanthus longirostris*	3
Pomacentridae	*Chromis viridis*	415
	Dascyllus aruanus	30
	Chrysiptera unimaculata	5
	Centropyge multispinis	2
Scorpaenidae	*Pterois volitans*	4
Serranidae	*Epinephelus hexagonatus*	2
Zanclidae	*Zanclus cornutus*	2

organisms (Ulfah et al. 2020). Breeding habitats in the transplantation site were preferred for live baits such as *Chromis viridis* and *Dascyllus aruanus*, particularly among the branching coral of *Acropora* and *Pocillopora*. Populations of *Chromis viridis* and *Dascyllus aruanus* were higher than those of other fish species, indicating that the transplanted site serves as their favorable spawning ground (Goren 1992). As a fundamental objective, coral restoration targeted at reef recovery should consider re-establishing breeding populations of corals (Cruz & Harrison 2017).

Furthermore, an array of reef fishes consistently inhabits the transplantation site, which functions as a significant feeding area. This phenomenon can be attributed to the presence of diverse marine organisms including sponges, molluscs, and algae within the transplantation site. Consequently, numerous fish species reliant on these organisms for sustenance and other essential requirements are known to establish their habitats within this area. At the transplantation site, initial sightings included fish species from the family Labridae, such as *Thalassoma lunare* and *Halichoeres scapularis*. Labrids are invertebrate-eating fish species that are often found looking for food in concrete cracks or substrate surfaces. Similarly, herbivorous fish from the family Acanthuridae were observed throughout the transplantation site, exhibiting greater abundance during the initial stages of transplantation. These fish primarily feed on algae present within the site and are frequently encountered close to transplantation sites. Acanthuridae contributes to a certain extent in mitigating algae proliferation, thus aiding in the facilitation of coral growth during the initial stages of transplantation. The abundance of herbivorous fish is a good indicator of a healthy reef (Abelson et al. 2016). Pomacentridae was another major family that had a high abundance in the transplantation site. Fishes of family Pomacentridae including *Chromis viridis* and *Dascyllus aruanus*, were predominantly observed following the establishment of branching corals such as *Acropora*. This trend can be attributed to the feeding behaviour of these fish, which utilize the water column for foraging, and seek refuge within coral reefs to evade attacks from carnivorous fish (Kuiter & Tonozuka 2001). The families Chaetodontidae, Balistidae, and Scorpaenidae were observed during the later stage of transplantation. The live coral cover condition at each age of transplantation shows the differences in the reef fish species community (Ulfah et al. 2020). This fish aggregation could also attract visitors and researchers to this location and highlight the importance of artificial reefs for marine restoration.

Coral transplantation tool can also be applied for underwater tourism while promoting a science-based coral reef management option for coral restoration (Edwards & Clark 1999). Transplantation of corals are also suggested to provide alternative livelihood (Young et al. 2012) for the fishing community (Bowden-Kerby 2003) as they depend on this site for the collection of live bait for tuna fishing and spearfishing during the southwest monsoon in this atoll. The transplantation site can, directly and indirectly, reduce the pressure on fragile natural coral growth through substitute aquaculture, community-based ecotourism, and increased environmental education, awareness and community stakeholder associations. The technique described in the article can easily be transferred to local communities, and imparting training to the fishers can be adopted using local expertise. Therefore, it is suggested that the development of coral transplantation sites can influence ecosystem services and indirectly benefit the livelihood of the fishing community. Therefore, the implementation of the coral restoration programme in all the islands of Lakshadweep is recommended for improved ecosystem services and enhanced livelihood opportunities.

CONCLUSION

The coral transplantation on artificial substrates in the shallow lagoon off the Lakshadweep archipelago has shown promising results in establishing a coral nursery, promoting coral growth and providing a habitat for marine life. The establishment of a coral nursery has led to increased fish aggregation, contributing to enhanced biodiversity and ecosystem resilience. These findings highlight the potential of this restoration technique as a valuable tool in reef conservation efforts for vulnerable ecosystems such as those found in the Lakshadweep archipelago. However, the use of artificial substrates instead of transplanting corals directly onto degraded reefs may present certain limitations, such as differences in the ecological interactions between the artificial and natural environments, potential changes in the structural complexity, and the long-term stability and durability of the artificial substrates. Additionally, the artificial substrates may not fully replicate the conditions necessary for the growth and survival of certain coral species. Continued monitoring and research are essential to assess the long-term effectiveness and sustainability of this approach.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25843–25855

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8485.16.9.25843-25855

#8485 | Received 19 April 2023 | Final received 22 July 2024 | Finally accepted 10 September 2024

OPEN ACCESS

ARTICLE

Taxonomic review of genus *Gazalina* Walker (Thaumetopoeinae: Notodontidae: Lepidoptera) from India

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Abstract: The taxonomic position of the genus *Gazalina* Walker remained ambiguous and it continuously reshuffled its position in the family Notodontidae and subfamily Lymantriinae of family Erebidae. The present study has been carried out to elucidate its taxonomic position in accordance with the morphological, molecular, larval, and behavioural characteristics of its species. A detailed account of two species namely *Gazalina chrysolopha* (Kollar) and *Gazalina apsara* (Moore), the type species of this genus, has also been given. The CoI sequence of *Gazalina chrysolopha* (MH795522) and *Gazalina apsara* (MH790288) from the present study were compared with the available reference sequences in Genbank by using BLAST. Its placement under the subfamily Thaumetopoeinae of the family Notodontidae has been justified.

Keywords: *Apsara, Chrysolopha,* diagnosis, genitalia, Lymantriidae, phylogenetic, processionary moths, sequence analysis, taxonomic, wing venation.

Punjabi: ਸਾਰ: ਗਜ਼ਾਲੀਨਾ ਵਾਕਰ ਦੀ ਵਰਗੀਕਰਨ ਸਥਿਤੀ ਅਸਪਸ਼ਟ ਰਹੀ ਅਤੇ ਇਸਨੇ ਆਪਣੀ ਸਥਿਤੀ ਵਿੱਚ ਲਗਾਤਾਰ ਪਰਿਵਾਰ ਨੋਟੋਡੋਨਟੀਡੇ ਅਤੇ ਪਰਿਵਾਰ ਇਰੇਬਿਡੇ ਦੇ ਉਪ-ਪਰਿਵਾਰ ਲੀਮੰਨਟਰੀਨੀ ਵਿੱਚ ਫੇਰਬਦਲ ਕੀਤਾ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਇਸ ਦੀਆਂ ਸਪੀਸੀਜ਼ ਦੀਆਂ ਰੂਪ ਵਿਗਿਆਨਿਕ, ਅਣੂ, ਲਾਰਵਲ ਅਤੇ ਵਿਹਾਰਕ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ ਦੇ ਅਨੁਸਾਰ ਇਸ ਦੇ ਵਰਗੀਕਰਨ ਦੀ ਸਥਿਤੀ ਨੂੰ ਸਪੱਸ਼ਟ ਕਰਨ ਲਈ ਕੀਤਾ ਗਿਆ ਹੈ। ਦੋ ਕਿਸਮਾਂ ਅਰਥਾਤ ਗਜ਼ਾਲੀਨਾ ਕ੍ਰਾਈਸੋਲੋਫਾ (ਕੋਲਰ) ਅਤੇ ਗਜ਼ਾਲੀਨਾ ਅਪਸਰਾ (ਮੂਰ), ਜੋ ਕਿ ਇਸ ਜੀਨਸ ਦੀ ਕਿਸਮ ਸਪੀਸੀਜ਼ ਹੈ, ਦਾ ਵਿਸਤ੍ਰਿਤ ਬਿਰਤਾਂਤ ਕੀਤਾ ਗਿਆ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਤੋਂ ਗਜ਼ਾਲੀਨਾ ਕ੍ਰਾਈਸੋਲੋਫਾ (ਐਮ.ਐਚ795522) ਅਤੇ ਗਜ਼ਾਲੀਨਾ ਅਪਸਰਾ (ਐਮ.ਐਚ790288) ਦੇ ਸੀਓਆਈ ਕ੍ਰਮ ਦੀ ਤੁਲਨਾ ਜੀਨ ਬੈਂਕ ਵਿੱਚ ਉਪਲਬਧ ਸੰਦਰਭ ਕ੍ਰਮ ਨਾਲ ਧਮਾਕਾ ਵਿਧੀ ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਕੀਤੀ ਗਈ ਹੈ। ਇਸਦੀ ਪਲੇਸਮੈਂਟ ਨੂੰ ਨੋਟੋਡੋਨਟੀਡੇ ਪਰਿਵਾਰ ਦੇ ਉਪ-ਪਰਿਵਾਰ ਥੌਮੇਟੋਪੋਈਨੇ ਅਧੀਨ ਜਾਇਜ਼ ਠਹਿਰਾਇਆ ਗਿਆ ਹੈ।

Editor: Jatishwor Singh Irungbam, Centrum ALGATECH, Třeboň, Česká Republika.

Date of publication: 26 September 2024 (online & print)

Citation: Kaleka, A.S., G.P.K. Bali & N. Kaur (2024). Taxonomic review of genus *Gazalina* Walker (Thaumetopoeinae: Notodontidae: Lepidoptera) from India. *Journal of Threatened Taxa* 16(9): 25843–25855. https://doi.org/10.11609/jott.8485.16.9.25843-25855

Funding: University Grants Commission, New Delhi (MANF Scheme); F1-17.1/2O13-14/MANF/2013-14-SIK-27073 Dated: 6-02-2014.

Competing interests: The authors declare no competing interests.

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Author contributions: Study design and article drafting—ASK & GPKB; molecular analysis—GPKB; Lab & field work—ASK, GPKB & NK.

Acknowledgements: The authors are thankful to the authorities of forest departments of Himachal Pradesh, and Jammu & Kashmir for their support during field surveys for sample collection.

INTRODUCTION

Walker (1865) established the genus *Gazalina* Walker 1865 with *Gazalina venosata* Walker as its type species from northern India under the family Liparidae. Kirby (1892) followed the same nomenclature. Hampson (1892) reported three species namely *G. apsara* (Moore, 1859), *G. chrysolopha* (Kollar, 1844) and *transversa* Moore, 1879 from India. While dealing with Eastern and Australian moths, Swinhoe (1900) described a new species, *Gazalina intermixta*, under this family. Grunberg (1912) shifted this genus to the family Notodontidae. Later, Swinhoe (1922) revised various genera referable to the family Liparidae and discussed four species—*G. apsara* Moore (formerly *Venosata* Walker), *G. chrysolopha* (Kollar), *G. intermixta* Swinhoe, and *G. transversa* Moore—under the family Liparidae. Kiriakoff (1968) further placed *Gazalina* in the family Thaumetopoeidae, a distinct family. Further, he studied the male genitalia of *apsara* Moore, the type species of this genus, and diagnosed the absence of gnathos, a diagnostic feature of the family Notodontidae (Kiriakoff 1970). Cai (1979) treated it under the family Notodontidae and discussed three species *G. apsara* Moore, *G. chrysolopha* (Kollar), and *G. transversa* Moore in 'Economic Insect Fauna of China'. Miller (1991) again doubted the placement of the genus *Gazalina* Walker. Sugi (1994) described three species—*G. apsara* (Moore), *G. chrysolopha* (Kollar), *G. transversa* Moore—from Nepal under the family Notodontidae. Raman (1998) studied the outbreak of *G. chrsolopha* (Kollar) accounting for it under family Notodontidae. Wu (2002) described four species—*G. apsara* (Moore), *G. chrysolopha* (Kollar), *G. transversa* Moore, and *G. putrificata* Sugi—from China under Notodontidae. Srivastava & Mukhopadhyay (2006) studied the life cycle and bio-ecology of *G. chrsolopha* (Kollar) accounting for it under the family Notodontidae. Sanyal et al. (2011) studied *Gazalina apsara* (Moore) as an indicator species from the Himalaya under the family Notodontidae. Kocak & Kemal (2016) enlisted it under the family Thaumetopoeidae. While dealing with molecular phylogeny, Kobayashi & Nonaka (2016) also discussed the genus *Gazalina* Walker in the subfamily Thaeumatopoeinae. Uniyal et al. (2016) catalogued the genus *Gazalina* Walker under the subfamily Thaumetopoeinae of the family Notodontidae from Gangotri landscape, Uttarakhand, India. Shah et al. (2017) enlisted the genus *Gazalina* Walker under the subfamily Lymantriinae. While studying the medical complications caused by different species of *Gazalina* Walker, Manandhar *et al.* (2018) discussed it under the family Notodontidae. Bhattacharyya et al. (2019) enlisted the genus *Gazalina* Walker under the subfamily Thaumetopoeinae of the family Notodontidae from Neora Valley, West Bengal, India. Recently, Chettri et al. (2021) enlisted *Gazalina chrysolopha* Kollar and *G. transversa* Moore from Sikkim and placed these species under the family Notodontidae. Gurung et al. (2021) described *Gazalina chrysolopha* Kollar as a major pest consuming foliage of trees especially *Alnus nepalensis* D.Don, *Rhododendron arborium* Smith, and other fodder plants; but the taxonomic position was not clear. Khanal & Shrestha (2022) studied the diversity, distribution, and medical significance of *Gazalina* species from Nepal. The morphological characters including external as well as internal genitalic features, behavioural characters, and molecular analysis of two species namely *Gazalina chrysolopha* (Kollar) and *Gazalina apsara* (Moore), the type species of this genus have been compiled in detail to elucidate the position of genus *Gazalina* Walker.

MATERIAL AND METHODS

The adult moths were collected from different localities of Himachal Pradesh and Jammu & Kashmir (India) by using light traps equipped with a 160w mercury bulb and vertical white screen and their behaviour was observed during the collection period. The external morphological characters were studied as such from the preserved specimens. The permanent slides were prepared to study the wing venation. The male and female moths were dissected to examine the external and internal genitalic features and the terminology for naming various genitalic parts given by Klots (1970) was followed. The DNA was extracted from the preserved moth samples using the phenol-chloroform-isoamyl alcohol method given by Sambrook et al. (1989). The mitochondrial cytochrome oxidase subunit I (COI) gene was amplified using the universal primer pair under standard PCR conditions (Folmer et al. 1994).

Forward –
(LCO1490: 5'-GGTCAACAAATCATAAAGATATTGG-3')
Reverse –
(HC02198: 5'-TAAACTTCAGGGTGACCAAAAAATCA-3')

The purified PCR products were sequenced at Amnion Biosciences Pvt. Ltd, Sequencing Dept, #112, Doddenna industrial area, 16A Cross, Vishwaneedam post (D), Bangalore, Karnataka 560091, India.

The sequences were submitted to Genbank for accession numbers as *Gazalina chrysolopha* MH795522 & *Gazalina apsara* MH790288. Multiple sequence alignment was performed with CLUSTAL x software and a phylogenetic tree was constructed using the maximum likelihood method (ML) in MEGA (version 6) software. The confidence level of each branch was evaluated through bootstrap analysis with 1000 replicates (Tamura et al. 2021).

SYSTEMATIC ACCOUNT

Genus *Gazalina* Walker 1865

Walker, 1865, List *Spec. Lepid. Insects Colln. Brit. Mus*., 32: 298; Swinhoe, 1922, *Ann. Mag. Nat. Hist*., 9(9)10 (58): 472.

Oligoclona Felder, 1874, *Reis. Freg. Nov.,* 2: pl. 94.

Ansonia Kiriakoff, 1967, *in Wytsman*, *Genera Insect*., 217(B): 57.

Type Species: *Gazalina apsara* (Moore) = *venosata* Walker

Distribution: India; China.

Diagnosis: Medium-sized moths, usually white in colouration. Labial palpi extremely minute. Antennae bipectinate in males, serrate in females, and pectinations are reduced at the distal end. Forewing with ground colour white, without any distinct markings; discal cell more than half the length of the wing, closed; 1A+2A basally forked; 3A absent; Cu_1 and M_3 from lower angle of cell; M_2 from lower angle of cell; M_1 just above the middle of discocellulars; R_5 from the upper angle of cell; R_4-R_2 stalked from the upper angle of cell; R_1 well before upper angle of cell; Sc from the base of wing not reaching the apex. Hindwing without any distinct markings; discal cell more than half the length of wing, closed; Cu_1 and M_3 from near lower angle of cell; M_2 from near middle of discocellulars; M_1 and Rs stalked from upper angle of cell. Legs dressed with white scales; fore-tibia with an epiphysis, mid-tibia with one pair of tibial spurs; hind-tibia with two pairs of tibial spurs. Abdomen slender, banded with black and white scales; distal segments fringed with long white scales in males, distinct golden anal tuft in females. Male genitalia with uncus of moderate size, gnathos represented by conjoined, triangular processes; saccus absent; juxta well developed; valva simple, basal half broad, distal half narrow; aedeagus of moderate size, vesica without any distinct cornuti. Female with corpus bursae globular; signum absent; ductus bursae narrow, medially constricted; apophysis of moderate length, both pairs with equal length with dilated tips; papilla analis prominent, setosed; pseudo-papillae indistinct; sterigmatic plate well developed.

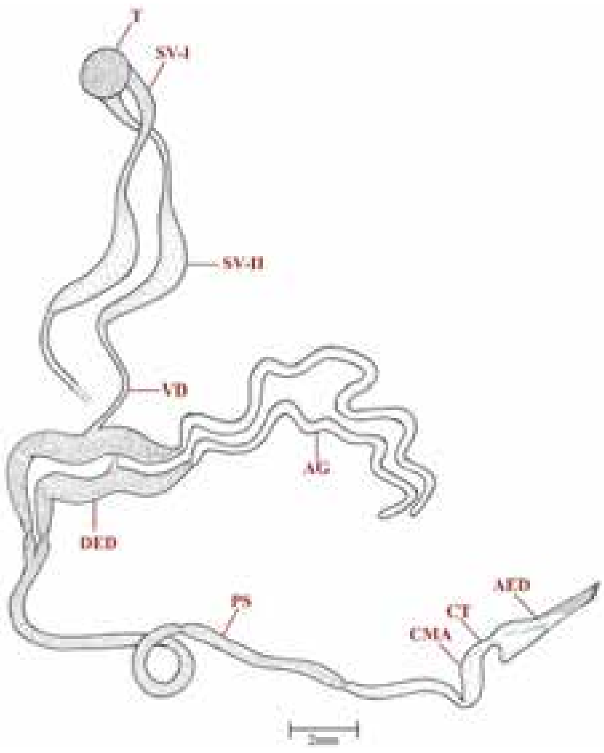

Figure 1. Internal male genitalic organs of *Gazalina chrysolopha* (Kollar). AG—Accessory gland | AED—Aedeagus | CMA—Constrictor muscular area | CT—Cuticular tube | DED—Ductus ejaculatorius duplex | PS—Primary simplex | SV-I—Seminal vesicle—I | SV-II—Seminal vesicle—II | T—Testis | VD—Vas deferens.

Gazalina chrysolopha (Kollar, 1844)

Liparis chrysolopha Kollar, 1844, *Hügel Kaschmir und Das Reich der Siek*, 4: 470.

Gazalina chrysolopha Kollar: Hampson, 1892, *MothsIndia*, 1: 469; Swinhoe, 1922, *Ann. Mag. Nat. Hist.,* (9) 10 (58): 472; Wu, 1999, *Fauna Sinica*, 31: 832.

Dasychira antica Walker, 1855, *List Spec. Lepid. Insects Colln. Brit. Mus*., 4: 867; Swinhoe, 1922, *Ann. Mag. Nat. Hist.,* (9) 10 (58):472.

Oligoclona chordigera Felder, 1874, *Reis. Freg. Nov*. 2 (4): 94.

Type Locality: Kashmir, India

Wing Expanse: Male: 40–46 mm; Female: 52–60 mm.

Body Length: Male: 14–19 mm; Female: 18–21 mm.

Diagnosis: Forewing whitish, veins distinct with black scales beyond the medial oblique line; vein M_1 not stalked with radial veins. Male genitalia with uncus notched distally; juxta with distal end notched; distal end of valva rounded and produced. Internal male genitalic organs with testis rounded; seminal vesicle-I originating from testis separately; seminal vesicle-II sickle-shaped; ductus ejaculatorius duplex curled; accessory glands free distally; primary simplex divided into three sections.

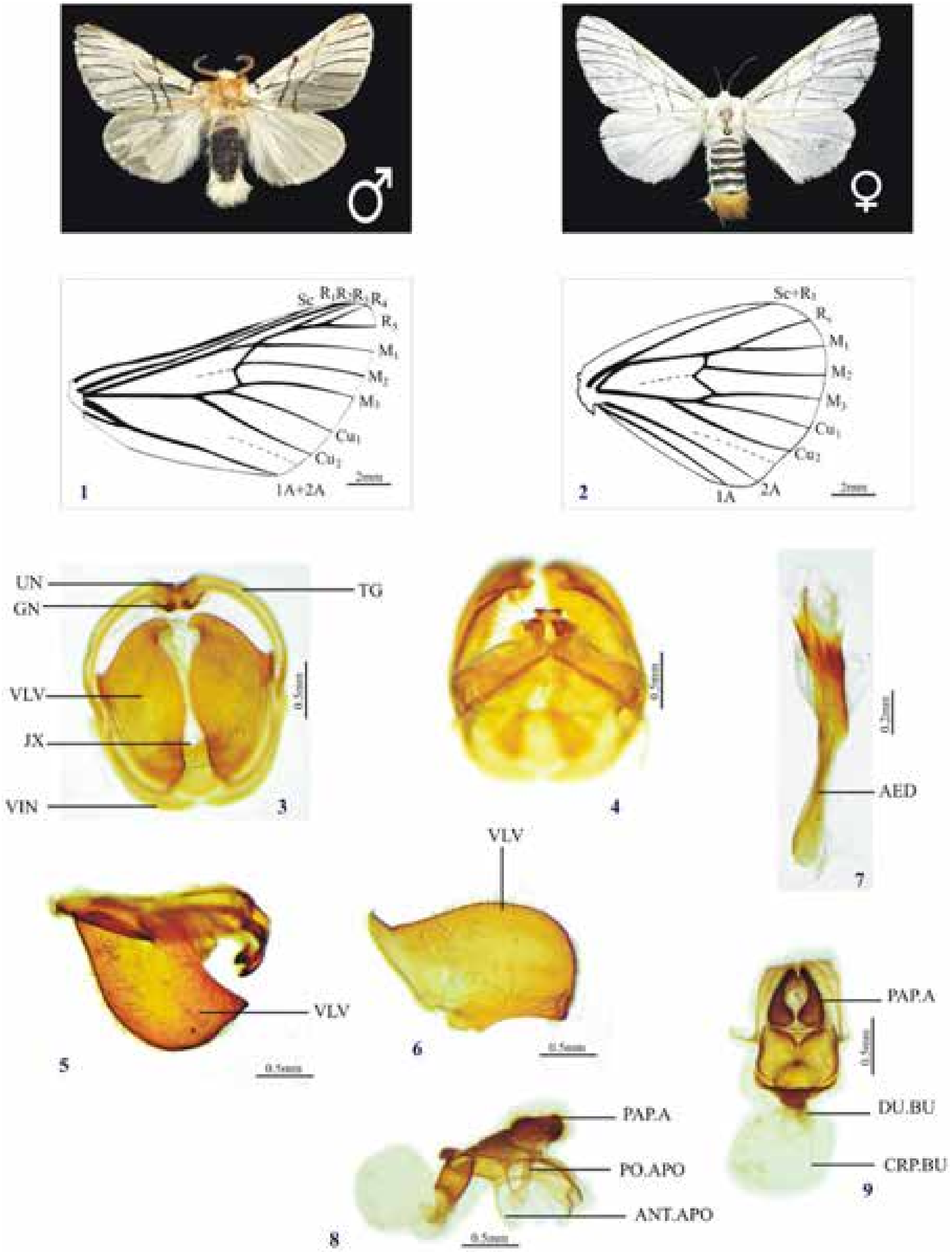

Image 1–8. *Gazalina chrysolopha* (Kollar): 1—forewing | 2—hindwing | 3—male genitalia – ventral view | 4—dorsal view | 5—lateral view | 6—valva | 7—aedeagus | 8—female genitalia. External Genitalia (Image 1–18): 1A—First anal vein | 2A—Second anal vein | AED—Aedeagus | ANT.APO—Anterior Apophysis | CRP.BU—Corpus bursae | CU1—First cubital vein | CU2—Second cubital vein | DU.BU—Ductus bursae | GN—Gnathos | JX—Juxta | M1—First median vein | M2—Second median vein | M3—Third median vein | PAP.A—Papilla analis | PO.APO—Posterior Apophysis | R1—First radial vein | R2—Second radial vein | R3—Third radial vein | R4—Fourth radial vein | R5—Fifth radial vein | Sc—Subcosta | Sc+R1—Subcosta + First radial vein | TG—Tegumen | UN—Uncus | VIN—Vinculum | VLV—Valva.

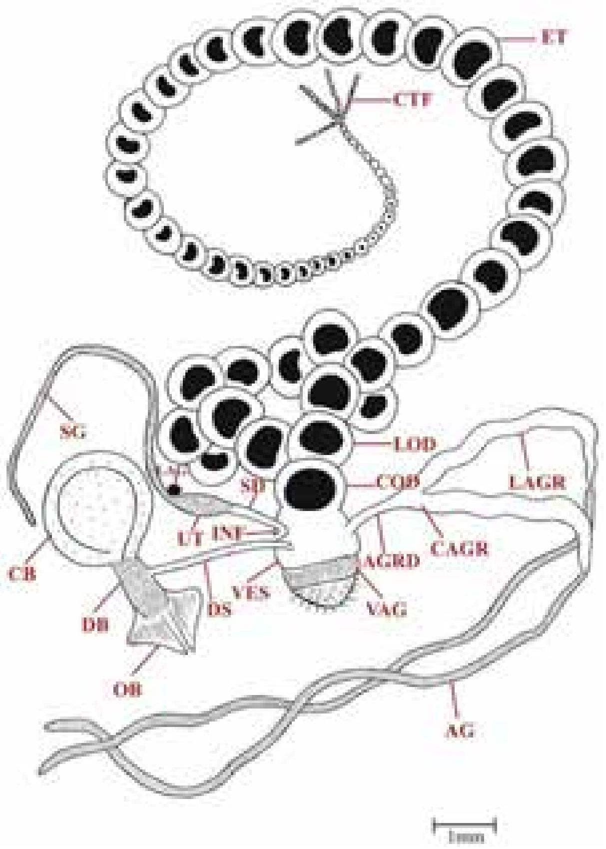

Figure 2. Internal female genitalic organs of *Gazalina chrysolopha* (Kollar). AG—Accessory gland | AGRD—Accessory gland reservoir duct | CAGR—Common accessory gland reservoir | CB—Corpus bursae | CTF—Common terminal filament | DB—Ductus bursae | DS—Ductus seminalis | ET—Egg tube | INF—Infundibulum | LAG—Lagena | LAGR—Lateral accessory gland reservoir | LOD—Lateral oviduct | OB—Ostium bursae | SD—Spermathecal duct | SG—Spermathecal gland | UT—Utriculus | VAG—Vagina | VES—Vestibulum.

Table 1. Morphometry of internal male genitalic organs of *Gazalina chrysolopha* (Kollar).

	Organ	Intraspecific range in length (mm)	Intraspecific range in width (mm)
1.	Testis	0.68–0.71	0.68–0.71
2.	Seminal vesicle- I	1.69–1.72	0.19–0.21
3.	Seminal vesicle- II	2.84–2.86	0.40–0.43
4.	Vasa deferentia	2.28–2.31	0.09–0.11
5.	Ductus ejaculatorius duplex	3.44–3.46	0.38–0.41
6.	Accessory gland	7.24–7.26	0.14–0.16
7.	Primary simplex	10.64–10.66	0.16–0.18
8.	Constrictor muscular area	1.09–1.11	0.25–0.28
9.	Cuticular tube	0.19–0.21	0.10–0.13

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8.	Constrictor muscular area	1.09–1.11	0.25–0.28
9.	Cuticular tube	0.19–0.21	0.10–0.13

Internal female genitalic organs with eggs rounded, covered by a thin translucent sheath; accessory gland ducts long.

Description: Head with vertex and frons clothed with white scales. Labial palpi fringed with black scales. Antennae with scape covered with white scales, flagellum black. Thorax, collar, and tegula dressed with yellowish-white scales; underside white. Legs dressed with white scales. Abdomen slender, furnished with black scales with white bands; distal segments fringed with long white scales; distinct golden anal tuft in females. Hindwing white. Forewing (Image 1) with Cu_2 beyond two-thirds of cell; Cu_1 from well before lower angle of cell; M_3 from lower angle of cell; M_2 from middle of discocellulars; M_1 from upper angle of cell; R_5-R_3 well stalked from upper angle of cell; R_2 absent; R_1 beyond three-fourth of cell; Sc from base of wing, not reaching to apex. Hindwing (Image 2) with Cu_2 from well beyond two-thirds of the cell; Cu_1 from well before the lower angle of the cell; M_3 from the lower angle of the cell; M_2 from well above the middle of discocellulars; M_1 and Rs well stalked from upper angle of cell; Sc+R_1 from base of wing anastomosing at one-third of cell reaching till apex of wing.

Male genitalia (Image 3–7): Uncus of moderate size, basal half broad, distal end notched giving bifid appearance, setosed and more sclerotized; gnathos represented by well-sclerotized, triangular, setosed paired projections; tegumen U-shaped, moderately sclerotized, both arms of equal width, longer than vinculum; vinculum V-shaped, weakly sclerotized, without any distinct saccus; juxta moderately sclerotized, medially dilated on lateral sides, distal end notched. Valva simple, broad, rounded; moderately sclerotized; setosed; distal end produced on costal side with round, setosed tip. Aedeagus long, narrow; proximal half flap-

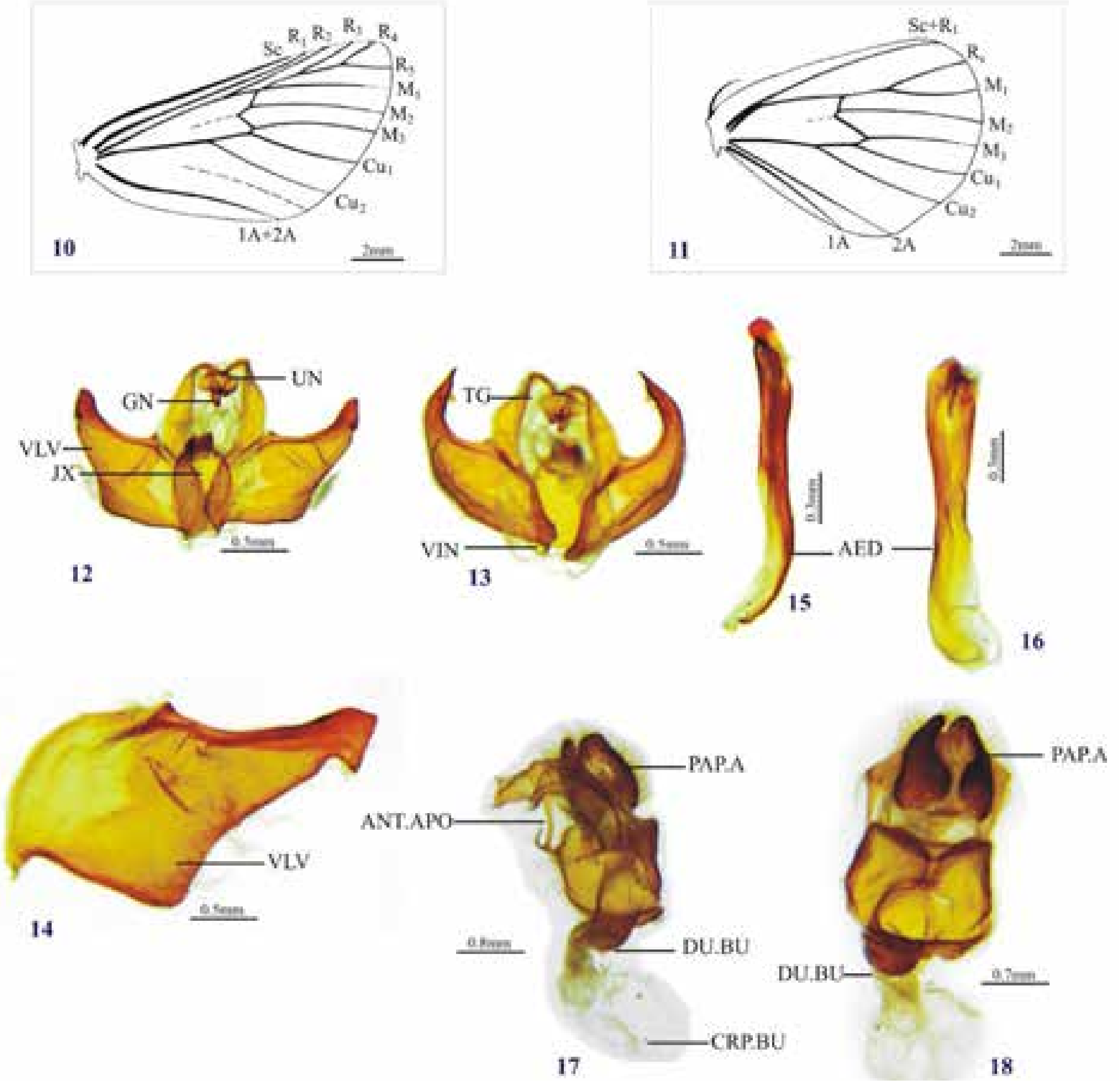

Image 10–18. *Gazalina apsara* (Moore): 10—forewing | 11—hindwing | 12—male genitalia – ventral view | 13—Dorsal view | 14—valva | 15–16—Aedeagus | 17–18—female genitalia. 1A—First anal vein | 2A—Second anal vein | AED—Aedeagus | ANT.APO—Anterior Apophysis | CRP.BU—Corpus bursae | CU1—First cubital vein | CU2—Second cubital vein | DU.BU—Ductus bursae | GN—Gnathos | JX—Juxta | M1—First median vein | M2—Second median vein | M3—Third median vein | PAP.A—Papilla analis | PO.APO—Posterior Apophysis | R1—First radial vein | R2—Second radial vein | R3—Third radial vein | R4—Fourth radial vein | R5—Fifth radial vein | Sc—Subcosta | Sc+R1—Subcosta + First radial vein | TG—Tegumen | UN—Uncus | VIN—Vinculum | VLV—Valva.

like; ductus ejaculatorius entering under this flap; distal half tubular; distal end produced with an extension having serrations; walls of aedeagus near distal end with minute denticles; vesica without any distinct armature. The internal male genitalic (Image 1) attributes along with the morphometric analysis have been studied in detail (Table 1).

Female genitalia (Image 8–9): Corpus bursae large, circular, membranous; signum absent; ductus bursae membranous, narrow, entering into well sclerotized oblong antrum; ductus seminalis originating from the middle of ductus bursae; apophysis of moderate length, semi-sclerotized, posterior apophysis slightly longer than anterior apophysis, both pairs with prominently dilated apices; papilla analis ovoid, well setosed with short and long setae; sterigmatic plate rectangular, notched medially, well sclerotized. The internal genitalic (Image 2) details are tabulated in Table 2.

Material examined: India: Himachal Pradesh: Baijnath, 998m, 32.052°N & 76.648°E, 09.x.2013, 1♂; Baila, 1,520 m, 31.056°N & 76.831°E, 04.vi.2014, 1♂; Basantpur, 2,148 m, 31.208°N & 77.174°E, 09.vii.2013, 1♂; 10.vii.2013, 7♂♂, 8♀♀; Dalhousie, 1,970 m, 32.587°N & 75.971°E, 07.vi.2013, 1♂, 2♀♀; Dilman, 1,552 m, 30.824°N & 77.134°E, 11.viii.2013, 12♀♀; 03.ix.2015, 4♂♂, 2♀♀; Fagu, 2,533 m, 31.085°N & 77.300°E, 04.ix.2016, 4♂♂, 3♀♀; Habban, 2,063 m, 30.915°N & 77.325°E, 07.vii.2014, 1♀; 07.ix.2015, 4♂♂, 4♀♀; Hadsar, 2,300 m, 32. 455°N & 76.613°E , 11.vi.2013, 1♂; Khajjiar, 1,920 m, 32.555°N & 76.065°E, 08.vi.2013, 1♂; Kharouth, 1,300 m, 32.065°N & 76.450°E, 09.vi.2017, 5♂♂, 3♀♀; Naina Tikkar, 1,552 m, 30.804°N & 77.119°E, 01.09.2015, 4♂♂, 4♀♀; Narkanda, 2,708 m, 31.257°N & 77.460°E, 17.vi.2013, 1♂; Nauni, 1,275 m, 30.860°N & 77.173°E, 07.viii.2013, 1♀; Sabathu, 1,265 m, 30.975°N & 76.990°E, 09.viii.2013, 1♂; 15.vii.2016, 4♂♂, 2♀♀; Serighat, 1,520 m, 31.050°N & 77.069°E, 10.viii.2013, 54♂♂, 10♀♀; 26.vi.2017, 5♂♂, 5♀♀; Theog, 1,965 m, 31.118°N & 77.359°E, 20.vi.2014, 1♂, 1♀; 08.ix.2016, 4♂♂, 3♀♀; Jammu & Kashmir: Batote, 1,560 m, 33.121°N & 75.32°E,11.vii.2014, 1♀; Hote, 400 m, 32.825°N & 75.641°E, 04.ix.2013, 2♀♀, Lamberi, 336 m, 33.130°N & 74.260°E, 11.ix.2013, 1♂, 2♀♀. Coll.: Gagan Bali & Navkiran Kaur.

Distribution: India: Himachal Pradesh, Jammu & Kashmir, Sikkim, West Bengal; China.

Comments: Kollar (1844) originally described this species under the genus *Liparis* Ochsenheimer from Kashmir. Hampson (1892) transferred it to the present genus. Haruta (1993) collected *crysolopha* Kollar from Godawari (1,600 m) southeastern Kathmandu. During another expedition, the species was recorded from Dagchu (2,880 m) and Jin (2,340 m) in eastern Nepal (Haruta, 1994). Shah et al. (2017) reported this species from West Bengal. Chettri et al. (2021) enlisted *Gazalina chrysolopha* Kollar from the Tadong region of Sikkim under the family Notodontidae. Dewan et al. (2022) recorded *chrysolopha* Kollar in the Trans Himalayan region of western Nepal and placed it under the family Notodontidae.

Gazalina apsara (Moore, 1859)

Dasychira apsara Moore, 1859, *Cat. Lepid. Ins. Mus. Nat.*, 2: 341.

Gazalina apsara Moore: Hampson, 1892, *Moths India*, 1: 468-469; Swinhoe, 1922, *Ann. Mag. Nat. Hist.,* (9) 10 (58): 472; Wu, 1999, *Fauna Sinica*, 31: 830–832.

Gazalina venosata Walker, 1865, *List. Spec. Lepid. Insects Colln. Brit. Mus*., 32: 398; Swinhoe, 1922, *Ann. Mag. Nat. Hist.* (9) 10 (58): 472.

Oligoclona nervosa Felder and Rogenhofer, 1875; *Reis. Freg. Nov.*, 2(4): 95.

Type Locality: Northern India.

Wing Expanse: Male: 40–42 mm; Female: 54 mm.

Body Length: Male: 14–17 mm; Female: 19–21 mm.

Diagnosis: Forewing whitish, veins without black scales; vein M1 stalked with radial veins from the upper angle of the cell. Male genitalia with uncus having a curved hook-like distal end; juxta with distal end curved; distal end of valva beaked. Internal male genitalic organs with testis ellipsoidal; seminal vesicle-I originating from the testis in the fused state; seminal vesicle-II spindle-shaped; ductus ejaculatorius duplex comma-shaped; accessory glands fused distally; primary simplex divided into four sections. Internal female genitalic organs with eggs are rectangular, without any covering; accessory gland ducts are small.

Description: Head with vertex and frons clothed with white scales. Labial palpi fringed with black scales. Antennae with scape covered with white scales, flagellum black. Thorax, collar, and tegula dressed with yellowish-white scales; underside white. Legs dressed with white scales. Abdomen slender, furnished with black scales with white bands; distal segments fringed with long white scales; distinct golden anal tuft in females. Hindwing white. Forewing (Image 10) with Cu_2 from beyond two-thirds of cell; Cu_1 well before lower angle of cell; M_3 from lower angle of cell; M_2 just above middle of discocellulars; M_1, R_5-R_3 stalked from upper angle of cell; R_2 absent; R_1 well before upper angle of cell; Sc from base of wing, not reaching apex. Hindwing (Image 11) with Cu_2 from well before two-thirds of the

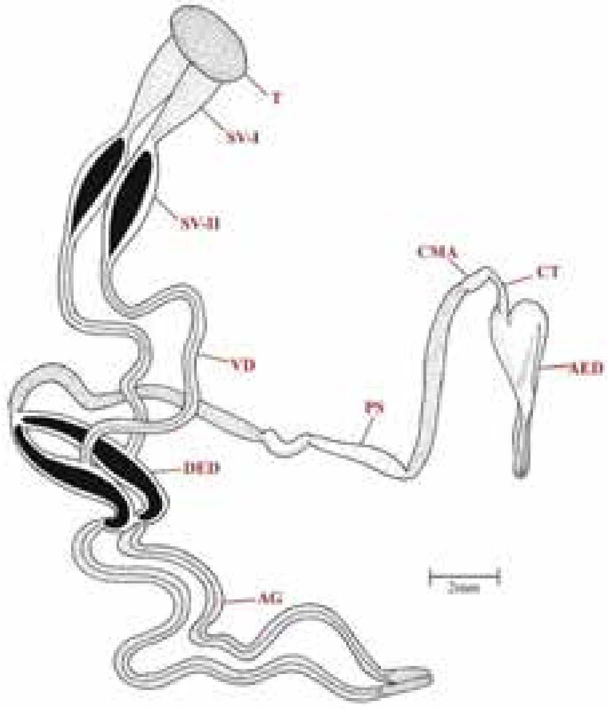

Figure 3. Internal male genitalic organs of *Gazalina apsara* (Moore). AG—Accessory gland | AED—Aedeagus | CMA—Constrictor muscular area | CT—Cuticular tube | DED—Ductus ejaculatorius duplex | PS—Primary simplex | SV-I—Seminal vesicle—I | SV-II—Seminal vesicle—II | T—Testis | VD—Vas deferens .

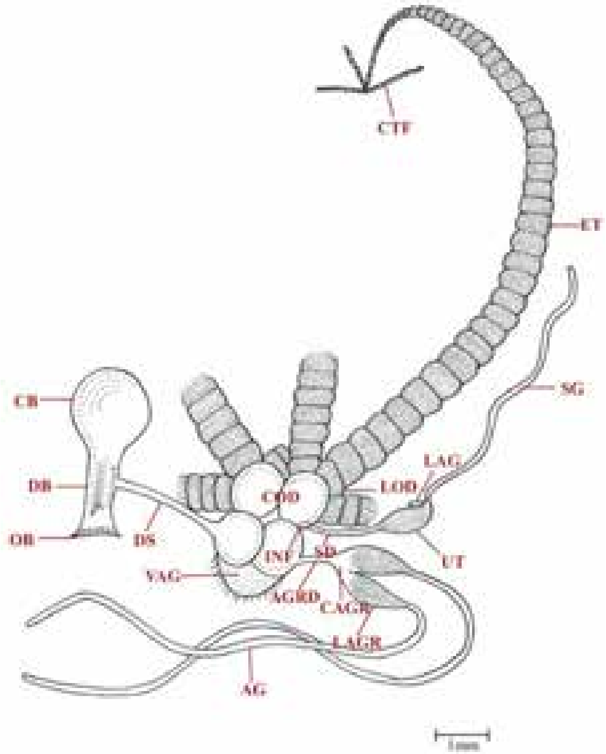

Figure 4. Internal female genitalic organs of *Gazalina apsara* (Moore). AG—Accessory gland | AGRD—Accessory gland reservoir duct | CAGR—Common accessory gland reservoir | CB—Corpus bursae | CTF—Common terminal filament | DB—Ductus bursae | DS—Ductus seminalis | ET—Egg tube | INF—Infundibulum | LAG—Lagena | LAGR—Lateral accessory gland reservoir | LOD—Lateral oviduct | OB—Ostium bursae | SD—Spermathecal duct | SG—Spermathecal gland | UT—Utriculus | VAG—Vagina | VES—Vestibulum.

lower angle of the cell; Cu_1 from well before the lower angle of the cell; M_3 from lower angle of cell; M_2 from well above middle of discocellulars; M_1 and Rs well stalked from upper angle of cell; $Sc+R_1$ from base of wing anastomosing with cell well before its middle.

Male genitalia (Image 12–16): Uncus small, basal half oval, distal half narrow, curved, hook-like, dorsally setosed with short setae, well sclerotized; gnathos represented by small, conjoined triangular processes, setosed with short setae; tegumen moderately sclerotized, both arms dilated laterally beyond middle towards vinculum; vinculum moderately sclerotized, narrow, without distinct saccus; juxta large, oblong, dome-shaped, well sclerotized, distal end having a well sclerotized nearly squarish, curved projection. Valva simple, well sclerotized, basal half broad, saccular margin produced, setosed, distal half narrow, distal end produced on dorsal margin giving weakly bifid appearance. Aedeagus of moderate length, well sclerotized; proximal half flap-like; distal end bifid, one wedge-shaped and other with prominent serrations on inner margins; vesica without any distinct cornuti. The internal male genitalic (Figure 3) attributes along with the morphometric analysis have been summarized in Table 3.

Female genitalia (Image 17–18): Corpus bursae globular, membranous; signum absent; ductus bursae membranous, narrow, medially constricted; ductus seminalis originating from the middle of ductus bursae; antrum well sclerotized, nearly squarish; apophysis of moderate length, almost of equal length, prominently dilated at distal end; papilla analis prominent, broad, well setosed with long and short setae; pseudo-papillae not distinct; sterigmatic plate large, prominently developed. The internal genitalic (Figure 4) details are given in the tabulated form (Table 4).

Material examined: India: Himachal Pradesh: Basantpur, 2,148 m, 31.208°N & 77.174°E, 10.vii.2013, 1♂; Cheog, 2,086 m, 31.068°N & 77.312°E, 05.ix.2016, 4♂♂, 3♀♀; Fagu, 2,533 m, 31.085°N & 77.300°E, 03.ix.2016, 3♂♂, 4♀♀; Ghoond, 2,086 m, 31.075°N & 77.425°E, 01.ix.2016, 4♂♂, 3♀♀; Jhumar, 2,133 m, 32.548°N & 76.146°E,11.vii.2015, 6♂♂, 3♀♀; Mahasu, 2,086 m, 31.100°N & 77.504°E, 30.viii.2016; 3♂♂, 2♀♀; Narkanda, 1,265 m, 31.257°N & 77.460°E, 17.vi.2013, 1♀; Serighat, 1,520 m, 31.050°N & 77.069°E, 11.viii.2013, 1♂, 4♀♀; 25.vi.2017, 4♂♂, 3♀♀; Jammu & Kashmir: Lamberi, 336 m, 33.130°N & 74.260°E, 11.ix.2017, 1♀. Coll.: Gagan Bali & Navkiran Kaur.

Distribution: India: Himachal Pradesh, Jammu & Kashmir, Sikkim; China.

Comments: Moore (1859) described this species under the genus *Dasychira* Stephens from northernIndia. Hampson (1892) shifted it in the present genus and placed *Gazalina venosata* Walker under it. This placement remained stable.

PHYLOGENETIC ANALYSIS

For the construction of the phylogenetic tree related to known species of the genus *Gazalina* Walker, the nucleotide sequences from the present study and the sequences retrieved from the NCBI database were used (Table 1). The nucleotide sequences for the *Gazalina transversa* (Moore) are not available in the NCBI database and thus not included. Multiple sequence alignment was performed with CLUSTAL x software and a phylogenetic tree was constructed using the maximum likelihood method (ML) in MEGA (version 6) software. The high posterior probabilities depicted the confidence of each branch in the phylogenetic tree. A confidence bootstrap value of 100 was observed for *Gazalina chrysolopha* (MH795522.1); *Gazalina chrysolopha* (HQ991385.1) and *Gazalina apsara* (KX863079.1). The phylogenetic tree obtained from the nucleotide sequences belonging to genera of Notodontidae family and subfamily Lymantriinae depicts that the genus *Gazalina* Hübner has a close relationship with the two mentioned taxa and thus has been taxonomically interchanging places between the two.

For strong validation of the molecular analysis, three different phylogenetic trees were constructed using three different genera, i.e., *Phalera* Hübner, *Cerura* Schrank, and *Clostera* Samouelle of the family Notodontidae as out groups. The trees (Figure 5–8) with outgroup as *Phalera bucephala* (MN696381) and *Clostera restitura*

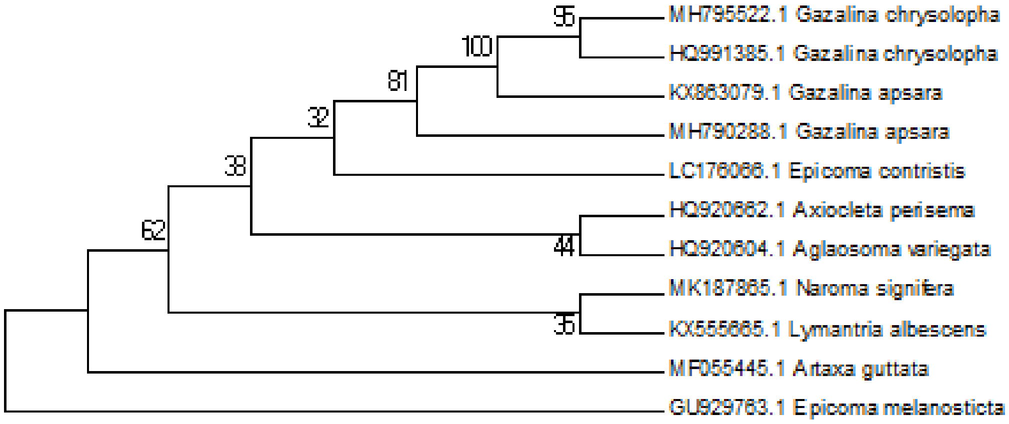

Figure 5. Phylogenetic tree of the sequences studied and sequences retrieved from the NCBI.

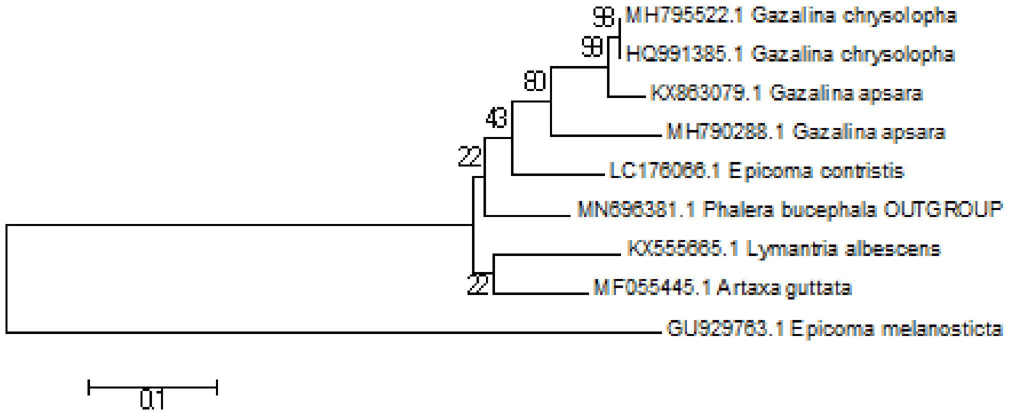

Figure 6. Phylogenetic tree of the sequences studied and sequences retrieved from the NCBI using *Phalera bucephala* as outgroup.

(OR064768) provide a vague analysis as outgroups merge within the clades formed by the other sequences. While the outgroup *Cerura vinula* (MN696387) formed a separate clade with *Epicoma melanosticta* (GU929763) having a significant bootstrap value of 100.

DISCUSSION

Walker (1865) established this genus with *venosata* Walker (*apsara* Moore) as its type species from North-India under family Lymantriidae. The taxonomic position of genus *Gazalina* Walker remained ambiguous due to its continuous reshuffling between subfamily Lymantriidae of family Erebidae and family Notodontidae.

Gardner (1943) recorded secondary setae on the mandibles of *Thaumetopoea cheela* Moore (Thaumetopoeinae) and Godfrey (1984) noted the presence of two distinct mandibular setae in Dudusinae. But in genus *Gazalina* Walker, the mandibular setae are altogether absent (Gardner, 1943). The presence or absence of these setae can also be utilized for stabilizing the systematic position of the present genus. Kiriakoff (1970) considered the subfamily Thaumetopoeinae of processionary moths as a self-standing family, i.e., Thaumetopoeidae. The rank of Thaumetopoeinae, whether it is a subfamily or it receives a family status, had been a long controversy till Miller (1911) concluded to give it the subfamily rank. On the basis of cladistic analysis, he considered it as a homogeneous clade within Notodontidae. Schintlmeister (2008) in his work to recognize Thaumetopoeidae as a distinct family due to its probable link with Lymantriidae. But, he did not give the basis on morphological cladistics or molecular phylogeny to his notion. Zahiri *et al*. (2010) also recognized this subfamily well nested within Notodontidae based on molecular phylogeny. The subfamily Thaumetopoeinae is composed of approximately 100 species in 20 genera occurring in Africa (including Madagascar), the Mediterranean, Europe, Asia, and Australasia in a belt from the Middle East to Taiwan, New Caledonia, and Australia (Schintlmeister, 2013). Kobayashi & Nonaka (2016) analysed the 28S ribosomal RNA genes to infer molecular phylogeny and recognized ten subfamilies in the family Notodontidae. They discussed the genus *Gazalina* Walker under subfamily Thaeumatopoeinae. On the basis of morphological and molecular phylogenetic analyses of the group, Basso (2017) identified three major clades in subfamily Thaumetopoeinae. The first clade includes the Australian genera *Epicoma* Hübner and *Ochrogaster* Stephens and possibly seven other still unexplored genera, for a total of 30 known species. The second clade includes the African genera *Anaphe* Walker, *Epanaphe* Aurivillius, *Hypsoides* Butler, *Paradrallia* Bethune-Baker, and five other genera, for a total of 55 species. The third clade includes the African, Asian, and European genera *Gazalina* Walker and *Thaumetopoea*

Table 3. Morphometry of internal male genitalic organs of *Gazalina apsara* (Moore).

	Organ	Intraspecific range in length (mm)	Intraspecific range in width (mm)
1.	Testis	0.78–0.81	1.34–1.36
2.	Seminal vesicle– I	1.49–1.52	0.54–0.56
3.	Seminal vesicle– II	1.88–1.92	0.53–0.56
4.	Vasa deferentia	3.89–3.91	0.14–0.18
5.	Ductus ejaculatorius duplex	2.93–2.96	0.45–0.48
6.	Accessory gland	8.43–8.45	0.18–0.21
7.	Primary simplex	9.99–10.01	0.20–0.25
8.	Constrictor muscular area	0.48–0.51	0.23–0.26
9.	Cuticular tube	0.59–0.61	0.13–0.16

Table 4. Morphometry of internal female genitalic organs of *Gazalina apsara* (Moore).

	Organ	Intraspecific range in length (mm)	Intraspecific range in width (mm)
1.	Common terminal filament	0.35–0.38	0.09–0.11
2.	Egg tube	13.83–13.86	0.64–0.66
3.	Pedicel	Absent	Absent
4.	Lateral oviduct	0.94–0.96	0.74–0.77
5.	Common oviduct	0.99–1.01	0.74–0.76
6.	Spermathecal gland	5.44–5.47	0.74–0.77
7.	Spermathecal duct	0.93–0.96	0.74–0.78
8.	Utriculus	0.88–0.91	0.35–0.38
9.	Lagena	0.09–0.11	0.08–0.11
10.	Infundibulum	0.09–0.12	0.74–0.76
11.	Corpus bursae	1.14–1.16	0.98–1.01
12.	Ductus bursae	1.18–1.21	0.64–0.66
13.	Ostium bursae	0.14–0.17	0.34–0.36
14.	Ductus seminalis	1.64–1.66	0.11–0.14
15.	Bulla seminalis	Absent	Absent
16.	Accessory gland reservoir duct	0.68–0.71	0.74–0.76
17.	Accessory gland reservoir	0.88–0.91	0.34–0.36
18.	Accessory gland	4.19–4.22	0.74–0.76
19.	Vestibulum	0.34–0.37	1.58–1.61
20.	Vagina	0.43–0.46	1.59–1.62

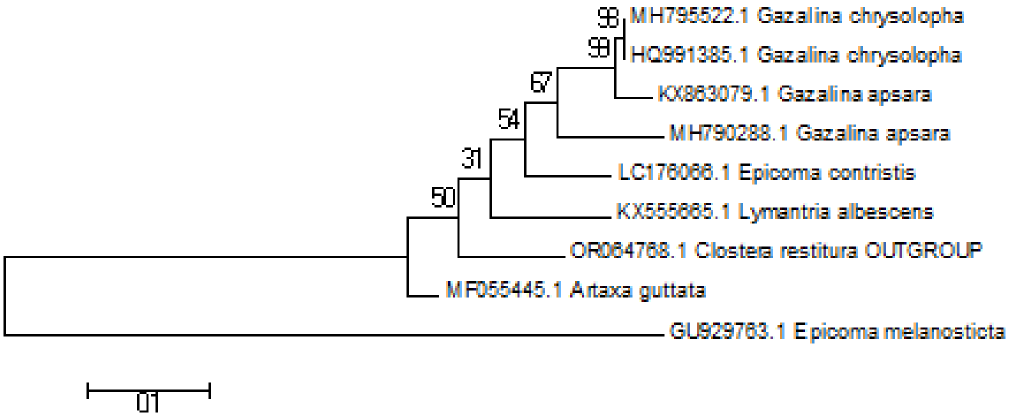

Figure 7. Phylogenetic tree of the sequences studied and sequences retrieved from the NCBI using *Clostera restitura* as outgroup.

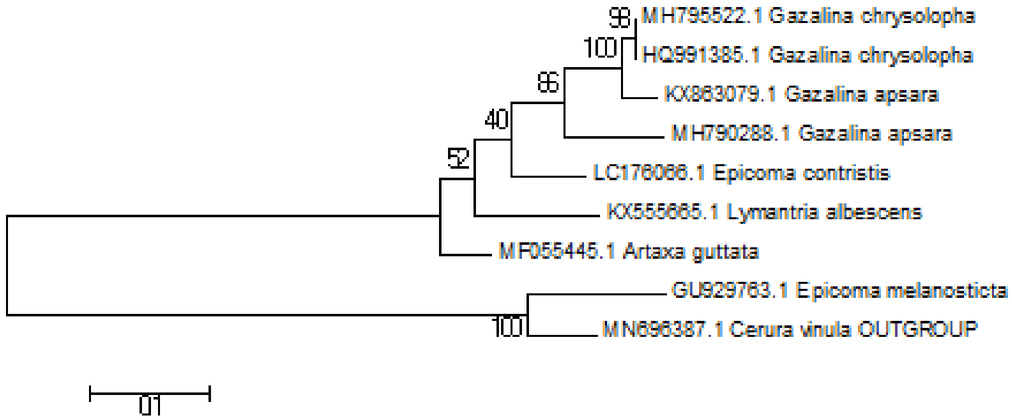

Figure 8. Phylogenetic tree of the sequences studied and sequences retrieved from the NCBI using *Cerura vinula* as outgroup.

Hübner for a total of 18 species. The species within the third clade (*Gazalina* spp. and *Thaumetopoea* spp.) are associated with economically important trees such as Fagaceae (oaks, Quercus), Pinaceae (pines, Pinus) and Anacardiaceae (pistachio, Pistacia) and can occasionally occur at high densities (outbreaks) in the northern part of their range, such as the Mediterranean basin and Europe for *Thaumetopoea* (Battisti et al. 2015) and the Himalaya foothills for *Gazalina* (Rahman & Chaudhry 1992). Battisti et al. (2017) talked about the traits which are shared by all species in this subfamily, most notably is the presence of urticating setae on larvae, adults, or both. The eggs are laid in clusters, and larvae are gregarious during the entire larval stage. In most species of processionary moths, the larvae build silken tents, from which they forage for food in a typical head-to-tail procession. This behaviour of moving in procession has been documented for all the species of these three clades of this subfamily.

The Co I sequence of *Gazalina chrysolopha* (MH795522) and *Gazalina apsara* (MH790288) from the present study were compared with the available reference sequences in Genbank maintained by NCBI by using BLAST. The BLAST results showed 86% similarity of *Gazalina apsara* with sequence (KX863079) from Pakistan and more than 96% similarity of *Gazalina chrysolopha* with sequence (HQ991385) submitted by Ashfaq et al. (2017) from Pakistan which signifies the geographic proximity. The interesting fact is that these sequences also showed more proximity with different genera of the subfamily Lymnatriinae and supported the ambiguous placement of the genus *Gazalina* Walker under Notodontidae. For example, the comparison of obtained sequences with sequences of species of three different genera namely *Epicoma* Hübner, *Axiocleta* Turner, and *Aglaossoma* Walker referable to the subfamily Thaumetopoeinae of the family Notodontidae and three different genera, i.e., *Artaxa* Walker, *Lymantria* Hübner, and *Naroma* Walker of the subfamily Lymantriinae, the similarity index lies between 80–84 %

Table 5. Details of species included in this study, their locality and accession number.

	Species	Locality	Submitter	Accession no.	Date of collection
1.	*Gazalina chrysolopha*	Himachal Pradesh Pakistan	Kaur. N Akhtar. S	MH795522 HQ991385*	08.vi.2016 05.viii.2010
2.	*Gazalina apsara*	Himachal Pradesh Pakistan	Kaur. N Ashfaq. M	MH790288 KX863079*	06.vi.2016 05.vii.2012
3.	*Epicoma contristis*	Australia	Kobayashi & Nonaka	LC176066*	12.ix.2016
4.	*Epicoma melanostica*	Australia	Mutanen	GU929763*	25.vii.2016
5.	*Axiocleta perisema*	Australia	Robinson	HQ920662*	13.ii.1980
6.	*Aglaosoma variegate*	Australia	Carale, J.	HQ920604*	01.iii.1995
7.	*Naroma signifera*	Afro tropical region (Gabon)	Ecotrop field class	MK187865*	27.ii.2011
8.	*Lymantria albescenes*	Japan	Stewart	KX555665*	17.vii.2016
9.	*Artaxa guttata*	China	Hao et al.	MF055445*	30.iv.2020

*Sequences retrieved from the Genbank.

with Thaumetopoeinae of the family Notodontidae and more than 84% with the subfamily Lymantriinae of the family Erebidae (Table 5).

This suggested that the genus *Gazalina* Walker can be placed under the subfamily Lymantriinae on the basis of molecular analysis. As far as behavioral aspects are concerned, the adult moths referable to the genus *Gazalina* Walker show no movements with disturbance and feign dead similar to that of typical lymantrids. The adult moth possesses distinct anal tuft which is a characteristic feature of adults of subfamily Lymantriinae. The external morphological characters including genitalic features completely conform to the characterization of subfamily Lymantriinae except its wing venation which seems to be trifid. The internal genitalic studies on the basis of bulbous constrictor muscular area, small and transparent cuticular tube and its subapical entry position into aedeagus in males and presence of oval lagena and origin of ductus seminalis from middle of ductus bursae in females make both the studied species congeneric. However, these can be differentiated on the basis of certain features such as shape of testis, seminal vesicle-II, ductus ejaculatorius duplex, division of primary simplex in males and shape of eggs, utriculus and length of accessory glands in females. Though *Gazalina* possess a stable generic position, but its placement in a proper family still remains a taxonomic mystery and accounts for more studies and validation.

CONCLUSION

Walker (1865) established the genus *Gazalina* Walker with *venosata* Walker (*apsara* Moore) as its type species from northern India under family Lymantriidae. The taxonomic position of this genus remained ambiguous due to its continuous reshuffling between the subfamily Lymantriidae of the family Erebidae and the family Notodontidae. Though the sequence analysis in present study showed the proximity of its species with species of different genera of the subfamily Lymnatriinae and supported the ambiguous placement of the genus *Gazalina* Walker under Notodontidae. But on the basis of morphological, molecular, larval, pupal and behavioural characteristics and thorough review of previous works particularly of Kobayashi & Nonaka (2016) and Basso (2017), the genus *Gazalina* has been placed under the subfamily Thaeumatopoeinae of Notodontidae.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25856–25871

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9018.16.9.25856-25871

#9018 | Received 06 March 2024 | Final received 14 August 2024 | Finally accepted 30 August 2024

ARTICLE

Diversity and distribution pattern of ebony trees *Diospyros* L. (Ebenaceae) in the forests of central Western Ghats, India

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Abstract: *Diospyros* trees, commonly known as persimmons or ebonies, have high economic and medicinal value. This study presents here a detailed analysis of the diversity and distribution of *Diospyros* species across 20 sites in the Western Ghats region of Karnataka, encompassing different forest types. Data collected from belt transects were used to calculate species richness and quantitative characters such as frequency, density, abundance, importance value index, basal area cover, and distribution type. Alpha and beta diversity across the different study sites were also determined. Non-metric multidimensional scaling analysis was performed to study the relationship between forest types and species composition. The results indicate *Diospyros montana* had the greatest frequency, density, basal area cover, and importance value. Agumbe and Hosagunda areas of Shivamogga district, and Makutta region of Kodagu district, showed rich diversity.

Keywords: Contagious, deciduous, diversity indices, evergreen, NMDS, richness, transects, tropical.

Editor: Kannan C.S. Warrier, KSCSTE - Kerala Forest Research Institute, Thrissur, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Shashwathi, H.S. & Y.L. Krishnamurthy (2024). Diversity and distribution pattern of ebony trees *Diospyros* L. (Ebenaceae) in the forests of central Western Ghats, India. *Journal of Threatened Taxa* 16(9): 25856–25871. https://doi.org/10.11609/jott.9018.16.9.25856-25871

Funding: The financial support was provided by Karnataka Science and Technology Promotion Society (KSTePS) in the form of fellowship award for Shashwathi H. S.

Competing interests: The authors declare no competing interests.

Author details: H.S. Shashwathi, research scholar, Kuvempu University. Presently working on diversity, distribution, ecology and molecular authentication and phylogeny of *Diospyros* trees. Field of interest—biodiversity and conservation, plant taxonomy, ecology, bioinformatics. Dr. Y.L. Krishnamurthy, professor, Kuvempu University. Subject expert—plant biodiversity, taxonomy, documentation & conservation and fungal endophytes - enhancement of plant growth by incorporation of beneficial fungi and fungal metabolite profiling, exploration and characterization of lichens, endo-lichenic fungi.

Author contributions: H.S. Shashwathi—carried out the field work, data collection, identification, photography, software handling, data interpretation, manuscript writing. Y.L. Krishnamurthy—carried out the field work, guided for data interpretation and manuscript writing.

Acknowledgements: The authors would like to acknowledge the research supervisor Dr. Y.L. Krishnamurthy, Department of Applied Botany, Kuvempu University, and host University Jnana Sahyadri, Kuvempu University for providing all necessary facilities. The authors are also grateful to the Karnataka Forest Department, India for allowing them to work in the forests. The authors would like to acknowledge the Karnataka Science and Technology Promotion Society (KSTePS) for financial support in the form of a fellowship.

INTRODUCTION

Mother nature has equally distributed her wealth all over the earth in terms of natural resources. India is one of the richest countries in its natural resources and biodiversity. The biodiversity of any area can be measured by its flora and fauna, which is higher in the Western Ghats and northeastern parts of India. The Western Ghats and the eastern Himalaya are not only regarded as the treasure of biological diversity but also, they are two important hotspots of biodiversity. Western Ghats are accomplished with different levels of biological diversity along many gradients from temperate to the tropics. Diversity in the Western Ghats in terms of plant species increases from east to west and also from north to south with an increase in rainfall (Gadgil 1996; Karthik & Vishwanath 2012).

There are many plant species in the Western Ghats which are economically and medicinally important. The Ebenaceae family is one of the valuable sources of economically important products. *Diospyros* is a genus that belongs to the family Ebenaceae. They are dioecious trees with a highly polymorphic nature and show great morphological variations among individuals. *Diospyros* species are a source of several important products such as edible fruits, medicines, and timber (Singh 2005). Some are useful as ornamentals and have local ecological importance. These trees are also known to have folklore medicinal uses, mainly in the treatment of diarrhoea, for decreasing the increased cholesterol level, improve cognitive function used for inflammatory disorders (Sirisha et al. 2018). Persimmon fruits have anti-inflammatory, anti-atherosclerosis, hypo-cholesterolemic, antioxidant, antidiabetic, and anticancer properties (Ferrara 2021). Species of *Diospyros* have been revealed to be rich in naphthoquinones and naphthol, and these phytochemicals have proved to be good taxonomic markers of this genus (Sharma 2017).

Considering the status of *Diospyros* worldwide, a total of 607 species have so far been reported, of which 300 species occur in Asia and the Pacific area, 98 species in Madagascar and the Comoro Islands, 94 species in African Mainland, 100 species in America and 15 species in Australia (Wallnöfer 2001). In India, *Diospyros* is represented by 66 taxa (Singh 2005) of which 24 species of *Diospyros* were reported in Western Ghats (Gamble 1998), and 15 species occurred in Karnataka (Saldanha 1984).

The forests of the Western Ghats are the homeland for many such endemic and precious plants. There are several plant species that are threatened due to the activities of human beings, extensive harvesting of products, and also drastic climate change. The status of many plants in the forest is undetermined due to a lot of difficulties in identification and a lack of taxonomic knowledge. *Diospyros* L. is one such genus which needs to be conserved for its importance. Diversity studies oriented to such a single genus, are rare in this region. Therefore, the study was focused on: (1) investigating species composition and richness of the *Diospyros* trees in different forest types, basal area cover, and the pattern of distribution, (2) analysis of alpha and beta diversity in different areas of the central Western Ghats region**.** Moreover, the current study provides us the basic knowledge about the present status of these trees in forests and conserves them.

MATERIALS AND METHODS

Study area

This study was carried out from 2021 to 2023 at locations in the central Western Ghats of Karnataka State in India. Major districts in this area include Uttara Kannada, Shivamogga, Chikkamagaluru, Hassan, and Kodagu, which present a range of forest types that include dry and moist deciduous, evergreen and semi-evergreen, and shola vegetation.

Field survey and sampling

Stratified random sampling was used for the sampling process. Four distinct forest types were represented by 10, 250 x 4 m belt transects. A total of 20 locations (Table 1) were investigated. Within the transects, *Diospyros* trees and allied species were counted. Every plant that had a circumference of more than 10 cm was measured at breast height. Samples were photographed and collected in order to prepare the herbariums deposited at Kuvempu University (Table 2). Utilizing floras, monographs, and other literature the identified trees were verified (Saldanha 1984; Gamble 1998; Ramaswamy et al. 2001; Singh 2005). The currently approved names for the identified tree species were assigned using an online database by means of the World Flora Online (www. worldfloraonline.org).

STATISTICAL ANALYSIS

Assessment of species composition and structural diversity.

Quantitative characteristics of the forest community such as frequency, density, abundance, basal area, (IVI) important value index, relative frequency, relative density, relative abundance, and dominance were computed in a Microsoft Excel spreadsheet (Cottam & Curtis 1956; Uddin et al. 2020).

Formulas used for data analysis are given below:

- Frequency = (Number of transects in which the species occurred) / (Total number of transects studied)
- Relative Frequency = (Frequency of a species) / (Total frequency of all species) × 100
- Density = (Number of individuals of the species) / (Total number of transects studied)
- Relative Density = (Density of a species) / (Total density of all species) × 100
- Abundance = (Total number of individuals of a species in all transects) / (Number of transects in which the species occurred)
- Relative Abundance = (Abundance of a species) / (Total abundance of all species) × 100
- Relative dominance = (Basal area of a species) / (Total basal area of all species) × 100
- Basal area = $(GBH)^2/4\pi$ where, GBH = girth at breast height and $\pi = 3.1416$
- IVI (Important value index) = Relative frequency + Relative density + Relative dominance
- Distribution pattern of the trees was calculated using (WI) Whitford value = Abundance/Frequency (Whitford 1949; Srinivas & Krishnamurthy 2016).

Analysis of alpha and beta diversity:

Alpha diversity was analysed by using Shannon-Wiener and Simpson's diversity indices (Magurran 1988). They were calculated with the help of ecological Past software version, 4.03. and by Microsoft Excel.

formulas used for calculation;

$$\text{Shannon} - \text{Wiener index: } H = -\sum_{i=1}^{n} P_i \ln P_i$$

where, $P_i = n_i/N$

n_i = number of individuals in the species

N = the total number of individuals of all species

Here, quantity Pi is the proportion of individuals found in the species

$$\text{Simpson's index (D)} = \sum \left(\frac{n_i(n_i-1)}{N(N-1)}\right)$$

where n_i = the number of individuals in the i^{th} species

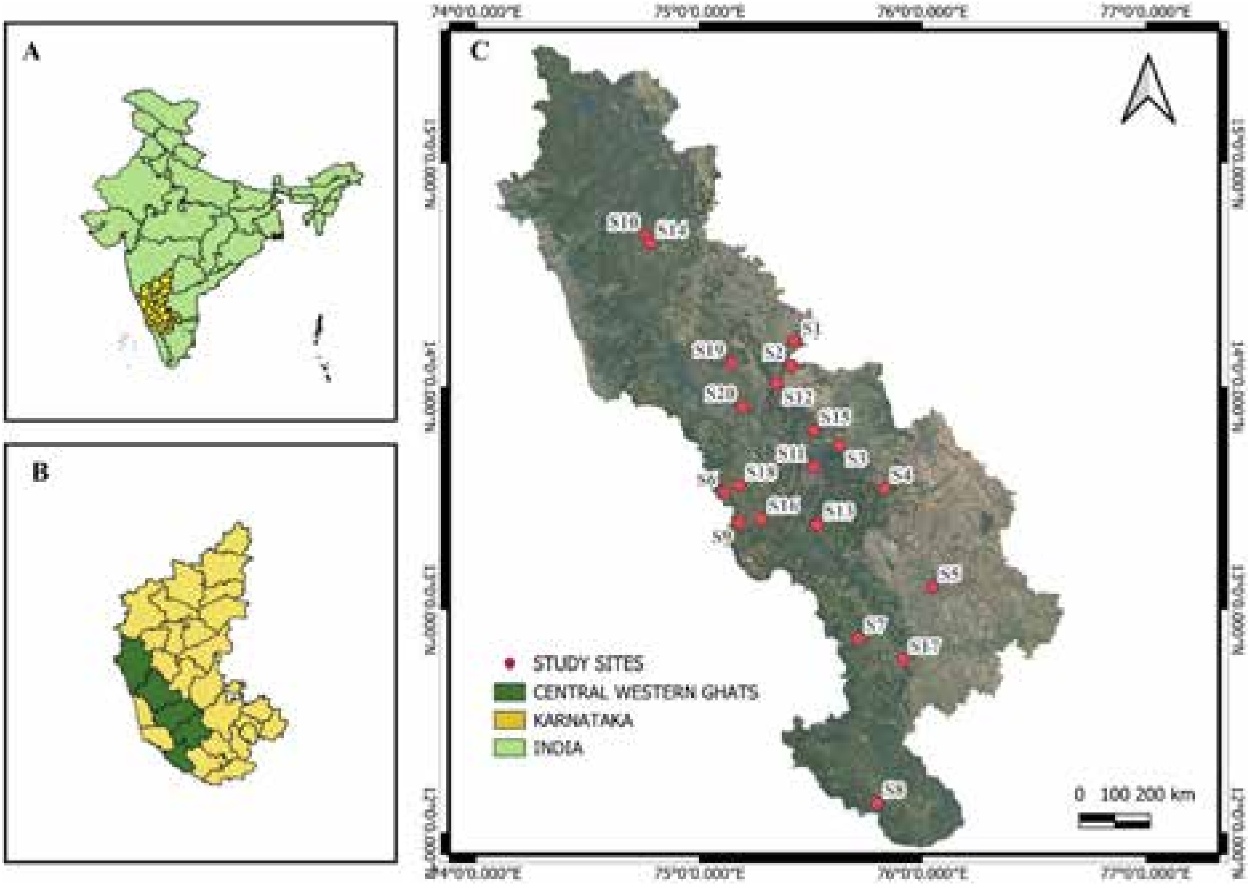


Figure 1. Map of the study area indicating investigated sites (A–C): A—India map | B—Karnataka state showing study area | C—Map of central Western Ghats including study sites.

Table 1. Details of the study sites with forest type and district.

Name of the study site	Location name	Latitude	Longitude	Forest type	District
S1	Shikaripura	14.200° N	75.427° E	Dry deciduous	Shivamogga
S2	Ayanoor	14.091° N	75.411° E	Dry deciduous	Shivamogga
S3	Shankarghatta	13.736° N	75.627° E	Dry deciduous	Shivamogga
S4	Shanthveri	13.542° N	75.827° E	Dry deciduous	Chikkamagaluru
S5	Seege Gudda	13.099° N	76.044° E	Dry deciduous	Hassan
S6	Agumbe	13.523° N	75.111° E	Evergreen	Shivamogga
S7	Sakleshpura	12.869° N	75.711° E	Evergreen	Hassan
S8	Makutta	12.130° N	75.794° E	Evergreen	Kodagu
S9	Kigga	13.391° N	75.177° E	Evergreen	Chikkamagaluru
S10	Hulekal	14.676° N	74.761° E	Evergreen	Uttara Kannada
S11	N R Pura	13.639° N	75.511° E	Moist deciduous	Chikkamagaluru
S12	Arasaalu	14.016° N	75.344° E	Moist deciduous	Shivamogga
S13	Balehonnur	13.381° N	75.527° E	Moist deciduous	Chikkamagaluru
S14	Sirsi	14.643° N	74.777° E	Moist deciduous	Uttara Kannada
S15	Mandagadde	13.803° N	75.511° E	Moist deciduous	Shivamogga
S16	Sringeri	13.404° N	75.277° E	Semi evergreen	Chikkamagaluru
S17	Arehalli	12.775° N	75.911° E	Semi evergreen	Hassan
S18	Kundadri hills	13.556° N	75.177° E	Semi evergreen	Shivamogga
S19	Hosagunda	14.101° N	75.144° E	Semi evergreen	Shivamogga
S20	Kunnur	13.910° N	75.194° E	Semi evergreen	Shivamogga

N = the total number of individuals.

A comparison of 20 distinct research sites was used to perform a beta diversity analysis. To determine beta diversity, similarity, and distance indices were calculated utilising the presence and absence data for *Diospyros* species, in the Past software version, 4.03 (Hammer et al. 2001). The Jaccard similarity index was computed to check the relationship between study sites (Newton 2007). The distribution of *Diospyros* trees in different forest types and their significance was studied by non-metric multidimensional scaling or NMDS analysis using Past software version, 4.03.

RESULTS

Species richness and structural composition

The floristic study was conducted in 20 different study sites with different forest types. A total of 4178 individuals of 189 species belonging to 130 genera and 51 families were recorded. Around 374 *Diospyros* trees were distributed among 16 species (Table 2). Other trees were identified belonging to Fabaceae (13), Rubiaceae (8), Rutaceae (7), Lauraceae (6), Meliaceae (6), Phyllanthaceae (6), Anacardiaceae (5), Apocyanaceae (5). Associated with *Diospyros*, the genera with the highest species composition were *Ficus* (7), from the Moraceae family, *Terminalia* (7) from Combretaceae, *Syzigium* (7) from Myrtaceae and *Holigarna* from Anacardiaceae (5) (Table 4).

The number of individuals and species composition of *Diospyros* trees were used to examine the species richness of 20 distinct study areas. S6-Agumbe exhibits the highest species richness. Eight *Diospyros* species with an overall 97 individuals were represented at the Agumbe region namely *Diospyros saldanhae* (25), *D. ebenum* (10), *D. candolleana* (8), *D. paniculata* (26), *D. sylvatica* (14), *D. ferrea* (7), *D. oocarpa* (2), *D. pruriens* (5) were documented.

With five species and 19 individuals of *Diospyros*, the S19-Hosagunda region had the highest species richness, next to S6. The species documented were *D. candolleana* (1), *D. crumenata* (6), *D. montana* (4), *D. sylvatica* (4), and *Diospyros ridleyi* (4) (Ramesh & Franceschi 1993; Vasudeva 2007). *Diospyros crumenata* is one of the endangered species found within the transect.

S8-Makutta also showed better species richness with five species and 14 individuals. The species observed

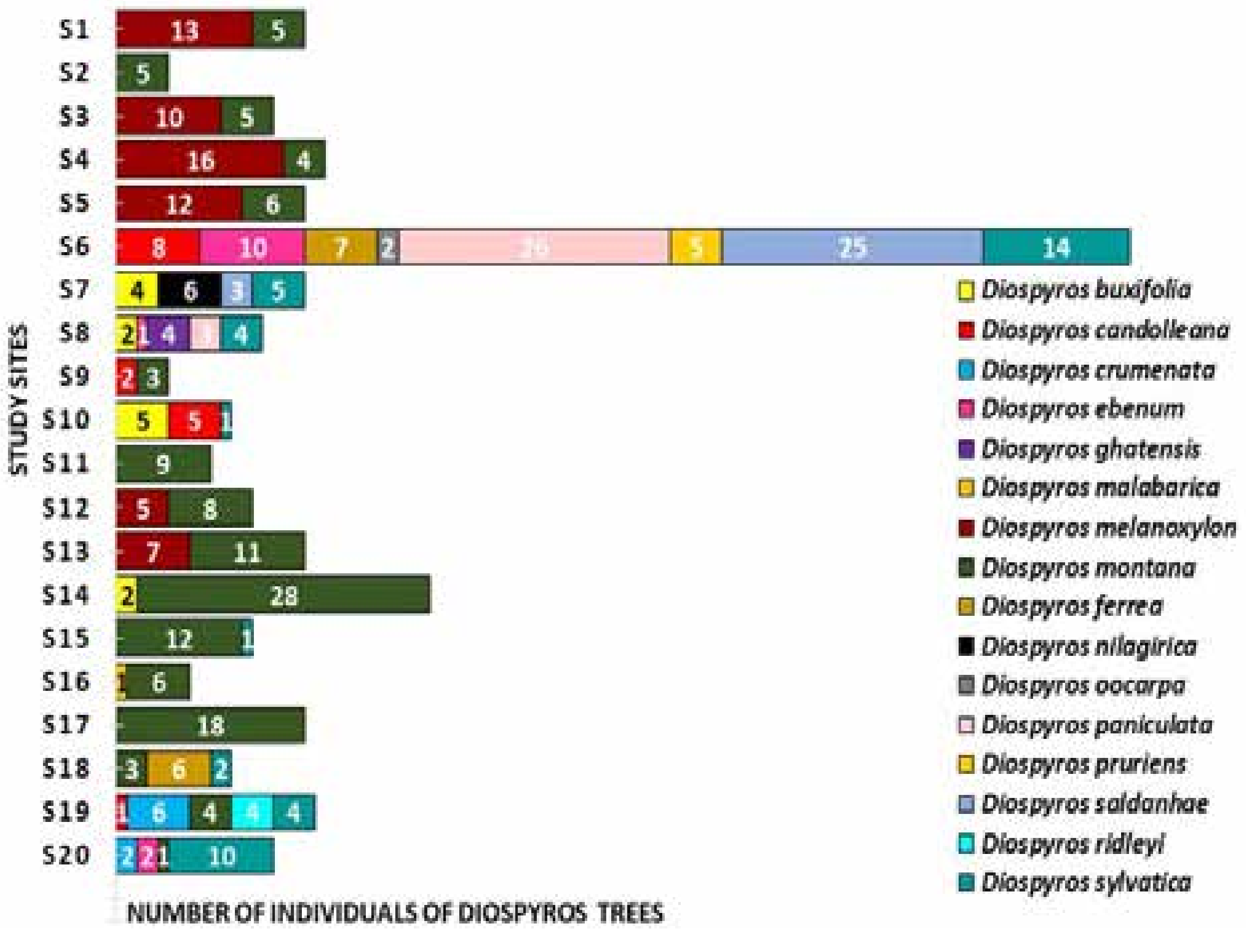


Figure 2. *Diospyros* species composition along with the number of individuals in different study sites.

were *D. buxifolia* (2), *D. ebenum* (1), *D. ghatensis* (4), *D. paniculata* (3), *D. sylvatica* (4).

S17 -Arehalli (18), S11-N.R. Pura (9), S2-Ayanoor (5) showed the least richness among study sites. Details of all 16 species of *Diospyros* and their distribution in different study sites along with the number of individuals are depicted in (Figure 2).

Frequency: *Diospyros montana* was the most frequently distributed tree species (72.50%) among 16 species according to a floristic enumeration of the study area (Figure 3) *Diospyros sylvatica*, on the other hand, also showed a high frequency value of 32.50% (Figure 3) and was not present in dry deciduous forests, but was observed in eight study sites of evergreen forests. *Diospyros nilagirica*, *D. malabarica*, and *D. ridleyi* exhibited the lowest frequency value of 2.50% and were limited to one study site each**.**

Density: *Diospyros montana* was the most densely observed species with a value of 3.20. *Diospyros melanoxylon* was also distributed densely next to *Diospyros montana* with a value of 1.58. *Diospyros melanoxylon* was recorded in six sites among 20 and restricted to deciduous forests. Least density was reflected by *Diospyros malabarica* with the value 0.03 (Figure 3).

Abundance: *Diospyros paniculata* was found to be the most abundantly distributed species (9.67). *Diospyros saldanhae* was also an abundant species with a value of 9.33. These trees were observed only in two sites each among 20 sites and were purely evergreen trees. *Diospyros malabarica* (1.00) and *Diospyros oocarpa* (1.00) were the trees with the least abundance among *Diospyros* trees (Figure 3).

Importance value index (IVI): The importance value index is a measure that indicates the importance of individual species in the forest which is the relative measure of density, dominance, and frequency. The importance value index of *Diospyros* trees ranges from 0.11–6.51. Among *Diospyros, D. montana* was noted with the highest IVI (6.51). The lowest value of IVI was reflected by *D. malabarica.* Importance value index of all 16 *Diospyros* trees is shown in Figure 3.

Basal area: The basal area covered by *Diospyros montana* was 104.103 m^2/ha, which is the highest among *Diospyros* species. This was followed by *Diospyros melanoxylon* with a basal area value 26.21 m^2/ ha. *Diospyros malabarica* has the least basal area value of 0.0002 m^2 / ha among *Diospyros* species (Figure 4)

Pattern of distribution

The ratio of abundance to frequency indicates a pattern of distribution. (Whitford 1949). A value less than 0.025 indicates regular distribution, values between 0.025–0.05 imply a random type of distribution, and values more than 0.05 imply a contagious type of distribution (Ndah et al. 2013). The abundance and frequency (A/F) ratio of all the *Diospyros* species shows values >0.05 which ranges from 0.06– 2.40 (Table 3). This indicates the clumped or contagious pattern of distribution.

Diversity indices: overall diversity of study sites

Species diversity can be assessed by using some type of diversity index, which provides us with information on species richness and evenness. Alpha diversity of 20 different study sites was calculated by using two important non-parametric diversity indices namely Shannon-Wiener index (H) and Simpson's index (D).

According to the Shannon-Wiener index, S19 shows the highest value 3.96 that is Hosagunda region is enriched with good diversity. Next to S19 highest Shannon index value was observed at S8-Makutta Ghat 3.93. The least Shannon value,1.56 was observed at S2 which is the Aynoor region. The Shannon index of all the study sites is given in Figure 5. According to Simpson's index a value, near 1 denotes less diversity, and the value 0 refers to infinite diversity. In the present study Simpson index of study site 19 shows the lowest value 0.018 (Figure 5). This implies that the diversity is rich in S19 that is Hosagunda region which is followed by the S8 Makutta region also shows the lowest value of 0.0195 with good diversity (Figure 5). Among 20 study sites S2 that is Aynoor region shows the highest value of the Simpson index 0.248, which is represented by less diversity when compared to others.

Beta diversity

Beta diversity is a measure to determine the change in diversity among transects or environmental gradients and with species composition. Beta diversity was measured for 20 study sites using the Jaccard similarity index, to observe variation among the study sites in terms of *Diospyros* species composition. Jaccard similarity values for all the study sites were computed tabulated and given in Figure 6.

Among 20 study sites S1, S3, S4, S5, S12, and S13 exhibited a similarity index of 1.00, which indicates that these sites are 100 percent similar to each other (Figure 6). The next group with a value of 1.00 was S11, S2, and

Table 2. Checklist of the *Diospyros* trees observed in study sites.

	Species name	Collection ID	Herbarium ID
1	*Diospyros buxifolia* (Blume) Hiern	ABDIO1	KUAB805
2	*Diospyros candolleana* Wight	ABDIO2	KUAB806
3	*Diospyros crumenata* Thwaites	ABDIO3	KUAB807
4	*Diospyros ebenum* J.Koenig ex Retz.	ABDIO4	KUAB808
5	*Diospyros ghatensis* B.R.Ramesh & D.DeFranceshi	ABDIO5	KUAB809
6	*Diospyros malabarica* (Desr.) Kostel	ABDIO6	KUAB810
7	*Diospyros melanoxylon* Roxb.	ABDIO7	KUAB811
8	*Diospyros montana* Roxb.	ABDIO8	KUAB812
9	*Diospyros ferrea* (Willd.) Bakh.	ABDIO9	KUAB813
10	*Diospyros nilagirica* Bedd.	ABDIO10	KUAB814
11	*Diospyros oocarpa* Thwaites	ABDIO11	KUAB815
12	*Diospyros paniculata* Dalzell	ABDIO12	KUAB816
13	*Diospyros pruriens* Dalzell	ABDIO13	KUAB817
15	*Diospyros ridleyi* Bakh.	ABDIO15	KUAB819
14	*Diospyros saldanhae* Kosterm	ABDIO14	KUAB818
16	*Diospyros sylvatica* Roxb.	ABDIO16	KUAB820

Table 3. Abundance / Frequency ratio of *Diospyros* trees.

Species name	Abundance / Frequency
Diospyros buxifolia	0.21
Diospyros candolleana	0.18
Diospyros crumenata	0.80
Diospyros ebenum	0.21
Diospyros ferrea	0.58
Diospyros ghatensis	0.40
Diospyros malabarica	0.40
Diospyros melanoxylon	0.31
Diospyros montana	0.06
Diospyros nilagirica	2.40
Diospyros oocarpa	0.20
Diospyros paniculata	1.29
Diospyros pruriens	0.50
Diospyros ridleyi	1.60
Diospyros saldanhae	1.24
Diospyros sylvatica	0.10

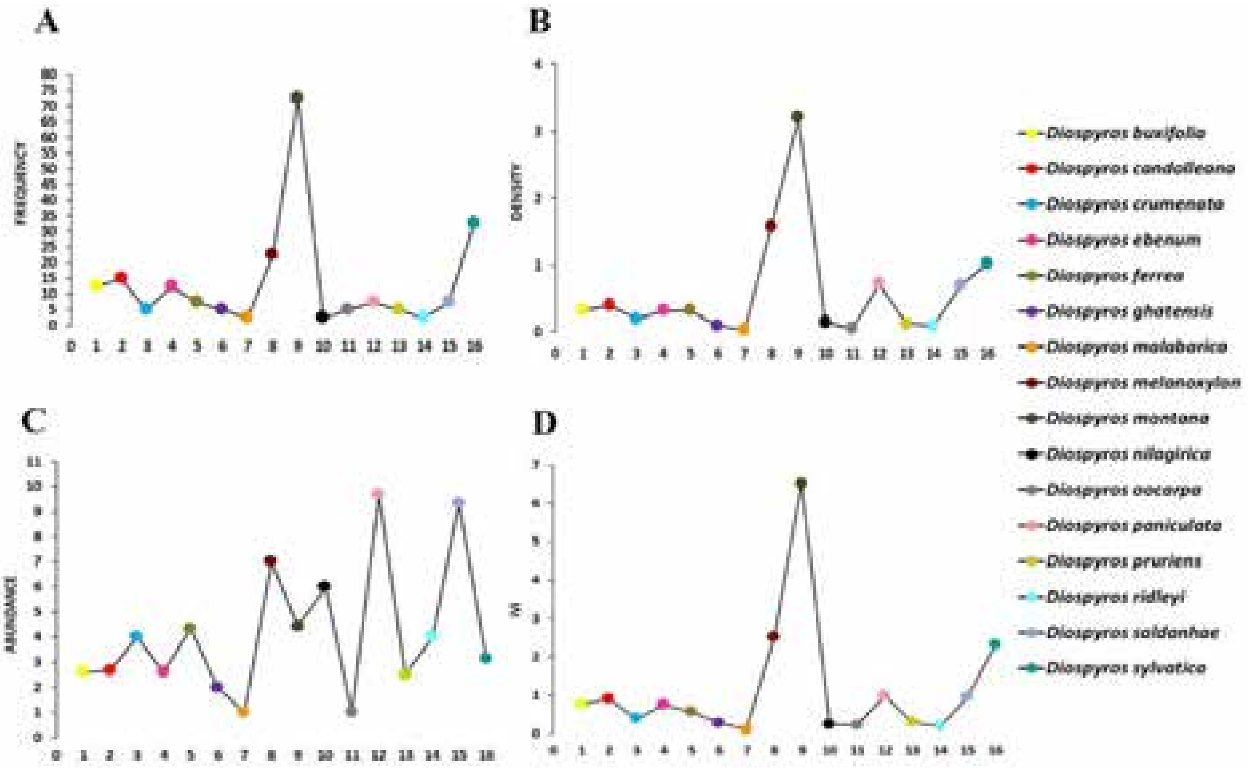


Figure 3. Quantitative characters of *Diospyros* species (A–D): A—Frequency | B—Density | C—Abundance | D—Importance value index.

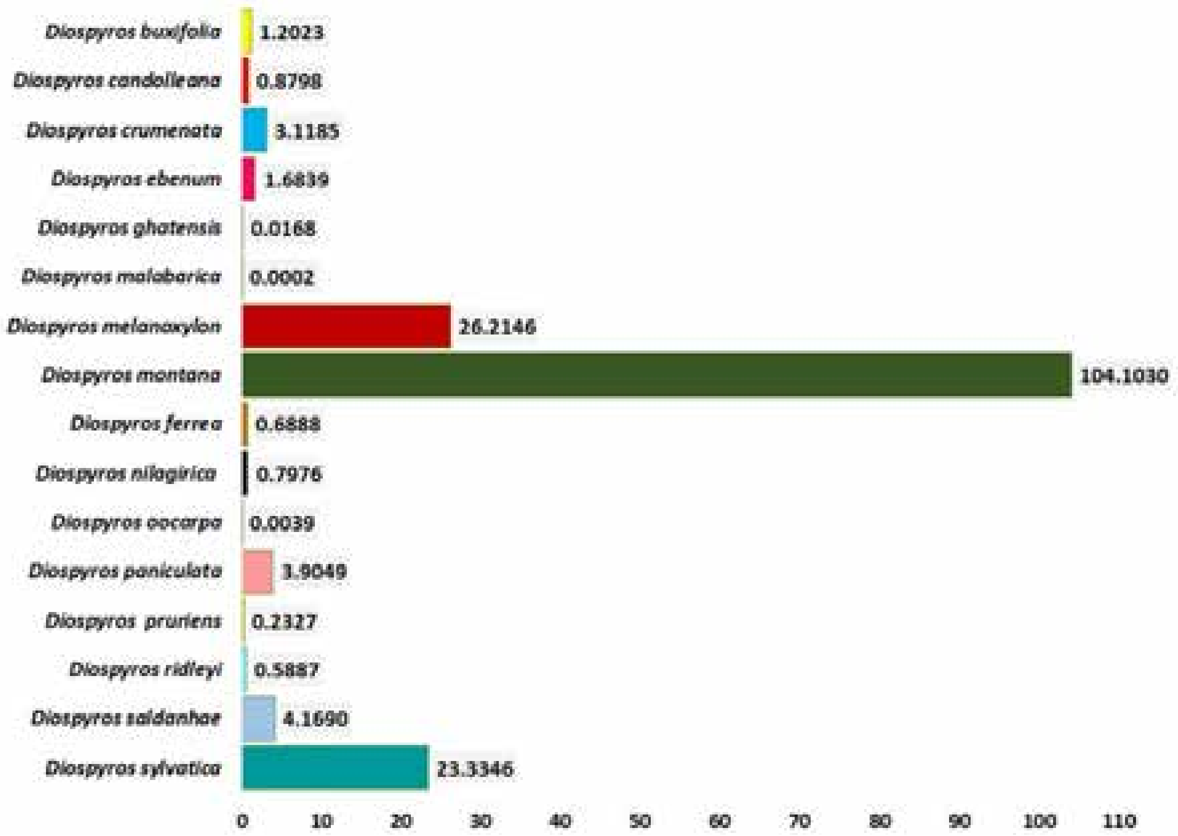


Figure 4. Chart representing basal area of *Diospyros* species.

Figure 5. A—Shannon-Wiener index of all study sites | B—Simpson's index of all study sites.

S17 which are overlapping in their species composition. These both groups are study sites representing dry and moist deciduous which are very similar in species composition.

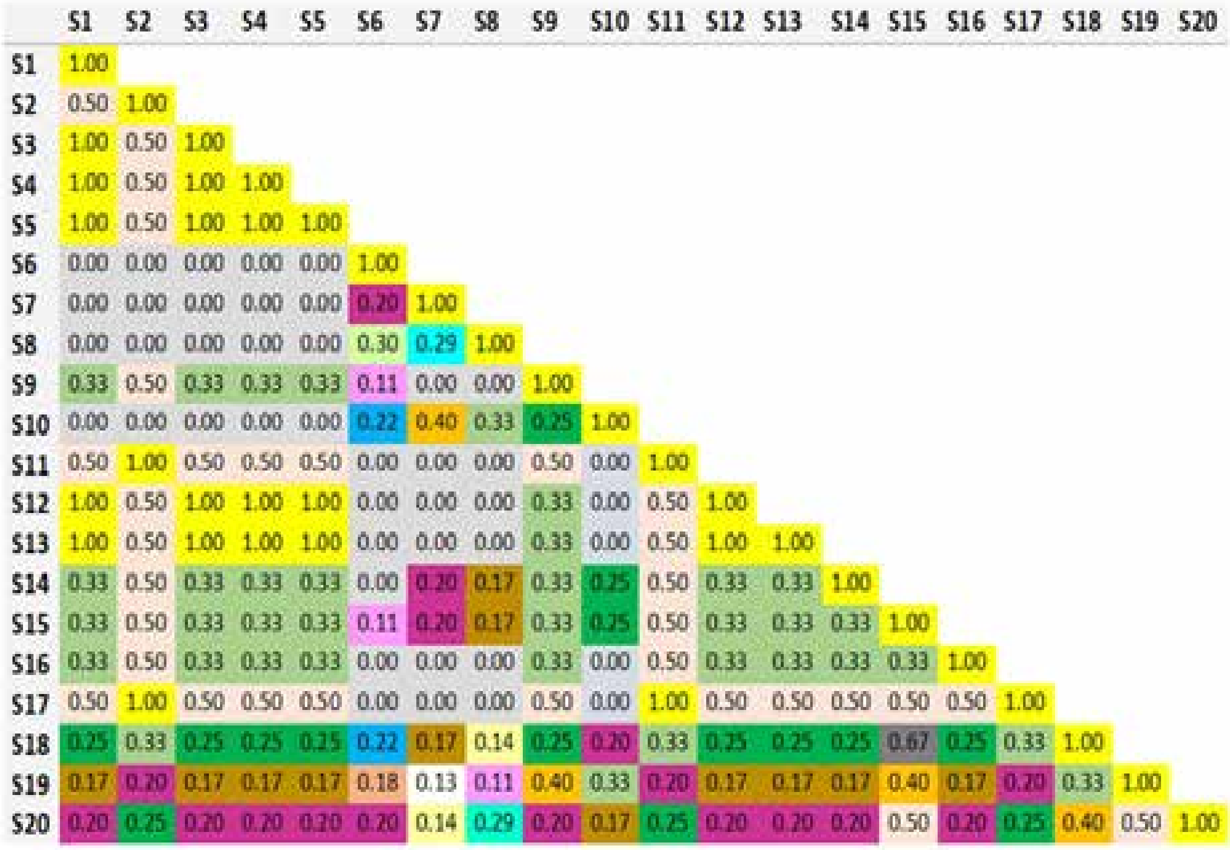
Some study sites presented a Jaccard similarity value of 0.00, indicating that these sites are completely dissimilar in their species composition. This type of trend is observed by S6, S8, S7, and S10 which exhibit the value 0.00 in relation to study sites S1, S2, S3, S4, and S5 indicating the completely dissimilar groups.

Sixty-seven percent similarity is observed between S18 and S15 with a similarity value of 0.67. The study sites S2, S11, and S17 shows value (0.50) 50% similarity with S1, S3, S4, S5, S9, S12, S13, S14, S15, S16. This predicts that only half of the species composition among these groups is similar.

Observing the tabulated Jaccard similarity index (Figure 6), study sites exhibited other similarity values like 0.40, 0.33,0.30, 0.29, 0.25, 0.22, 0.20, 0.18, 0.17, 0.14, 0.13, and 0.11 which are all less than 0.50, indicating the similarity between study sites are less than 50%. Each value in the columns and rows indicates their respective percentage similarity between the two study sites.

DISCUSSION

Tropical regions of the world are generally adorned with rich species diversity. The diversity of tree species is a basement for total biodiversity in numerous ecosystems because most of the organisms are dependent on them for food and habitat (Jayakumar & Nair 2013). Tropical forests which provide the best ecosystem services, nurture about 50–90 % of the known terrestrial plant and animal species and cover less than 10 percent of the total land area. In India, 40% of the rural population are relied on forest resources (Gopalakrishna 2015). Western Ghats of India is one such region endowed with a wide variety of ecosystems from tropical wet evergreen forests to grasslands with an enormous type of flora and fauna (Revathy et al. 2023). For several decades research on tropical forests has been conducted, yet understanding their ecology is a difficult task (Anitha et al. 2010). Every



	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
S1	1.00																			
S2	0.50	1.00																		
S3	1.00	0.50	1.00																	
S4	1.00	0.50	1.00	1.00																
S5	1.00	0.50	1.00	1.00	1.00															
S6	0.00	0.00	0.00	0.00	0.00	1.00														
S7	0.00	0.00	0.00	0.00	0.00	0.20	1.00													
S8	0.00	0.00	0.00	0.00	0.00	0.30	0.29	1.00												
S9	0.33	0.50	0.33	0.33	0.33	0.11	0.00	0.00	1.00											
S10	0.00	0.00	0.00	0.00	0.00	0.22	0.40	0.33	0.25	1.00										
S11	0.50	1.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	1.00									
S12	1.00	0.50	1.00	1.00	1.00	0.00	0.00	0.00	0.33	0.00	0.50	1.00								
S13	1.00	0.50	1.00	1.00	1.00	0.00	0.00	0.00	0.33	0.00	0.50	1.00	1.00							
S14	0.33	0.50	0.33	0.33	0.33	0.00	0.20	0.17	0.33	0.25	0.50	0.33	0.33	1.00						
S15	0.33	0.50	0.33	0.33	0.33	0.11	0.20	0.17	0.33	0.25	0.50	0.33	0.33	0.33	1.00					
S16	0.33	0.50	0.33	0.33	0.33	0.00	0.00	0.00	0.33	0.00	0.50	0.33	0.33	0.33	0.33	1.00				
S17	0.50	1.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00			
S18	0.25	0.33	0.25	0.25	0.25	0.22	0.17	0.14	0.25	0.20	0.33	0.25	0.25	0.25	0.67	0.25	0.33	1.00		
S19	0.17	0.20	0.17	0.17	0.17	0.18	0.13	0.11	0.40	0.33	0.20	0.17	0.17	0.17	0.40	0.17	0.20	0.33	1.00	
S20	0.20	0.25	0.20	0.20	0.20	0.20	0.14	0.29	0.20	0.17	0.25	0.20	0.20	0.20	0.50	0.20	0.25	0.40	0.50	1.00

Figure 6. Jaccard similarity index values for different study sites.

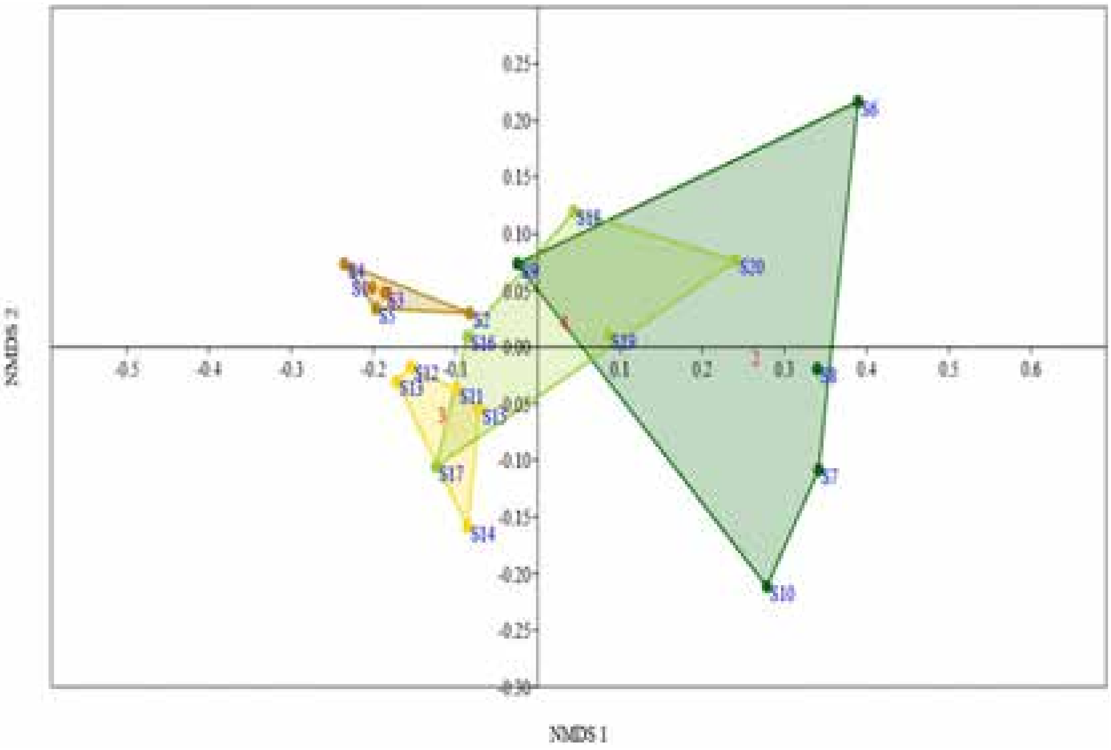


Figure 7. NMDS plot representing the relation between forest types, study sites, and species composition.

Table 4. List of other associated tree species with *Diospyros* in central Western Ghats.

Family	Genus	Species
1. Achariaceae	*Hydnocarpus*	*Hydnocarpus pentandrus* (Buch.-Ham.) Oken
2. Anacardiaceae	*Holigarna* *Lannea* *Mangifera* *Nothopegia* *Spondias*	*Holigarna arnottiana* Hook.f. *Holigarna beddomei* Hook.f. *Holigarna ferruginea* Marchand *Holigarna grahamii* Kurz *Holigarna nigra* Bourd. *Lannea coromandelica* (Houtt.) Merr. *Mangifera indica* L. *Nothopegia beddomei* Gamble *Nothopegia castanefolia* (Roth) Ding Hou *Spondias pinnata* (L.f.) Kurz
3. Annonaceae	*Meiogyne* *Monooon*	*Meiogyne pannosa* (Dalzell) J.Sinclair *Monooon fragrans* (Dalzell) B.Xue & R.M.K.Saunders
4. Apocyanaceae	*Tabernaemontana* *Wrightia* *Alstonia* *Carissa* *Holarrhena*	*Tabernaemontana alternifolia* L. *Wrightia tinctoria* R.Br. *Alstonia scholaris* (L.) R.Br. *Carissa carandas* L. *Holarrhena pubescens* Wall. & G.Don
5. Arecaceae	*Caryota* *Pinanga*	*Caryota urens* L. *Pinanga dicksonii* (Roxb.) Blume
6. Bignoniaceae	*Kigelia* *Oroxylum*	*Kigelia africana* ssp. *africana* *Oroxylum indicum* (L.) Kurz
7. Burseraceae	*Boswellia* *Canarium*	*Boswellia serrata* Roxb. *Canarium strictum* Roxb.
8. Calophyllaceae	*Mesua* *Poeciloneuron* *Calophyllum*	*Mesua ferrea* L. *Poeciloneuron indicum* Bedd. *Calophyllum apetalum* Willd.
9. Cannabaceae	*Celtis* *Trema*	*Celtis timorensis* Span. *Trema orientalis* (L.) Blume
10. Capparaceae	*Crateva*	*Crateva religiosa* G.Forst.
11. Celastraceae	*Euonymus*	*Euonymus indicus* B.Heyne ex Wall.
12. Clusiaceae	*Clusia* *Garcinia*	*Clusia* sp. *Garcinia gummi-gutta* (L.) N.Robson *Garcinia* sp. *Garcinia talbotii* Raizada *Garcinia xanthochymus* Hook.f.
13. Combretaceae	*Terminalia*	*Terminalia anogeissiana* Gere & Boatwr. *Terminalia arjuna* (Roxb. ex-DC.) Wight & Arn. *Terminalia chebula* Retz. *Terminalia elliptica* Willd. *Terminalia paniculate* B. Heyne ex Roth *Terminalia tomentosa* Mart. ex-Eichler *Terminalia bellirica* (Gaertn.) Roxb.
14. Cornaceae	*Alangium*	*Alangium salviifolium* (L.f.) Wangerin
15. Dichapetalaceae	*Dichapetalum*	*Dichapetalum gelonioides* (Roxb.) Engl.
16. Dilleniaceae	*Dillenia*	*Dillenia pentagyna* Roxb.
17. Dipterocarpaceae	*Dipterocarpus* *Hopea* *Vateria*	*Dipterocarpus indicus* Bedd. *Hopea canarensis* Hole *Hopea parviflora* Bedd. *Hopea ponga* (Dennst.) Mabb. *Hopea* sp. *Vateria indica* L.
18. Elaeocarpaceae	*Elaeocarpus*	*Elaeocarpus serratus* L. *Elaeocarpus tuberculatus* Roxb.
19. Euphorbiaceae	*Blachia* *Paracroton* *Macaranga* *Mallotus*	*Blachia denudata* Benth. *Paracroton pendulus* ssp. *zeylanicus* (Thwaites) N.P.Balakr. & Chakrab. *Macaranga peltata* Müll.Arg. *Mallotus philippensis* (Lam.) Müll.Arg. *Mallotus tetracoccus* Kurz
20. Fabaceae (Cercidoidae)	*Bauhinia*	*Bauhinia variegata* L.
Fabaceae (Caesalpinioideae)	*Acacia* *Cassia* *Xylia* *Albizia*	*Acacia* sp. *Cassia fistula* L. *Cassia* sp. *Xylia xylocarpa* (Roxb.) W.Theob. *Albizia chinensis* (Osbeck) Merr. *Albizia lebbeck* (L.) Benth. *Albizia odoratissima* (L.f.) Benth.
Fabaceae (Detarioidae)	*Humboldtia* *Saraca* *Tamarindus*	*Humboldtia brunonis* Wall. *Saraca asoca* (Roxb.) Willd. *Tamarindus indica* L.
Fabaceae (Papilionoideae)	*Dalbergia* *Erythrina* *Pongamia* *Pterocarpus* *Butea*	*Dalbergia latifolia* Roxb. *Erythrina indica* Lam. *Pongamia pinnata* (L.) Pierre *Pterocarpus marsupium* Roxb. *Butea monosperma* (Lam.) Kuntze
21. Icacinaceae	*Mappia*	*Mappia nimmoniana* (J. Graham) Byng & Stull
22. Lamiaceae	*Callicarpa* *Tectona* *Vitex*	*Callicarpa tomentosa* (L.) L. *Tectona grandis* L.f. *Vitex altissima* L.f.
23. Lauraceae	*Actinodaphne* *Beilschmiedia* *Cinnamomum* *Cryptocarya* *Litsea* *Machilus*	*Actinodaphne angustifolia* (Blume) Nees *Actinodaphne hookeri* Meisn *Beilschmiedia wightii* (Nees) Benth. ex-Hook.f. *Cinnamomum malabathrum* (Burm.f.) J.Presl *Cinnamomum* sp. *Cinnamomum verum* J.Presl *Cryptocarya wightiana* Thwaites *Litsea floribunda* (Blume) Gamble *Litsea ghatica* Saldanha *Litsea laevigata* (Nees) Gamble *Machilus glaucescens* (Nees) Wight
24. Lecythidaceae	*Careya*	*Careya arborea Roxb.*
25. Loganiaceae	*Strychnos*	*Strychnos nux-vomica* L.
26. Lythraceae	*Lagerstroemia*	*Lagerstroemia macrocarpa* Wight *Lagerstroemia* sp. *Lagerstroemia speciosa* Pers.

Family	Genus	Species
27. Magnoliaceae	*Magnolia*	*Magnolia champaca* L.
28. Malvaceae	*Bombax* *Microcos* *Grewia* *Helicteres* *Kydia*	*Bombax ceiba* L. *Microcos heterotricha* (Mast.) Burret *Grewia tiliifolia* Vahl *Helicteres isora* L. *Kydia calycina* Roxb.
29. Melastomataceae	*Memecylon*	*Memecylon edule* var. *edule* *Memecylon talbotianum* D.Brandis *Memecylon terminale* Dalzell *Memecylon umbellatum* Burm.f.
30. Meliaceae	*Aglaia* *Azadirachta* *Dysoxylum* Reinwardtiodendron *Toona* *Heynea*	*Aglaia elaeagnoidea* Benth. *Aglaia* sp. *Azadirachta indica* A.Juss. *Dysoxylum malabaricum* Bedd. ex C.DC. *Reinwardtiodendron anamalaiense* (Bedd.) Mabb. *Toona ciliata* M.Roem. *Heynea trijuga* Roxb.
31. Moraceae	*Artocarpus* *Ficus*	*Artocapus lacucha* Roxb. Ex Buch.-Ham. *Artocarpus heterophyllus* Lam. *Artocarpus hirsutus* Lam. *Ficus exasperata* Vahl *Ficus benghalensis* L. *Ficus religiosa* L. *Ficus hispida* L.f. *Ficus racemosa* L. *Ficus* sp. *Ficus tsjahela* Burm.f.
32. Myristicaceae	*Knema* *Myristica*	*Knema attenuata* (Wall. ex-Hook.f. & Thomson) Warb. *Myristica dactyloides* Gaertn. *Myristica fragrans* Houtt. *Myristica malabarica* Lam.
33. Myrtaceae	*Eugenia* *Syzygium*	*Eugenia aloysii* C.J.Saldanha *Eugenia roxburghii* DC. *Syzygium caryophyllatum* (L.) Alston *Syzygium cumini* (L.) Skeels *Syzygium gardneri* Thwaites *Syzygium laetum* (Buch.-Ham.) Gandhi *Syzygium* sp. *Syzygium xanthophyllum* (C.B.Rob.) Merr. *Syzygium zeylanicum* (L.) DC.
34. Nyssaceae	*Mastixia*	*Mastixia arborea* (Wight) C.B.Clarke
35. Oleaceae	*Chionanthus* *Tetrapilus* *Ligustrum*	*Chionanthus mala-elengi* ssp. *mala-elengi* *Tetrapilus dioicus* (Roxb.) L.A.S.Johnson *Ligustrum nepalense* Wall.
36. Phyllanthaceae	*Aporosa* *Bischofia* *Breynia* *Phyllanthus* *Glochidion* *Bridelia*	*Aporosa cardiosperma* (Gaertn.) Merr. *Bischofia javanica* Blume *Breynia retusa* (Dennst.) Alston *Phyllanthus acidus* (L.) Skeels *Phyllanthus emblica* L. *Phyllanthus assamicus* Müll. Arg. *Phyllanthus velutinus* (Wight) Müll.Arg. *Glochidion zeylanicum* (Gaertn.) A.Juss. *Bridelia retusa* (L.) A.Juss.
37. Polygalaceae	*Xanthophyllum*	*Xanthophyllum flavescens* Roxb.
38. Primulaceae	*Myrsine*	*Myrsine wightiana* Wall. ex A.DC.
39. Rhamnaceae	*Ziziphus* *Maesopsis*	*Ziziphus oenopolia* (L.) Mill. *Ziziphus rugosa* Lam. *Ziziphus xylopyrus* (Retz.) Willd. *Maesopsis eminii* Engl.
40. Rhizophoraceae	*Carallia*	*Carallia brachiata* (Lour.) Merr.
41. Rosaceae	*Prunus*	*Prunus* sp.
42. Rubiaceae	*Adina* *Neolamarckia* *Psydrax* *Canthium* *Ixora* *Catunaregam* *Oxyceros* *Randia*	*Adina cordifolia* (Roxb.) Brandis *Neolamarckia cadamba* (Roxb.) Bosser *Psydrax dicoccum* Gaertn. *Canthium coromandelicum* (Burm.f.) Alston *Canthium* sp. *Ixora coccinea* var. *coccinea* *Ixora brachiata* Roxb. *Catunaregam spinosa* (Thunb.) Tirveng. *Oxyceros rugulosus* (Thwaites) Tirveng. *Randia* sp.
43. Rutaceae	*Aegle* *Atalantia* *Chloroxylon* *Clausena* *Zanthoxylum* *Murraya* *Naringi*	*Aegle marmelos* (L.) Corrêa *Atalantia monophylla* (L.) DC *Atalantia* sp. *Chloroxylon swietenia* DC. *Clausena anisata* (Willd.) Hook.f. *Zanthoxylum rhetsa* (Roxb.) DC. *Murraya paniculata* (L.) Jack *Naringi crenulata* (Roxb.) Nicolson
44. Salicaceae	*Casearia* *Flacourtia*	*Casearia tomentosa* Roxb. *Flacourtia montana* J.Graham
45. Santalaceae	*Santalum*	*Santalum album* L.
46. Sapindaceae	*Dimocarpus* *Sapindus* *Schleichera*	*Dimocarpus longan* Lour. *Sapindus trifoliatus* L. *Schleichera oleosa* (Lour.) Oken
47. Sapotaceae	*Chrysophyllum* *Manilkara* *Madhuca* *Palaquium*	*Chrysophyllum roxburghii* G.Don *Manilkara kauki* Dubard *Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev. *Madhuca* sp. *Palaquium ellipticum* (Dalzell) Baill.
48. Symplocaceae	*Symplocos*	*Symplocos cochinchinensis* S.Moore
49. Ulmaceae	*Holoptelea*	*Holoptelea integrifolia* (Roxb.) Planch.
50. Verbenaceae	*Citharexylum*	*Citharexylum spinosum* L.
51. Vitaceae	*Leea*	*Leea indica* (Burm.f.) Merr.
51 Families	**130 Genera**	**189 species**

plant species has its contribution to biodiversity. The presence or absence of plant species in the forest could not be underestimated, because balancing the forest ecosystem is dependent on every species present in the forest. Accordingly, the quantitative investigation of *Diospyros* trees revealed better diversity in some areas of central Western Ghats, Karnataka.

Species composition and richness: species richness in the community is determined by the productivity of the system and structural complexity or diverseness. The composition of species within a community suggests us flexibility and predictability of a particular environment (Upadhya et al. 2003) Wet tropical forests are characterised by their high species richness (Chandrashekara & Radhakrishnan 1994). The present study depicted 16 species of *Diospyros* trees in 20 different study sites in the central Western Ghats region which was higher than that of the 15 species reported previously in Karnataka state (Saldanha 1984). *Diospyros chloroxylon*, *D. ovalifolia*, and *D. cordifolia* which were reported by them were not observed in the present study. Other than this our study additionally reported *Diospyros ghatensis*, *D. nilagirica*, and *D. ridleyi* (Table 2).

Among the study sites, Agumbe S6 of Shivamogga district showed the highest species richness with a greater number of *Diospyros paniculata* (26) trees (Figure 2). A similar study showed that the vegetation of Agumbe is the richest along with that Ebenaceae was the dominant family and *Diospyros paniculata* is one of the dominant species in this region (Srinivas & Parthasarathy 2000). Floristic studies in the Agumbe region of Western Ghats suggested that Ebenaceae family members were frequently distributed, and documented eight species of *Diospyros* (Rao & Krishnamurthy 2021). The study also reported eight species of *Diospyros* and in addition to previous studies *Diospyros ferrea*, *D. pruriens*, and *D. sylvatica* were observed from this region.

Along with species composition some of the characteristics like frequency, density, abundance, basal area, and IVI also determine the forest structure. The percentage frequency of the *Diospyros* trees in this study varied from 2.5– 72% (Figure 3). The top ranking of frequency was depicted by *Diospyros montana* (72%). This result is higher when compared to the frequency values of *Diospyros melanoxylon* and *Diospyros embryopteris* ranging 10–40 in three different regions of Eastern Ghats, India (Sahu et al. 2019). The present study also depicts good results in comparison with the relative frequency of *Diospyros burmanica* Kz. 4.58% from central Myanmar (Kyaw et al. 2022).

The total density of *Diospyros* trees per transect varied from 0.03–3.20 in the sites studied (Figure 3). The highest density was observed by *Diospyros montana* (3.20). The present result is lesser when compared to the density of *Diospyros sylvatica* (16) (Naidu & Kumar 2016) from Eastern Ghats of Andra Pradesh and Tamil Nadu region of India respectively.

Abundance values of *Diospyros* trees range between 1.00–9.67 in the current study (Figure 3). A great value of abundance was observed by *Diospyros paniculata* (9.67). The studies on tree abundance by species and family across six elevation zones of Mahendragiri Hill Forests of Eastern Ghats, Odisha, India depicted the four Ebenaceae family members with their abundance values ranging 3–35. Among them, *Diospyros malabarica* (26) was a highly abundant species (Khadanga et al. 2023) and the range of abundance values is comparatively higher than our current study in central Western Ghats.

Analysis of the Importance Value Index can be used to identify patterns of association of dominant species in a community, which in turn represents the status of species within the community. Analysis of IVI in 20 different sites revealed that values ranged from 0.11–6.51 (Figure 3). *Diospyros montana* showed the highest (IVI, 6.51) followed by *Diospyros melanoxylon* (IVI, 2.52). (Sharma et al.2023) reported that *Diospyros melanoxylon* showed the great value of (IVI 16.01, and 20.85) in highly and moderately disturbed tropical dry forests of northern India respectively. Borah & Garkoti (2011) showed that the IVI of *Diospyros toposia* Buck- Ham. was 9.92 in the disturbed forest of Barak reserves in southern Assam, India. A species with a high importance value index (IVI) demonstrates dominance and ecological success, as well as good regeneration and ecological amplitude. These plants require conservation management, while those with a low value require significant and intensive conservation efforts (Esor et al. 2023).

Stand basal area is a parameter used in quantifying a forest stand which estimates the volume of trees and helps in understanding competition among species. Basal area of *Diospyros* trees across 20 sites of central Western Ghats showed a wide range (0.0002–104.1030 m^2/ha). Among them *Diospyros montana* (104.1030 m^2/ha) showed great basal area cover with the highest number of stems (Figure 4). Naidu & Kumar (2016) reported that *Diospyros sylvatica* one of the important species depicted 2.02 m^2/ha.

Studies of quantitative parameters revealed that among *Diospyros* trees, *Diospyros montana* is recognised to be an important species with a high importance value index. *Diospyros montana* was found to be the most frequent and densely distributed one with the contribution of the highest basal area. This particular tree may be adapted to both dry and moist environments. Hence, we can observe this tree in all types of forests from evergreen to dry deciduous forests but a greater number of trees occurred in semi-evergreen and moist deciduous forests.

Pattern of distribution: spatial distribution pattern can be represented by abundance to frequency ratio which is known as the Whitford value (Whitford 1949). In the current study, all *Diospyros* species show A/F values of more than 0.05 which range from 0.06–2.40 (Table 3). This indicates the clumped or contagious pattern of distribution. Similarly, (Ndah et al. 2013) reported *Diospyros herienasis* (0.49) showing the contagious distribution of the species from southwestern Cameroon. Both random and contagious distribution pattern of *Diospyros melanoxylon* (0.03–0.06) was reported in different study sites from tropical dry forests of northern India (Sharma et al. 2023). Primarily due to gap phase dynamics, tropical rain forests constitute highly patchy communities. The arrangement of members of the same species together is often directly linked to a mechanism for gap formation among the species and dispersal (Upadhya et al. 2003).

Diversity indices: diversity of any community can be recorded in the form of diversity indices. The Shannon index is one such parameter that depicts the diversity and richness of an area. Normally it ranges 1.5– 3.5 and occasionally surpasses 4.5. As the Shannon index value increases or is near 4.5 then it implies rich diversity in that area. In the same way, if the value is near 1 then it indicates less diverse organisms in a particular area. Usually, the range of the Shannon index prescribed for tropical forests is 0.83–4.1 (Subashree et al. 2021). (Tadwalkar et al. 2020) reported Shannon value from the northern region of Western Ghats ranging 0–2.86. In southern Western Ghats, it was 4.49 studied by (Sathish et al. 2013). The present investigation of 20 study sites of central Western Ghats represented the Shannon index value ranging 1.56–3.96. Among the 20 study sites, the Shannon index was highest at S19- Hosagunda (3.9638) indicating the highest diversity, which was followed by S8- Agumbe (3.9364) indicating a diverse population of trees. The least value of the Shannon index was observed at S2– (1.5675) Aynoor region which implies comparatively less diversity (Figure 5).

Simpson's index known as the dominance index indicates how abundantly the species exists in a region. The dominance index for Indian tropical forests ranges from 0.21–0.92 (Subashree et al. 2021). The Simpson's dominance index in different forest types of southern Western Ghats was reported by (Joseph et al. 2021) which depicted values were 0.021 in evergreen, 0.071 in shola, 0.054 in semievergreen, 0.075 in moist deciduous, and 0.093 in dry deciduous forest types. The present study shows values of Simpson's index ranging from 0.019–0.248 (Figure 5). Values of the Simpson index near 0 indicate the highest diverse community. In terms of diversity in current research, S19 located at Hosagunda sacred groove of Shivamogga district showed the richest diversity among the study sites with the highest value of the Shannon index and the lowest value of Simpson's index which was followed by S8- Makutta region (Figure 5). Hosagunda is one of the sacred grooves consisting of Kaan Forests with a rich floristic composition. About five species of *Diospyros* were represented with better species richness and among them, *Diospyros crumenata* one of the endangered trees was recorded in the sacred groove. Earlier studies on the floristic composition of the Kaan forests of Sagara Taluk in central Western Ghats were carried out by (Gunaga et al. 2015). This study helped to understand that the Kaan forests of Sagara Taluk harbours diverse flora in evergreen and semievergreen forests. Most of the plant species reported inside the Kaans do not occur outside this habitat, indicating their endemic nature.

Beta diversity: the integration of processes related to ecology and evolution at different levels of space is an important task for figuring out how biodiversity is structured and preserved over time. In order to achieve this, the analysis of beta diversity is a promising method that makes it possible to quantify heterogeneity in the distribution of gamma and alpha diversities. This enables the assessment of how species alter over time and in response to environmental variation (Pinto-Ledezma et al. 2018). The present study concentrated on the beta diversity of 20 study sites in central Western Ghats which was calculated with the help of Jaccard's similarity index. The Jaccard similarity index of different study sites was tabulated and given in Figure 6. The Jaccard similarity values range between 0 to 1, where 0 indicates the dissimilarity between study sites and 1 indicates 100% similar study sites. In current work study site S6, S7, S8, and S10 showed similarity value 0.00 with respect to study sites S1, S2, S3, S4, S5. It is clear that S6, S7, S8, and S10 are the evergreen forest sites that are completely different in species composition from S1, S2, S3, S4, and S5 which represent dry deciduous forests. Study sites S1, S3, S4, S5, S12, and S13 depicted a similarity value of 1.00 with each other indicating 100% similarity in their species composition. In the same way, another set of study sites S2, S11, and S17 also show a similarity value of 1.00 with each other. Most of these sites mentioned above are dry deciduous and moist deciduous forests showing similarity among themselves in terms of species composition of *Diospyros.* The study sites S2, S11, S17 represented the similarity value 0.50 with the study sites S3, S4, S5, S9, S12, S13, S14, S15, S16. This infers that the former three sites are 50% similar to the later study sites. In the same way, S20 showed 50% similarity with the sites S19 and S15.

The trend shows that evergreen study sites (S6, S7, S8, S9, S10) and dry deciduous sites (S1, S2, S3, S4, S5) are completely dissimilar in the composition of *Diospyros* species. Semi-evergreen sites (S5, S16, S18, S19, S20) show less than 50% of similarity with evergreen, moist deciduous, and dry deciduous sites except S17. Moist deciduous sites (S11, S12, S13, S14, S15) show 50% or less than 50% similarity with evergreen and semi-evergreen sites. In this way, the similarity values are picturised in the Figure 6, which represents the similarity of each study site with respect to other study sites in terms of the composition of *Diospyros* species. This type of analysis is very similar to a study conducted in human-disturbed forests of Uttara Kannada, central Western Ghats by Rao et al. (2013). Another study aimed at analysis of site quality with the Jaccard similarity index in northeastern India was undertaken by Thangjam et al. (2022).

Forest types and species composition: the Western Ghats have a wide range of vegetation types due to their complex geography, altitudinal temperature decrease, and large variations in annual precipitation (1,000–6,000 mm), in addition to human influences (Rao et al. 2013). The Western Ghats are home to four main types of forests: moist deciduous, dry deciduous, semi-evergreen, and evergreen, according to different field-based analyses of vegetation groups and satellite photograph interpretation. Along with the forest types mentioned above, the parts of central Western Ghats included in the current research consist of mainly low-altitude and middle- altitude evergreen forest types (Pascal 1990). Species composition changes across the different forest types which is true in the case of *Diospyros* trees. According to (Saldanha 1984; Gamble 1998), among 16 species of *Diospyros* trees observed by us majority of trees are restricted to evergreen and semi-evergreen forests. Only *Diospyros montana* and *D. melanoxylon* are the species found in moist and dry deciduous types. *Diospyros montana* is found in both the forest types along with semi-evergreen forests. In this study *D. melanoxylon* was restricted to dry deciduous forests as before, but slight deviation was observed in study site S14 where it is a moist deciduous type of forest. *Diospyros buxifolia* which is a typical evergreen tree was found in the S14 region. The reasons for this may be rainfall and the dispersal mechanism of seeds. Species diversity of *Diospyros* is correlated with the vegetation types. NMDS analysis presents us with clear evidence regarding this (Figure 7). Study sites were classified into four groups based on forest types where group-1 dry deciduous forests, group-2 evergreen forests, group-3 moist deciduous forests, group-4 semi-evergreen forests, and dataset including the existence of *Diospyros* trees were considered for analysis. This plot indicates the four different forest types where group- 1 is dry deciduous forests which include study S1–S5. They are grouped separately in the plot because the species composition of dry deciduous forests is a peculiar one. Group- 2 indicates wet evergreen forests that include study sites S6–S10. All of them are grouped but S9 overlaps with group 4 which indicates in terms of *Diospyros* species composition this site is a similar composition to semi- evergreen site. In the same way, the group–3 indicates moist deciduous forests from S11–S15 whereas S12 overlaps with group- 4 depicting similar species composition. Group- 4 represents S16–S20 which is semi-evergreen forests. Here S19 and S20 overlap with the Evergreen Forest group indicating species diversity similar to evergreen forests. Similar floristic studies using NMDS analysis were conducted by (Bueno et al. 2017).

The analysis of species composition and diversity of *Diospyros* trees suggests that evergreen and semi-evergreen forests show the highest richness, alpha, and beta diversity than dry deciduous forests. The dry deciduous forest of the lower rainfall region is peculiar in species composition but has low tree densities and low levels of alpha diversities. Not only vegetation types community composition is also strongly influenced by elevation, and edaphic factors of the area (Mwakalukwa et al. 2014). Vegetation types, rainfall, and the dioecious nature of trees also play a very important role in the distribution of these trees. Some of the trees are not known to the world and are only used by local people. Many protected areas like sacred grooves are naturally protecting these trees. Diversity in forests is decreasing due to some anthropogenic activities and the invasion of alien species. As these trees are economically and medicinally important, few are threatened, so there is a need for conservation. Gaining knowledge about forest trees is very essential aspect and the first step in the conservation of rich diversity and sustainable utilization.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25872–25881

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8779.16.9.25872-25881

#8779 | Received 10 October 2023 | Final received 09 August 2024 | Finally accepted 12 September 2024

OPEN ACCESS

ARTICLE

Tree community structure of selected green patches of Guwahati, Assam, India with special reference to spatio-temporal changes in vegetation

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Abstract: Green spaces are key aspects of urban ecology. The current study aims to estimate temporal changes in green spaces of Guwahati Metropolitan Development Authority, and also to investigate the tree community structure of three selected green patches. Change detection analysis of identified green spaces was done by comparing the normalized difference vegetation index (NDVI) maps of satellite images from 2022 with those from 1972. NDVI maps were classified into three threshold categories: no vegetation (NV), moderate vegetation (MV), and high vegetation (HV). The results show changes in the area of selected green patches as well as NV, MV, and HV regions between 1972 and 2022. The tree community structure in the three selected patches indicates a low diversity of plant species. The result of the current study prioritizes patch-wise management of urban green spaces in Guwahati city with the help of both remotely sensed and ground data. Thus, the present study can significantly contribute to plant community conservation and management of urban green spaces.

Keywords: Green spaces, GMDA, NDVI, QGIS, plant community, satellite images, urban ecology.

Abbreviations: Girth at breast height (GBH)—measurement of the circumference of a tree trunk at 4.5 ft (1.4 m) above ground level | Importance value index (IVI)—the measure of how dominant a species is in a given ecosystem | Normalized difference vegetation index (NDVI)—quantification of vegetation cover by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) reflection in images.

Editor: K. Haridasan, Palakkad, Kerala, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Goswami, M., J. Bayan, U. Dutta, A.K. Hazarika & K. Sarma (2024). Tree community structure of selected green patches of Guwahati, Assam, India with special reference to spatio-temporal changes in vegetation. *Journal of Threatened Taxa* 16(9): 25872–25881. https://doi.org/10.11609/jott.8779.16.9.25872-25881

Funding: No funding was provided for the current study.

Competing interests: The authors declare no competing interests.

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Author contributions: Conceptualised by Kuladip Sarma; Material preparation, data collection, draft preparation by Maitreyee Goswami and analysis done by Kuladip Sarma and Maitreyee Goswami. The final draft of the manuscript was written by Maitreyee Goswami and was read and approved by all the authors.

Acknowledgements: The authors are thankful to the Head of the Department (HoD), Department of Zoology, Cotton University and to the Head of the Department (HoD), Department of Zoology, Gauhati University for providing administrative support to carry out the research work

INTRODUCTION

Less than 3% of the earth's surface is covered by cities (Schneider et al. 2010), which are often located in regions rich in biodiversity. Rapid urbanisation is considered to be a major cause of declining natural habitats and resources, posing serious threats to many plant and animal species, and the expansion of cities in size and density (Turrini & Knop 2015) in some developing countries (Seto et al. 2012) has contributed to a particularly high rate of urbanization in southeastern Asia (Cohen 2006; UNDESA 2012). A potential measure of the impacts of urbanization can be made by identifying urban green spaces that are maintained and conserved. As urban green spaces by its definition are inclusive of all the public and private open spaces, primarily covered by vegetation (Tuzin et al. 2002), it can be an effective interdisciplinary approach towards sustainable development and encompass environmental, economic, social, and psychological values. They also act as protected areas for the breeding of various animal species and the conservation of plants, soil, and water quality (Haq 2011). Although urban areas are known to have a lesser number of native species (Emlen 1974; Rebele 1994) as compared to natural habitats, urban green spaces house a number of different species and also act as dispersal corridors (Bolger 2001). Quality urban green spaces in higher numbers can also be a refuge habitat for a numbers of forest-dwelling species (Mortberg & Wallentinus 2000; Park & Lee 2000).

The study of urban green spaces in India is limited. A few papers are available (Birkmann et al. 2016; Pawe & Saikia 2018) on population aspects and forest cover change. In the global context, urban landscapes are being studied for various aspects including the conservation importance of green spaces (Bolund & Hunhammar 1999; Baycan-Levent & Nijkamp 2004; Tian et al. 2011; Jennings et al. 2016). The nature of urban green spaces has been evaluated by certain criteria viz. their quantity in a particular city (Oguz 2000), their existing qualities like activities and experiences, and their benefits as perceived by users (Van Herzele & Wiedemann 2003), and their services determined by location, distribution, and accessibility (Grahn & Stigsdotter 2003; van Herzele & Wiedemann 2003; Neuvonen et al. 2007). Different methodologies have been used to study the urban green spaces and the plant communities within them such as random stratified sampling (Nowak et al. 2008), GBH and NDVI calculation (Nero et al. 2017), analytic hierarchy process (AHP) modeling and use of GIS (De Ridder 2004; Sharma et al. 2022).

Owing to various consequences of urban sprawl, green spaces are at risk of vast changes and degradation, which will ultimately affect urban wildlife and human residents. In India, nearly half of the 100 million new urban residents are expected to occupy the secondary or mid-sized cities including the cities of northeastern India (Birkmann et al. 2016). Guwahati is one such secondary city that is likely to experience population outbursts in a few decades. Guwahati, like many other Indian cities, faces problems of unplanned land use land cover (LULC) change due to negligible or even non-existent planning efforts added by the rapid urban population growth (Pawe & Saikia 2018).

With this background, this study aims to determine the temporal changes in the urban green spaces within the boundary of GMDA and also to detect the changes in three selected green patches between 1972 and 2022 in terms of area with the help of remote sensing (RS) and geographic information system (GIS), which shall shed light on the impact of urbanization on urban green spaces. The plant community structure of three selected urban green patches of Guwahati has also been studied to emphasize the importance of urban green spaces in the conservation of wildlife.

MATERIALS AND METHODS

Study Area

Guwahati city, situated on the southern bank of the Brahmaputra River, is the biggest and one of the most important cities in northeastern India. It falls under the jurisdiction of the Guwahati Metropolitan Development Authority (GMDA). The GMDA boundary currently covers an area of 262 km^2. As per the report, the area is scattered with a great number of hills that are mostly covered with forests and some exposed rocky surfaces.

The selected sites for studying tree community structure include three urban green spaces within Guwahati city (Figure 1), viz., patch 1 (P1) with Navagraha Hill at its entrance, patch 2 (P2) at the entry point of Kamakhya Temple and patch 3 (P3) including the area around Basistha Temple. The first patch is at the Navagraha Hill, also known as the Chitrachal Hill and is located at the southeastern part of the Guwahati city in Assam. It is known for the Navagraha Temple located at its top. The second patch which is at the entrance to the world famous Kamakhya Temple, is located at the Nilachal Hill in the western part of Guwahati. Basistha, where the third patch has been designated, is located at the south-east corner of Guwahati and it stands at

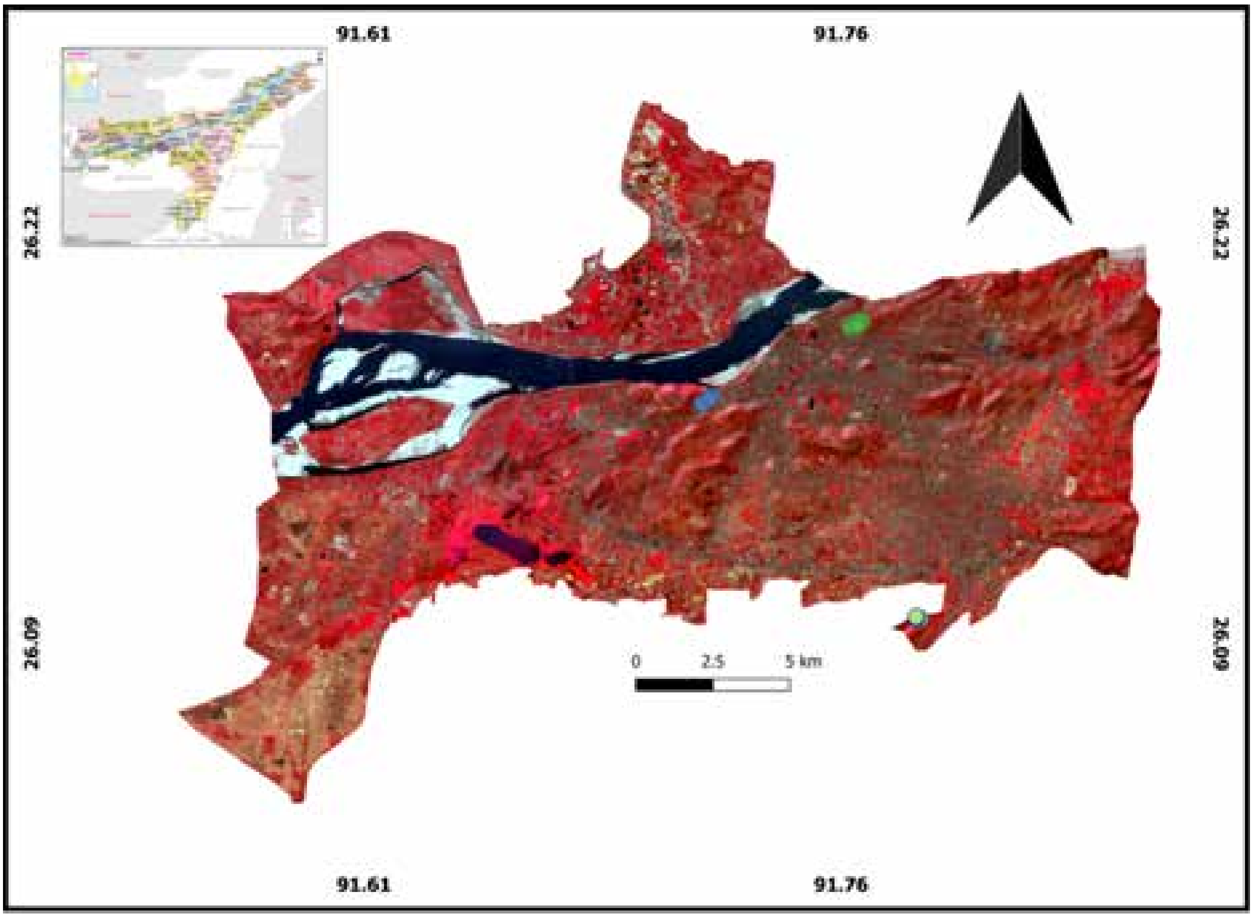


Figure 1. Map of GMDA area in 2022 showing the study sites with the dark green dots indicating patch 1, blue dots indicating patch 2, and light green dots indicating patch 3.

the bank of the mountain streams coming from the Meghalaya Hills, which ultimately form the rivers Basistha and Bahini or Bharalu flowing through Guwahati. These particular study sites were selected as they are some of the extant green patches within Guwahati city which are also easily accessible. Moreover, all of the selected sites are having an area greater than 1 ha in order to be considered as green patches for this specific study.

METHODS

Acquisition of Satellite Images and Identification of Green Spaces using normalized difference vegetation index (NDVI)

Satellite imagery of 1972 (Landsat MSS) and 2022 (Sentinel) were downloaded from the websites of United States Geological Survey (USGS; https://www.usgs.gov) and Copernicus (Table 1). The band designation for Landsat MSS satellite image is – Band 4: Red spectral range; Band 5: NIR spectral range. Similarly, the band information for Sentinel satellite image is- band 4: red spectral range; band5, 6 and 7: vegetation red edge spectral range and band 8: NIR spectral range. The NDVI values were calculated for the downloaded satellite images using the following formula-

NDVI = (NIR - Red) / (NIR + Red)

After calculating the NDVI values, the NDVI maps for the years 1972 and 2022 were prepared. The urban green spaces in and around Guwahati were identified from this final map and the study sites were selected.

Table 1. Data acquisition details

Satellite	Sensor	Spatial resolution	Acquisition date	File format	Source
Landsat2	MSS	80	22.xi.1972	Geotiff	USGS
Sentinel-2	A	10	18.iv.2022	Geotiff	Coppernicus

Tree community structure of three selected green patches

Three green patches were selected from the NDVI map of 1972 and these are – Navagraha or Chitrachal Hill, Nilachal Hill, and Basistha Hill. Different numbers of quadrats of 10 x 10 m were randomly placed in each patch. A total of 16 quadrats of size 10 x 10 m were placed in all the three patches. Eight quadrats were taken for P1, four quadrats were drawn in P2 and four quadrats placed in P3. A fiber measuring tape of 15 m was used to lay the random quadrats and also to calculate the GBH of plants. The coordinates of the quadrats were recorded using a handheld Garmin etrex 30x GPS device.

Mapping of selected study sites and calculation of their area Using QGIS

Estimation of change in the geometric area of the three selected patches, viz., P1, P2, and P3 was done between the years 1972 and 2022 in QGIS platform. The selected green patches and their temporal changes over the years in terms of area were then made into maps.

Reclassification of the NDVI maps and detection of temporal change of the classified zones between 1972 and 2022

The NDVI maps for 1972 and 2022 were reclassified into three major zones, viz., no vegetation (NV), moderate vegetation (MV) and high vegetation (HV) zones based on their NDVI values (Figure 2). The range of NDVI values for the three zones are 0–0.2, 0.2–0.4, and >0.4 for NV, MV, and HV zones, respectively. The change in total area covered by each of these three zones was calculated using Q-GIS.

Data analysis

The data collected on trees in every quadrat were then analyzed for determining their density, frequency, basal area, relative frequency, relative density, relative dominance, importance value Index (IVI), and Shannon-Weiner index of species diversity. A diversity dominance curve was plotted for the three urban green patches comparing their species diversities (Figure 5).

RESULTS

Identification of urban green spaces of Guwahati City and the estimation of area change in the three selected urban green patches

The NDVI maps of 1972 and 2022 (Figures 3, 4) show all the green spaces within the boundary of GMDA. These maps show around 20 urban green spaces in and around Guwahati city. When compared, the satellite image of 2022 shows reduction and fragmentation in the urban green spaces of Guwahati from 1972 (Figure 4). The area of the selected study sites in 1972 were approximately 1593.95 ha, 253.68 ha, and 85.81 ha for P1, P2, and P3, respectively; while the same in 2022 are approximately 233.36 ha, 220.36 ha, and 92.78 ha, respectively. P1 and P2 show decrease in their area over the span of 50 years and the differences in their area between 1972 and 2022 are 1360.59 ha for P1 and 33.32 ha for P2. Contrarily, P3 shows an increase in area of about 6.97 ha within the given time period (Table 2).

Table 2. Change in area (1972–2022), number of plant species, and diversity indices of three selected urban green patches of Guwahati City, Assam, India

	Patch ID	Change of area in hectare (1972–2022)	Number of plant species	SWI for plant diversity
1	P1	1360.59	14	2.43
2	P2	33.32	6	1.68
3	P3	-6.97	4	1.29

Table 3a. Tree community parameters of selected patch 1 of GMDA, Assam

Name	Density/m²	Frequency	Basal area (m²)	IVI
Albizia procera	0.125	12.5	0.29	14.62
Bombax ceiba	0.25	12.5	0.19	17.56
Musa sp.	0.125	12.5	0.09	11.78
Cocos nucifera	0.125	12.5	0.09	11.85
Mangifera indica	0.125	12.5	0.02	10.88
Artocarpus heterophyllus	0.125	12.5	0.05	11.23
Melia azedarach	0.125	12.5	0.18	13.05
Tectona grandis	0.125	12.5	0.88	22.63
Syzygium cumini	0.125	12.5	0.62	19.09
Albizia saman	0.5	37.5	2.73	73.62
Unknown sp. 1	0.125	12.5	0.10	11.94
Sterculia sp.	0.75	12.5	0.60	40.51
Unknown sp. 3	0.125	12.5	1.04	24.90
Unknown sp. 4	0.125	12.5	0.42	16.32
Total			7.29	

Study of the plant communities of the selected urban green patches

For the first green patch P1 (Table 3a), it has been found that *Albizia saman* is the most frequent species, while *Sterculia* sp. has the highest density of all. Eleven species out of 14 having the same density were each present in one number in the eight quadrats laid in patch 1. *Albizia saman* and *Mangifera indica* occupies the highest and the lowest basal area in the study site,

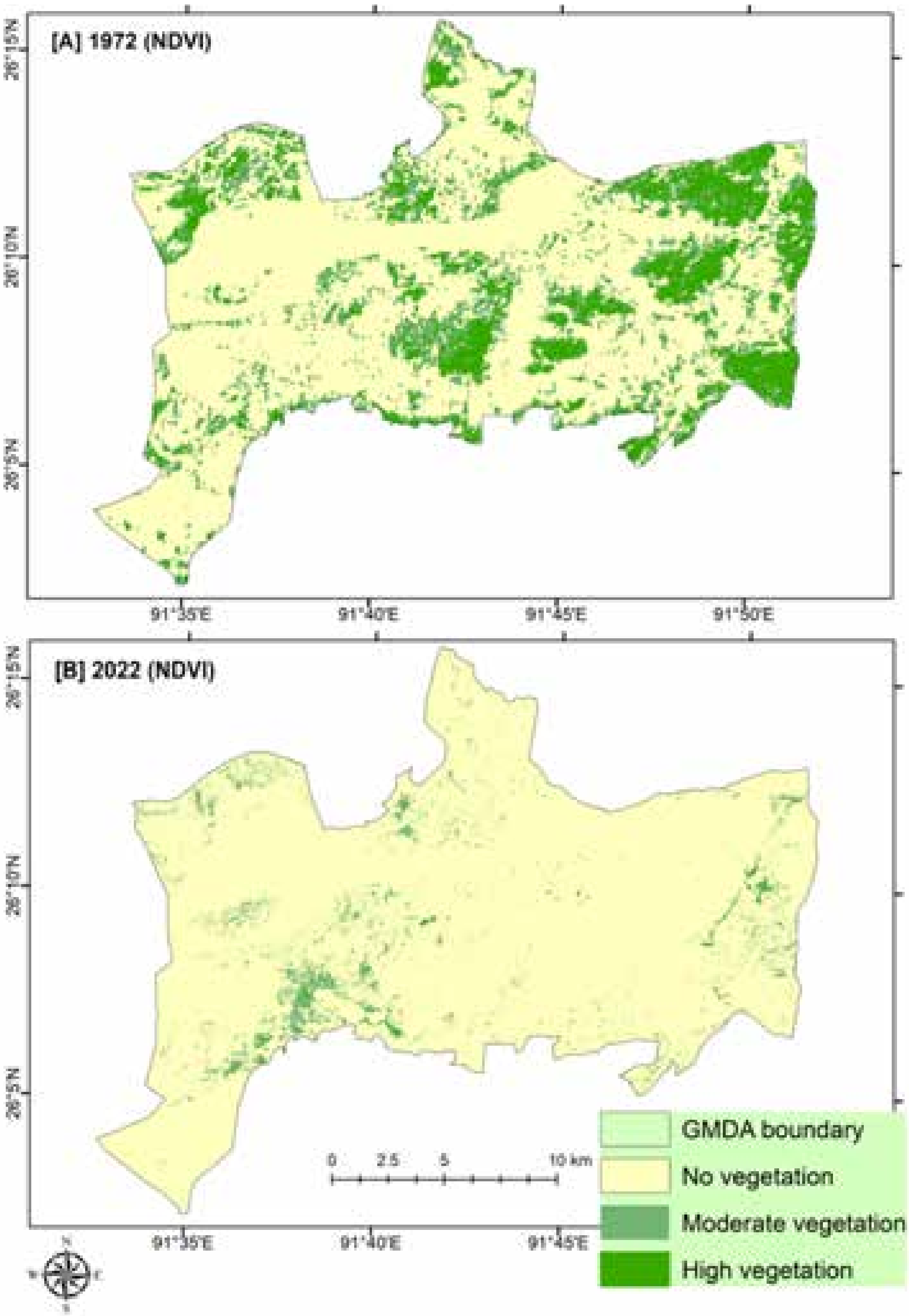


Figure 2. NDVI-based reclassified zones, i.e., No Vegetation, Moderate Vegetation, and High Vegetation zones.

respectively, with *Albizia saman* showing the highest IVI value. The species diversity as calculated by Shannon-Weiner index is found to be 2.43.

In the second urban green space P2 (Table 3b), *Delonix regia* and *Albizia procera* have the highest frequency and density, respectively. All the remaining five species have the same frequency, whereas *Albizia saman* and *Shorea robusta* exhibit the lowest density of 0.25. The basal area as well as the IVI is largest for *Delonix regia*. The Shannon-Weiner index for species diversity is 1.68 for the green patch under consideration.

In the third study site P3 (Table 3c), the highest and the lowest densities are shown by *Shorea robusta* and *Ficus religiosa* and the most frequent species is *Albizia procera* with a frequency of 75%. The basal area is greatest for *Shorea robusta* and so is the IVI. The

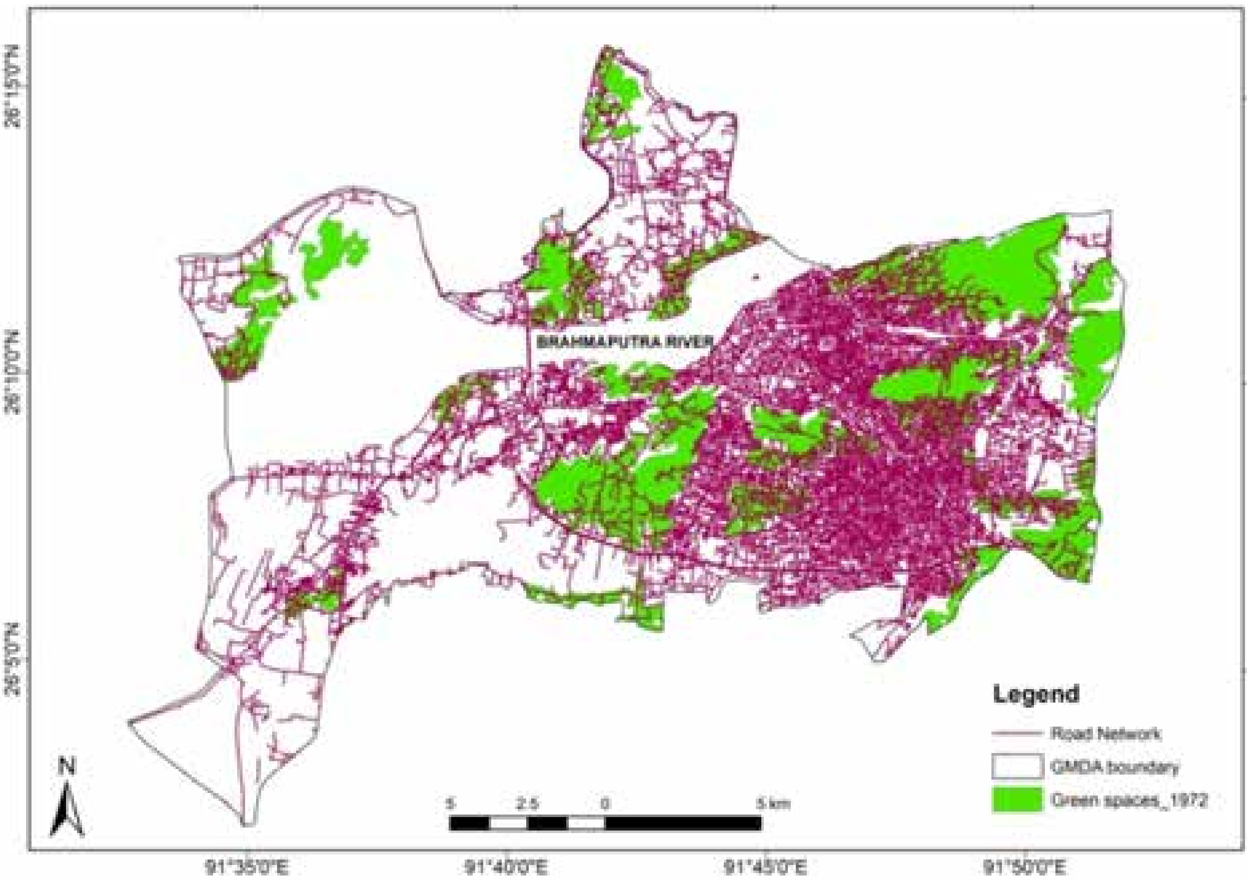


Figure 3. Identified green spaces within the GMDA area in the year 1972.

Table 3b. Tree community parameters of selected Patch 2 of GMDA, Assam.

Name	Density/m²	Frequency	Basal area (m²)	IVI
Delonix regia	0.75	50	1.75	89.26
Albizia saman	0.25	25	0.82	40.05
Shorea robusta	0.25	25	0.19	25.46
Magnolia champaca	0.5	25	0.10	29.94
Plumeria sp.	0.5	25	0.43	37.60
Albizia procera	1.5	25	1.01	77.69
Total			4.29	

Table 3c. Tree community parameters of selected Patch 3 of GMDA, Assam.

Name	Density/m²	Frequency	Basal area (m²)	IVI
Albizia procera	1	75	0.55	82.56
Tectona grandis	0.5	25	0.36	36.40
Ficus religiosa	0.25	25	1.34	56.06
Shorea robusta	2.25	50	1.51	124.98
Total			3.77	

Shannon-Weiner index is 1.29 for the area.

From the above data, a diversity dominance curve is plotted comparing the species richness and abundance of the selected sites having species rank on the X-axis and IVI value on the Y-axis (Figure 5), indicating that P1 has the greatest and P3 has the lowest plant diversity in terms of species richness and abundance.

Temporal change detection from NDVI map between 1972–2022

The three zones, viz., No Vegetation (NV), Moderate Vegetation (MV), and High Vegetation (HV), into which the green spaces of Guwahati have been classified based on their NDVI values, show drastic changes over the last 50 years from 1972 to 2022 (Figure 6). The % area of each of the three classes or zones for 1972 and 2022 respectively are shown in the table given below (Table 4).

Table 4. shows an increase (in %) of 26.75 in the NV zone in the year 2022 from 1972, whereas MV and HV zones show sharp decrease (in %) of 12.09 and 14.66, respectively, from 1972 to 2022. The NV zone has

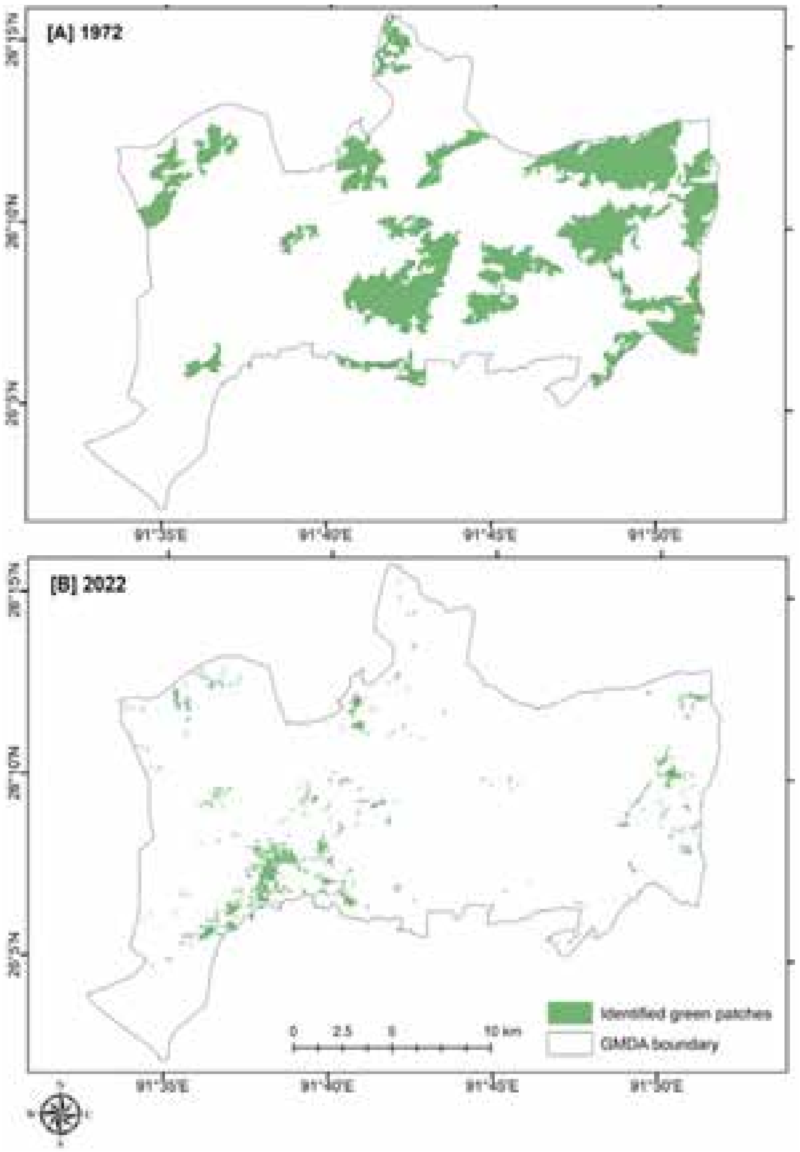


Figure 4. Comparison of the identified green spaces within GMDA between the years 1972 [A] and 2022 [B].

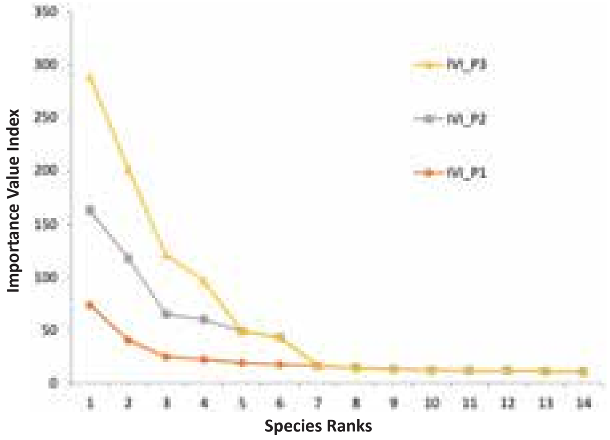


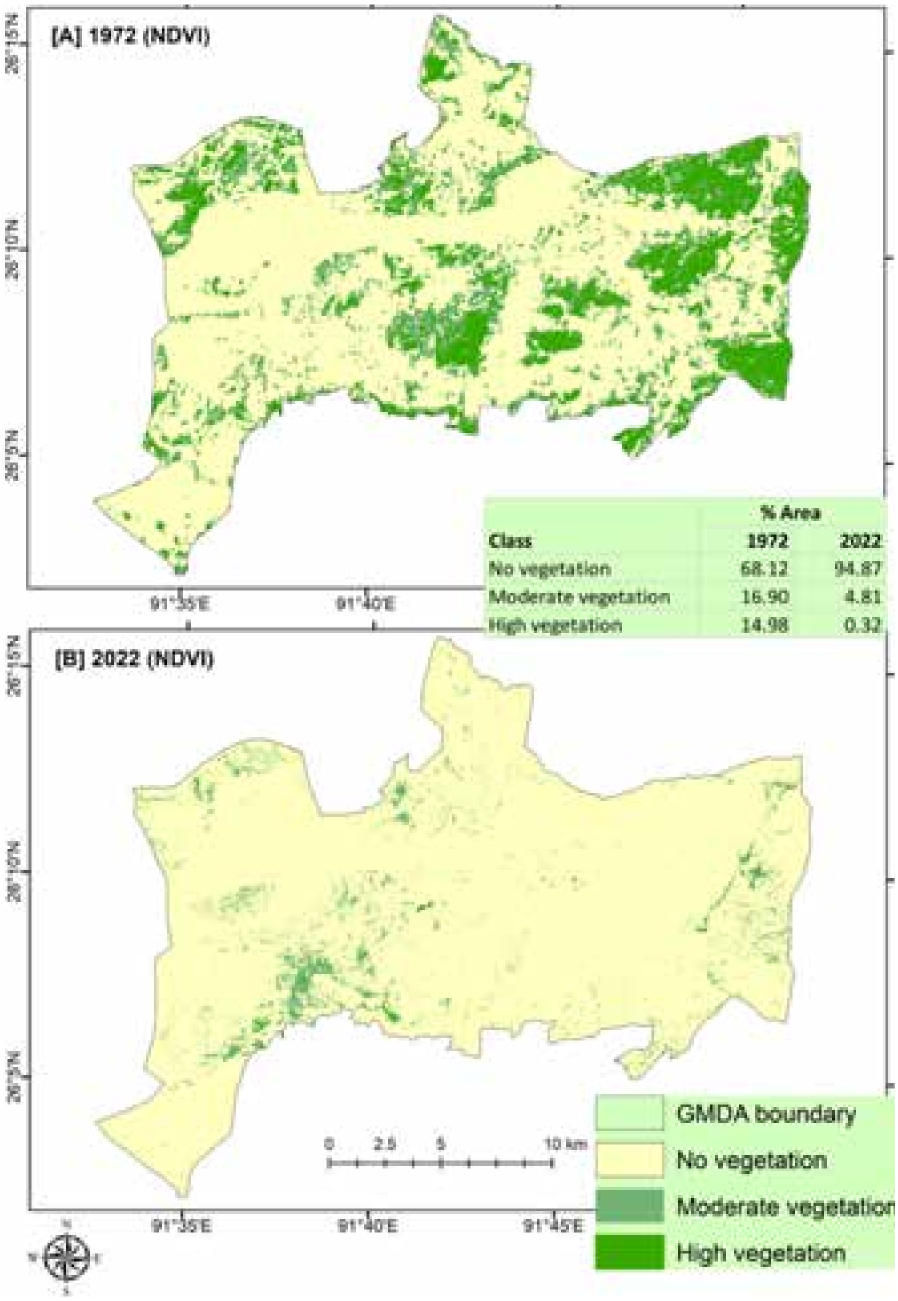
Figure 5. Diversity Dominance Curve of the plant communities of the Study Sites, where P1, P2 and P3 are Patch 1, Patch 2 and Patch 3.

remained the same throughout those 50 years whereas, the HV and MV zones have mostly been converted to NV zone directly (Table 5).

DISCUSSION

The area changes of the urban green spaces of Guwahati including the selected study sites are a clear indication that the urban green spaces are facing depletion due to various reasons, among which the primary reason can be attributed to anthropogenic activities. The increase in the total area of the no vegetation zone and the subsequent decrease in the areas covered by moderate and high vegetation zones

(Figure 6) suggest the expansion of human settlements and built-up areas and the subsequent decline of vegetated areas or green spaces. The dynamics of the changes in the three zones are as such that the NV zone has not changed from 1972 to 2022, but the HV and the MV zones have changed directly into NV Zone and only a small fraction (2.62%) of HV zone has been converted to MV zone. The increasing establishment of human settlements has brought about the fragmentation of urban green spaces and has led to a reduction in the total area occupied by these green spaces in Guwahati. With the influx of people into the city from various other parts of Assam as well as from different corners of the country, the relatively uninhabited green spaces are being occupied at a much faster rate. This can negatively affect the biotic communities within the green spaces and can also interfere with the role of urban green spaces in biodiversity conservation. A similar type of observation has been made in a study by Sangwan et al. (2022), which mentions the challenges faced by



Class	% Area 1972	% Area 2022
No vegetation	68.12	94.87
Moderate vegetation	16.90	4.81
High vegetation	14.98	0.32

Figure 6. Comparison of the % change in the area of the three NDVI zones between 1972 [A] and 2022 [B].

Table 4. Area statistics of the green patches between 1972 and 2022.

Class/Zones	% Area	
	1972	2022
No vegetation	68.12	94.87
Moderate vegetation	16.90	4.81
High vegetation	14.98	0.32

Table 5. Change detection matrix of three vegetation classes in the study area between 1972 to 2022.

Class name		2022 (Area in %)			
		No vegetation	Moderate vegetation	High vegetation	Total
1972	No vegetation	68.12			68.12
	Moderate vegetation	14.61	2.19	0.1	16.9
	High vegetation	12.14	2.62	0.22	14.98
	Total	94.87	4.81	0.32	100.00

the urban green spaces of many Indian cities due to competing economic interests and demand on land for various purposes such as residential, commercial, industrial and institutional. In a case study of Noida (Sharma et al. 2022), it has been noticed that the green spaces are isolated and fragmented limiting the additive benefits that can be derived from larger interconnected green spaces. Nevertheless, they are an integral component of urban ecosystems harbouring a wide array of animal and plant communities.

As a whole, the species richness of plants was found to be higher in the urban green spaces as compared to urban built-up areas which may be due to the presence of a variety of microhabitats and greater resource availability in the green spaces (Nielsen et al. 2013). According to the diversity-dominance curve (Figure 5) that was plotted for the plant communities of the green patches, species evenness is more in P1, as all the species are relatively equally abundant than in the other two sites where one species is much more abundant as compared to the other species of that particular area. A greater biodiversity of an area indicates more productivity and hence greater availability of resources leading to a healthy and stable ecosystem that can provide various ecosystem services. Thus, urban green spaces are very much necessary for the maintenance of urban ecosystems. Moreover, they have an undeniable impact on the health and well-being of humans, encouraging human positive emotions (Cameron et al. 2020); and master planning is required to keep these green spaces intact (Nora et al. 2017).

CONCLUSION

Urban green spaces—open areas within cities covered with vegetation—are an important aspect of urban ecology, and due to rapid urban sprawl, they are changing. This study shows that these changes can be detected and determined with the help of remote sensing (RS) and GIS software by highlighting the changes occurring in green patches within Guwahati City. Using satellite imagery, it was shown that most of the green spaces are undergoing degradation and fragmentation. These green spaces also play an important role in preserving the biodiversity of urban areas. In the current study, observations have been made regarding the plant communities of selected green patches with the help of random quadrate sampling. The diversity dominance curve for the plant communities of the study sites is included in comparing the plant diversity among the selected green patches. The challenges faced by these green spaces within the city should be addressed properly through appropriate planning in order to maintain the overall well-being of the urban ecosystem as well as the city dwellers.

There is scope for more work that can be done on the urban green spaces of Guwahati which can shed light on the condition of the extant green spaces and can highlight their importance. The study of the plant communities can be performed more comprehensively. These data would help in the formulation of plans to improve and protect the green spaces in the city of Guwahati.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25882–25887

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9349.16.9.25882-25887

#9349 | Received 05 August 2024 | Final received 27 August 2024 | Finally accepted 15 September 2024

COMMUNICATION

First record of leucistic Sloth Bear *Melursus ursinus* Shaw, 1791 (Mammalia: Carnivora: Ursidae) in Panna Tiger Reserve, India

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Abstract: The first photographic evidence of a leucistic Sloth Bear from Panna Tiger Reserve, Madhya Pradesh, was obtained during a camera trapping survey conducted during 2019–2021. Despite the wide distribution of Sloth Bears in the Indian sub-continent, leucism is extremely rare to find. This record evokes the need for scientific reporting of such encounters and further research on the causal factors of leucism with respect to the species' ecological and conservation implications.

Keywords: Camera trapping, central India, coat colour, leucism, Madhya Pradesh, melanin, ursid, Vindhya Hills.

Editor: L.A.K. Singh, Bhubaneswar, Odisha, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Chaudhuri, S., S. Dutta & K. Ramesh (2024). First record of leucistic Sloth Bear *Melursus ursinus* Shaw, 1791 (Mammalia: Carnivora: Ursidae) in Panna Tiger Reserve, India. *Journal of Threatened Taxa* 16(9): 25882–25887. https://doi.org/10.11609/jott.9349.16.9.25882-25887

Funding: This research was funded by the Madhya Pradesh Forest Department (MPFD), National Tiger Conservation Authority (NTCA) (No. WII/KR/PROJECT/PTRP/2013-2014/012(B)) and National Water Development Agency (NWDA) (No. WW/KR/PROJECT/PLMP/2017-18/F(1)).

Competing interests: The authors declare no competing interests.

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Author contributions: SC, SD & KR- Concept, design, and supervision. SD- Data collection. SC & SD- Data synthesis, analysis, and interpretation. SC- Manuscript writing. SC, SD & KR- Manuscript review and comments. KR- Funding acquisition.

Acknowledgements: We are thankful to the Madhya Pradesh Forest Department, especially the field director, deputy director of PTR, and the National Tiger Conservation Authority for permission, logistics, and supporting the study financially. We express our gratitude to the Wildlife Institute of India for institutional and overall support. We sincerely acknowledge the support of field assistants and all frontline staff of PTR.

INTRODUCTION

The different colouration of pelage and or integuments in mammals is generally an outcome of the presence of pigments, especially melanin, and its different intensities cause various hues in coat colours (Slominski et al. 2004). Such colour variations in mammals and understanding the factors responsible for such occurrences have gained significant attention among biologists for centuries. The anomalies in pigmentation, or more specifically, the hypopigmentation, result in the lower production of pigments, leading to "albinism," "leucism," or "piebaldism" in birds and mammals (Abreu et al. 2013; Grouw 2013). Unlike albinism, which only affects melanin production, leucism is a congenital hypopigmentation condition characterized by either reduced or no integumentary pigmentation, but affected individuals retain normal eye colour (Grouw 2013).

In the wild, carnivores exhibited the second-most (after Eulipotyphla) number of records of leucism (Olson & Allen 2019). The Eulipotyphla group includes animals like hedgehogs, moles, shrews, and solenodons (Douady et al. 2002). The extreme rarity of leucistic morph in the animal kingdom could be linked with their odds of getting selected in nature, as these individuals may suffer from reduced foraging opportunities and communication, increased threats, as well as physiological disadvantages, which are often poorly understood (Caro 2005). Hence, it is imperative to document the presence of such colour anomalies in different taxa and determine the causal factors, in addition to their distribution and survival probability.

While the leucistic occurrence among a few large carnivores (such as tigers and lions) is well reported (Cho et al. 2013; Xu et al. 2013), records of leucistic bears are still extremely rare, except for the Kermode Bear, which is the leucistic form of American Black Bear (Marshall & Ritland 2002). India is the home of four species of bears, namely Sloth Bear, Himalayan Black Bear, Himalayan Brown Bear, and Sun Bear. The Sloth Bear *Melursus ursinus* is the most widely distributed, and is categorised as 'Vulnerable' due to the declining population trend (Dharaiya et al. 2016). Nevertheless, no scientific literature on leucistic Sloth Bears or the remaining three other species exists so far, although a few newspaper articles of photographic capture of leucistic and piebald individuals exist from central and western India (Tere 2019; Chatterjee 2020; TNN 2022). Albinism in Sloth Bears has previously been reported in Chhattisgarh State in central India (Bharos 1988). Between the years 1886 and 2013, a few instances of albino, white, and red-brown conditions in bears have been compiled with occurrences reported from central India, Bihar, and Orissa (Odisha) in Singh (2014) and Mahabal et al. (2019). Such sporadic occurrences of rare leucistic and albino Sloth Bears certainly require more comprehensive documentation.

STUDY AREA AND METHODS

Panna Tiger Reserve (PTR) is situated in the Vindhya Hill range of central India (Image 1). The total area of PTR is 1,574 km^2, which includes core and buffer zones of 542 km^2 and 1,032 km^2, respectively. The PTR has a varied terrain, ranging from flat areas to steep escarpments, with an elevation range of 164–555 m. Ken River is the only major perennial water source, which flows through PTR, dividing it into two parts (i.e., eastern and western). The major forest type of PTR is tropical dry-deciduous (Champion & Seth 1968). There are three different seasons in PTR, i.e., summer or hot season (March–June, mean maximum temperature 45°C), monsoon (July–October, average rainfall 1,100 mm), and winter or cold season (November–February, mean minimum temperature 5°C). Major tree species of PTR include Teak *Tectona grandis*, Tendu *Diospyros melanoxylon,* and Kardhai *Anogeissus pendula* (WII 2022). PTR harbours significant mammalian diversity, such as the Indian Tiger *Panthera tigris*, Leopard *Panthera pardus*, Striped Hyena *Hyaena hyaena*, Grey Wolf *Canis lupus*, Sloth Bear, Chital *Axis axis*, Sambar *Rusa unicolor*, Wild Boar *Sus scrofa*, Nilgai *Boselaphus tragocamelus*, Chinkara *Gazella bennettii*, and Chousingha *Tetracerus quadricornis* (WII 2022). The core zone includes three villages, while the buffer zone holds 63 villages.

Systematic camera trap surveys were conducted in PTR during 2019–2021 (Image 1) as a part of the ongoing research project entitled "Tiger Reintroduction and Recovery Programme in Panna Tiger Reserve, Madhya Pradesh", under permit number Technical/4301, dated 09/06/2015, issued by the principal chief conservator of forest (Wildlife Division), Madhya Pradesh, India. The study area was gridded (2 km^2), and double-sided motion-censored camera traps were deployed (Cuddeback C1) in each grid following the protocol of all India Tiger estimation (Jhala et al. 2019). Each year, the camera trap survey was conducted during cold and hot seasons (Image 1), except for 2021, when the cold season was the only sampling period. The camera traps were placed on the forest roads and trails to maximize the detection of carnivores (Karanth et al. 2011) and remained active

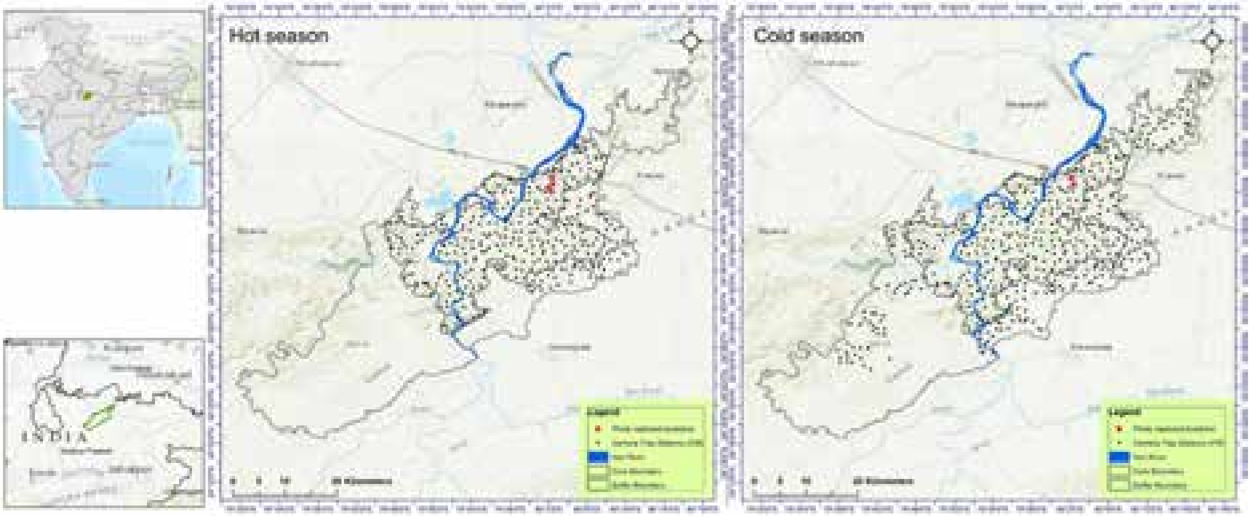

Image 1. Location of Panna Tiger Reserve in central India and camera trap locations during two seasons, i.e., summer or hot season and winter or cold season, from 2019 to 2021. The locations where the leucistic Sloth Bear was photo-captured, were marked (red stars) and represented season-wise.

on a 24-hour basis for 30 days. Photographs of Sloth Bears were considered independent if they were taken ≥30 minutes apart.

RESULTS

In the hot season of 2019, the first photograph of a leucistic adult female Sloth Bear (Image 2A, Image 2B) was obtained from camera traps in the core zone of PTR, accompanied by one yearling (≥ one year of age) with a natural (black) coat colour (Image 2C,D). Similarly, a leucistic adult female Sloth Bear carrying two cubs (≤ one year, natural coat colour) on its back was detected twice during the hot season of 2020 (Image 2E,F). Lastly, in the cold season of 2021, a total of four detections was obtained of leucistic Sloth Bears (three single individuals, one with a yearling) from camera traps (Image 2G,H). All the photo-captures (n = 9) were obtained from five unique camera trap locations in the core zone of PTR during hot and cold seasons, with an average distance of 1.06 km (ranging 0.57–2.57 km). Out of these five locations, the leucistic bear was detected from four and two locations (one unique and one previously observed location in the hot season) during hot and cold seasons, respectively (Image 1). Photographs of Sloth Bears showed the retention of the normal eye colour, along with a light brown pelage (Image 2A,B) due to the reduction of melanin production, which confirmed the case of leucism in Sloth Bears in PTR (Bahar Baviskar, pers. comm. 15.vii.2024).

Overall, the photographic captures of leucistic Sloth Bears were rare, consisting of 0.4–1.40 % of the total Sloth Bear photo-captures across the years and seasons. For the leucistic Sloth Bears, the number of photo-captures ranged 2–4, with a relative abundance index (RAI) of 0.02–0.04 captures per 100 trap-nights, whereas the number of photo-captures and RAI for Sloth Bears with normal colouration varied 215–634 and 1.48–6.88 captures per 100 trap-nights, respectively (Table 1). Leucistic Sloth Bears were detected in less than 1% (0.64–0.90 %) of the total camera trap locations; however, Sloth Bears with normal colouration were recorded 47.45–67.50 % of the total camera trap locations during each year and season (Table 1).

DISCUSSION

Evidence of the leucistic Sloth Bear's presence in Panna Tiger Reserve was provided, which is perhaps amongst the very few ever-reported from the central India and other parts of the country in the scientific literature (other than newspaper reports). Anecdotal occurrences of "brown" Sloth Bears were previously reported by naturalists and hunters (Pocock 1933; Prater 1980; Brander 1982). The leucistic bears found in PTR also showed a light brown coat colour (Image 2), indicating similarities with the past records of such "brown" Sloth Bears. Sloth Bears are individually unidentifiable since they do not have uniquely marked pelage (Prater 1965). As discussed previously, the

Table 1. Details of photographic captures in Panna Tiger Reserve, Madhya Pradesh, India, showing the number of camera trap nights, the total number of photo captures, and the relative abundance index (RAI) of Sloth Bears with normal colouration and leucistic ones. The number of camera trap locations is given where individual morphs were photo-captured. The data were obtained from camera trapping surveys conducted during three cold seasons (2019–2021) and two hot seasons (2019 and 2020). RAI is the number of photo captures per 100 trap nights.

Year	Camera trap effort (Trap-nights)	Total number of photographic captures		Relative abundance index (RAI; # per 100 trap-nights)		Number of camera trap locations where Sloth Bears were photo-captured	
		Sloth Bears with normal colouration	Leucistic Sloth Bears	Sloth Bears with normal colouration	Leucistic Sloth Bears	Sloth Bears with normal colouration	Leucistic Sloth Bears
2019 Cold season	14,500	215	0	1.48	0	136	0
2019 Hot season	11,719	634	3	5.41	0.025	211	3
2020 Cold season	12,813	394	0	3.07	0	192	0
2020 Hot season	7161	493	2	6.88	0.03	164	2
2021 Cold season	9261	284	4	3.06	0.04	149	2

presence of leucistic Sloth Bears is scarce in the wild (and like other mammals as well), and given such rarity, it seemed logical to consider it as a single individual. The nighttime photographs of the leucistic individual hinder us from firmly declaring it as the same one, primarily due to the exposure of white flash. Sloth Bears are not territorial and can occur in relatively high densities compared to other bear species (Garshelis et al. 1999; Joshi et al. 1999). The occurrence of leucistic individuals was found clustered (inter-camera trap distance ranged 0.67–2.57 km) in the northern part of the PTR, probably indicating highly localized suitable habitats and or small home ranges of Sloth Bears, especially for females with offspring. Although coat colour could play a role in the communication of carnivores, including ursids (Caro et al. 2017; Eizirik & Trindade 2021), it is poorly understood; hence, the evolutionary or behavioural advantages or disadvantages of being leucistic remained unknown for Sloth Bears, as well. The leucistic adult female was detected with offspring in 2019 and 2020, indicating successful breeding in consecutive years, given all the photo captures were of the same individual.

Leucism in mammals could also be an indication of inbreeding due to habitat fragmentation (Bensch et al. 2000). Singh (1999), while discussing the range of colour variations in tigers, did mention such apprehensions through chapters on conservation and biological implications in the light of melanistic tiger in Similipal Tiger Reserve, Odisha. The PTR is one of the protected areas (PAs) which offers the best quality habitats in its landscape for wildlife. However, the connectivity (for the large carnivores, such as tigers) between PTR and other PAs is still highly fragmented (Makwana et al. 2023). Moreover, very little is known about the habitat connectivity and effect of fragmentation on the genetics of Sloth Bears (Dutta et al. 2015); hence, this finding may not be inferential but long-term monitoring of the occurrences of leucistic bears in this landscape would be insightful in determining underlying factors behind leucism and any probable conservation implications. Due to the rarity and striking colouration, leucistic organisms are often at risk of poaching (Owen & Skimmings 1992), which warrants protection, especially if a species is vulnerable with a declining population, such as Sloth Bears (Dharaiya et al. 2016). A targeted conservation approach for leucistic individuals may not be required in PTR at present; rather strengthening the protection of the Sloth Bear population should be considered, especially in the outside PAs (human-dominated landscapes) where leucistic bears can occur with normal-coloured individuals. Also, physiologically, the coat colour of leucistic bears could negatively impact individual fitness in terms of thermoregulation in tropical countries (Caro 2005).

Monitoring elusive threatened species through camera traps has gained global attention in the past two decades (Burton et al. 2015). Long-term camera trap surveys, such as All India Tiger Estimation (Jhala et al. 2019), have the potential to detect and monitor the occurrences of such unique colourations in mammals, especially elusive carnivores. Researchers are encouraged to document and report the presence of leucistic individuals and other colour anomalies in mammals from the long-term camera trap studies (and other relevant field techniques) and determine the underlying reasons for any probable future conservation implications.

Image 2. Photographs of leucistic Sloth Bears obtained from camera trap surveys in Panna Tiger Reserve, Madhya Pradesh, India, during 2019–2021: A,B—In the 2019 hot season, a single adult leucistic female was detected | C,D—Followed by a leucistic female with a yearling (> 1 year age) | E,F—A female with cubs (<1 year) were detected during the hot season of 2020 | G,H—In the cold season of 2021, a single adult individual and a female with a yearling were detected.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25888–25893

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8805.16.9.25888-25893

#8805 | Received 31 October 2023 | Final received 19 August 2024 | Finally accepted 03 September 2024

COMMUNICATION

Occurrence and distribution of Indian Pangolin *Manis crassicaudata* (Mammalia: Pholidota: Manidae) in the protected area network of Jammu Shiwaliks, India

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Abstract: The Indian Pangolin *Manis crassicaudata*, a rare and elusive species distributed across the Indian sub-continent, remains poorly understood due to its nocturnal and solitary behaviour, resulting in a lack of understanding about its ecology. This study presents the distribution of the animal in protected areas in Jammu Shiwaliks, India using the data obtained from camera trap images. Eighteen mammals including the Indian Pangolin were recorded from 131 camera trap locations during 3,144 trap nights in a cumulative protected area of 127km^2 in an elevational range of 358–880 m. Given its ecological significance, more rigorous surveys need to be conducted to gain a comprehensive understanding of the distribution, ecology, and habitat utilization of Indian Pangolin across the Jammu Shiwaliks.

Keywords: Activity pattern, camera-trapping, conservation, distribution, ecology, mammal, poaching.

Dogri: अमूर्त: भारतीय पंगोलिन *मनिस क्रासिकाउडाटा*, इक दुर्लभ प्रजाति जेहड़ी पूरे भारतीय उप-महाद्वीप च बंड्डी दी ऐ, अपने निशाचर ते इकांत व्यवहार दे कारण खराब तरीके कन्नै समझी गेई ऐ, जिसदे फलस्वरूप इसदे पारिस्थितिकी दे बारे च समझ च कमी आई जंदी ऐ। एह् अध्ययन कैमरे ट्रैप दी तस्वीरें थमां हासल आंकड़ें दा इस्तेमाल करियै भारत दे जम्मू शिवालिक च संरक्षित इलाकें च जानवरें दे बंड गी पेश करदा ऐ। 3144 ट्रैप रातीं दौरान 131 कैमरे ट्रैप थाहरें थमां भारतीय पैंगोलिन समेत 18 स्तनधारी रिकार्ड कीते गे । इसदे पारिस्थितिक महत्व गी दिक्खदे होई, पूरे जम्मू शिवालिक च जानवरें दे बंड, पारिस्थितिकी, ते आवास दे उपयोग दी व्यापक समझ हासल करने आस्तै होर सख्त सर्वेक्षण करने दी लोड़ ऐ।

Editor: Anwaruddin Choudhury, The Rhino Foundation, Guwahati, India.

Date of publication: 26 September 2024 (online & print)

Citation: Ansari, A. & N. Sharma (2024). Occurrence and distribution of Indian Pangolin *Manis crassicaudata* (Mammalia: Pholidota: Manidae) in the protected area network of Jammu Shiwaliks, India. *Journal of Threatened Taxa* 16(9): 25888–25893. https://doi.org/10.11609/jott.8805.16.9.25888-25893

Funding: The surveys were funded by the Department of Wildlife Protection, Govt. of UT of Jammu and Kashmir.

Competing interests: The authors declare no competing interests.

Author details: Ajaz Ansari is a UGC junior research fellow working on a Ph.D on large carnivores in a mountainous protected area in Jammu and Kashmir. After completing his M.Phil on mammals of a subtropical protected area in the Jammu Shiwaliks, he developed an interest in studying high-altitude mammals in Lesser and Great Himalayan landscapes of upper Chenab catchment. He has developed vast expertise in collecting and analyzing the field data. Neeraj Sharma is an assistant professor in the faculty of Life Sciences IME, Bhaderwah Campus where he is actively involved in research on high altitude biodiversity, wildlife ecology, interface ecology, avian ecology, and hill stream dynamics, as well as conducting scientific outreach and extension activities on different facets of mountain environment.

Author contributions: NS conceptualized the idea; AA and NS conducted the field surveys, and camera trapping; AA performed the data analysis and mapping; NS assisted the first author in writing and editing the manuscript and communicated with the journal.

Acknowledgements: Authors are thankful to the Department of Wildlife Protection, Government of the UT of Jammu and Kashmir for funding the studies. Dr. M.K Kumar (IFS), CCF & Regional Wildlife Warden, Jammu is duly acknowledged for his unwavering support, technical help, and consistent guidance to the team. Sh. Vijay Kumar, Wildlife Warden (Kathua) and his field staff is thanked for helping the teams during the field surveys. The authors express their gratitude to Rector, Bhaderwah Campus, University of Jammu, for his administrative support during the surveys. Dinesh Singh, Sudesh Kumar, Rinku Sharma, Janardhan Singh, Anil Thakar and Manoj Rana are thanked for their help in the field surveys.

INTRODUCTION

The Indian Pangolin *Manis crassicaudata* is a medium-sized toothless, myrmecophagous mammal characterized by the presence of dorsal plate-like protective overlapping keratinized scales (Mahmood et al. 2020). Placed in the family Manidae and order Pholidota, it is one of the two species of pangolins found in India (Kumar et al. 2016), the other being the Chinese Pangolin *Manis pentadactyla*, restricted to the northeastern states (Challender et al. 2019). The Indian pangolin inhabits a range of habitats, including sub-tropical, tropical, dry-mixed evergreen, riverine forests, agricultural fields, and nearby human settlements (Irshad et al. 2015). This elusive mammal is predominantly nocturnal, solitary, and fossorial, with a specialized diet that primarily consists of ants and termites, which it captures using its long adhesive tongue (Karawita et al. 2018; Ram et al. 2022). The species plays a vital ecological role as a critical biological pest regulator, highlighting its ecological importance in the ecosystem (Akrim et al. 2017; Chao et al. 2020).

Though cryptic in nature, the Indian Pangolin is subject to multiple threats, including habitat alterations, degradation, and fragmentation (Challender 2014) which are amplified by its limited reproductive capacity and low population densities (Mishra & Panda 2012). It is widely recognized as the most trafficked wild mammal globally (Zhang et al. 2022) for its scales, bones, skin, and meat throughout its range (Kumar et al. 2016; Aditya et al. 2021; Chhabra 2023). Owing to its declining population and range constriction (Aditya et al. 2021), the animal has been listed as 'Endangered' (Mahmood 2019), 'Schedule I' in WPA, 2022 amendment, and, Appendix I by the CITES (2017). As habitat use and their characteristics vary with environmental conditions (Karawita et al. 2018), identifying potential hotspots is critical for designing conservation strategies for the animal (Katuwal et al. 2017; Lyngdoh et al. 2020).

Several studies have reported the presence of Indian Pangolin across the Shiwalik hills in Himachal Pradesh (Singh et al. 2023), Uttarakhand (Joshi 2016; Lyngdoh et al. 2020; Kumar et al. 2022) and Jammu & Kashmir (Noor et al. 2016; Ahmad et al. 2020). Noor et al. (2016) during their surveys, reported a sole sighting of the animal from Jasrota Wildlife Sanctuary prompting further investigations in the region. Intensive surveys were therefore undertaken to establish its presence as well as to investigate behavioural patterns and habitat preferences in three protected areas of Jammu Shiwaliks.

MATERIAL AND METHODS

As pangolins are difficult to observe in the wild (Khwaja et al. 2019), a combination of field surveys, camera-trap monitoring, opportunistic questionnaire and fact-finding interviews with local communities was adopted in three protected areas located in the lower Shiwalik range of the outermost foothills of the western Himalaya. These included Jasrota Wildlife Sanctuary (hereafter JWS, area coverage: 10 km^2, elevation: 353–623 m), Surinsar-Mansar Wildlife Sanctuary (SMWS, 95 km^2, 547–843 m), and Thein Conservation Reserve (TCR, 19km^2, 370–825 m) (Image 1). The vegetation comprises of subtropical scrub, broad-leaved associates interspersed with patches of Chirpine at the hilltops.

The protected areas were divided into 143 sampling units of 1 km^2, each (JWS = 16; SMWS = 91, TCR = 36), henceforth referred as grid-cells using QGIS, version 3.22 (QGIS Development Team, 2021). Two camera traps (Model – Cuddeback h-1453) each were deployed in 131 trapping stations (JWS: September 2020–December 2020 & March 2023; SMWS: January 2020–May 2021; TCR: January 2021–October 2021). The IR cameras were placed between 30 and 50 cm above the ground (Tobler et al. 2008; Jenks et al. 2011) along paths, forest trails, animal tracks, water holes, ridgelines, each spaced at least 400–600 m apart following Sathyakumar et al. (2011) and Colyn et al. (2018). The camera traps were programmed to take at least five photographs with a five-second delay for each encounter in rapid-fire mode (Perera et al. 2022). Camera trap nights were taken as number of days, the camera traps were deployed in the field. Relative Abundance Index (RAI) was determined using photo capture rates (Carbone et al. 2001), while naive occupancy was estimated following MacKenzie et al. (2002). Additional surveys were conducted in JWS for more photo-captures, and signs, including the burrow distributions following Shrestha et al. (2021). The burrows were counted according to Karawita et al. (2018) and Lyngdoh et al. (2020) and classified as 'old' or 'new' following Suwal (2011).

RESULTS AND DISCUSSION

Over a course of 3,144 trap nights, 18 mammals, including a sole insectivore, the Indian Pangolin (Images 2a–d) were photo-captured and these included Rhesus Macaque, Grey Langur, Indian Crested Porcupine, Indian Hare, Common Leopard, Leopard Cat, Jungle Cat, Asian Palm Civet, Small Indian Civet, Indian Grey

Mongoose, Golden Jackal, Wild Boar, Chital, Indian Muntjac, Himalayan Goral, Nilgai, and Sambar. The first photographic record of the Indian Pangolin was obtained on the 2nd day of the camera trapping. When examined independently, six independent photo-detections (RAI = 0.94) resulting in a naïve occupancy of 0.13 were recorded for JWS, whereas three photo-detections (RAI = 0.21; ψ =0.03) were observed for SMWS. No signs of the Indian pangolin were observed in TCR during the entire sampling effort. This may be attributed to high disturbances, xeric conditions, and lack of food base. This warrants further investigation.

The animal has been observed between 132 m and 2,704 m from different habitats in the Himalayas (Irshad et al. 2015; Akrim et al. 2017; Suwal et al. 2020). During the current surveys, it was found to occur in an elevational range of 500–580 m. The investigations revealed that the Indian pangolin has a specific habitat preference, with all photo-detections and burrows occurring in undisturbed forested areas with high to moderate canopy coverage, lower elevations, proximity to termitarium, and easy access to water as supported by others as well (Karawita et al. 2018; Shrestha et al. 2021). The findings of this study indicate that the Indian Pangolin predominantly exhibits nocturnal activity patterns (88.89% of all sightings during the night), as evidenced by Mishra & Panda (2010), Aditya et al. (2021), and Perera et al. (2022).

During additional investigations in JWS, 31 burrow sites were discovered in vegetation patches dominated by *Bombax cieba - Acacia modesta - A. catechu - Dalbergia sissoo.* Similar vegetation associations with the same physiography and phytoclimate have been reported as preferred pangolin habitats in Pakistan (Mahmood et al. 2018; Yasmeen et al. 2021). Two distinct types of burrows were observed, a single large burrow with a wide entrance (the living burrow) and other smaller branching burrows with multiple entrances (the feeding burrows). Twenty-five (80.65%) of these were classified as old burrows, while six (19.35%) as new that showed signs of recent activity, including freshly excavated, claw markings, and the presence of termites, primarily *Odontotermis* sp. in faeces. The majority of the burrows (Image 3a–d) were found near trematoriums (Image 3e–f) in bamboo-dominated hill slopes, away from human disturbances but close to water sources. Similar observations have been recorded by Katuwal et al. (2017); Karawita et al. (2018);

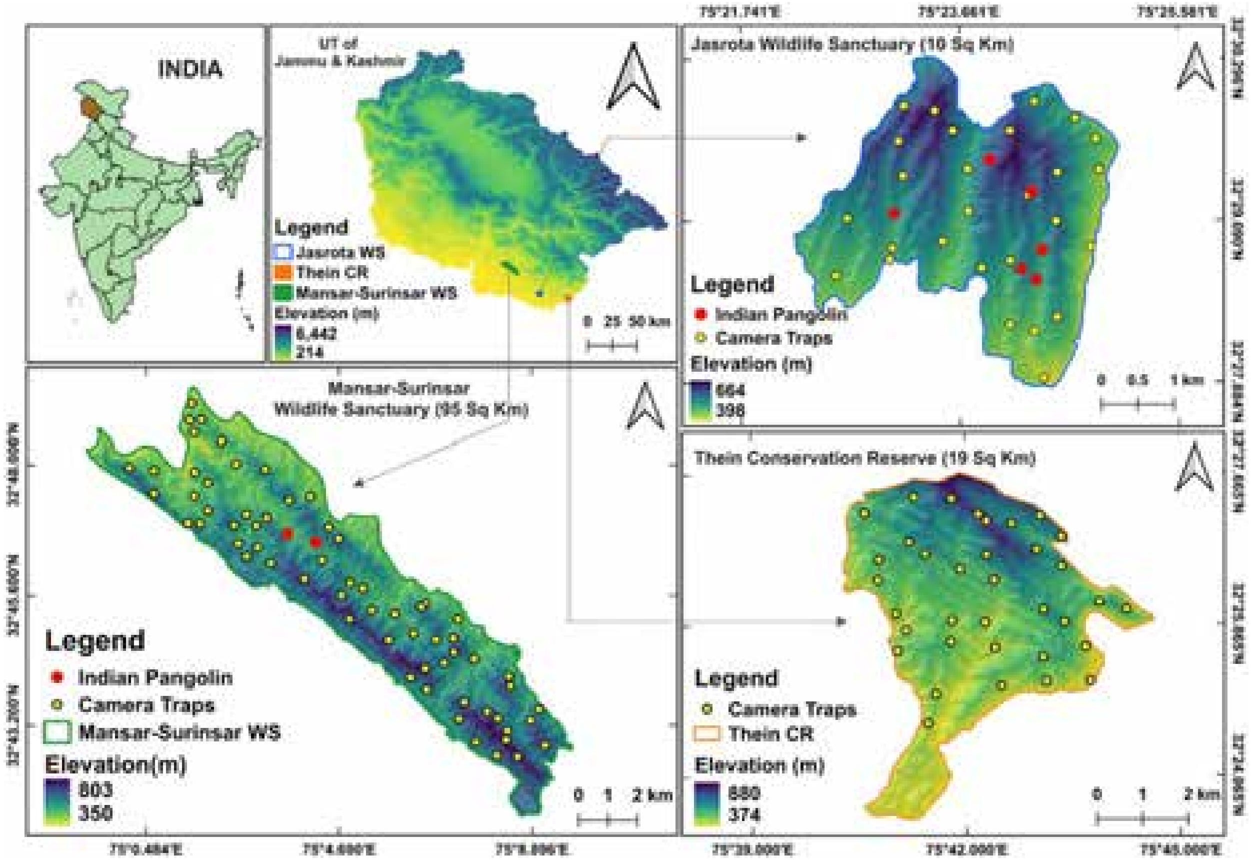

Image 1. Map of the protected areas (Surinsar-Mansar Wildlife Sanctuary, Jasrota Wildlife Sanctuary, and Thein Conservation Reserve) in Jammu Shiwaliks showing the camera trap locations, and Indian Pangolin sightings.

Image 2. Camera trap photographs of the Indian Pangolin *Manis crassicaudata*: a—Jasrota Wildlife Sanctuary (JWS) | b—Surinsar-Mansar Wildlife Sanctuary | c—New site 1 JWS | d—New site 2 JWS.

Lyngdoh et al. (2020), and Shrestha et al. (2021). At one burrow, the small mammals, including Grey Mongooses and Small Indian Civets, were also photographed thus confirming that pangolin's burrows are actively used by other small mammals as observed by Karawita et al. (2018), Lehmann et al. (2020), and Perera et al. (2022) as well.

A majority of locals were unfamiliar with the Indian Pangolin, though elderly respondents provided detailed descriptions of the animal's morphology and could correctly identify it when shown photographs. The unique animal with scales covering its body when disturbed rolls into a ball-like shape is known locally as 'challa' ('ring' in Dogri). As the evidences of hunting were minimal and there was no record of its trade or seizure so far, the poaching of Indian Pangolin is ruled out from the region. While the study provided valuable insights into the distributional patterns and habitat preferences of the Indian Pangolin in the region, it also highlights the need for effective management strategies to address the threats to the species and its habitat in the region, particularly fragmentation and habitat degradation. The study underscores the importance of conducting further research to better understand the ecological factors that influence the population dynamics and distribution of the Indian Pangolin to effectively implement conservation strategies for the vulnerable animal.

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Image 3. Habitat of the Indian Pangolin *Manis crassicaudata*: a–d—living burrows (fresh) (© Ajaz Ansari)| e–f—termitarium (© Neeraj Sharma) in Jasrota Wildlife Sanctuary.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25894–25903

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9088.16.9.25894-25903

#9088 | Received 11 April 2024 | Final received 01 September 2024 | Finally accepted 10 September 2024

COMMUNICATION

The first report of an assassin bug of the genus *Ademula* McAtee & Malloch (Reduviidae: Emesinae) from India and its rediscovery from Sri Lanka

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Abstract: Emesine bug *Ademula contaminata* (Distant, 1903) is recorded from India for the first time and rediscovered from Sri Lanka. Details of its morphology, including the male genitalia, are presented along with images of the habitat. Images of living bugs in natural habitat are presented along with some comments on natural history of these bugs.

Keywords: Assassin bug, distribution, emesine bug, Emesini, natural history, Oriental region, thread-legged bugs.

Editor: Hélcio R. Gil-Santana, Instituto Oswaldo Cruz, Rio de Janeiro, Brazil. **Date of publication:** 26 September 2024 (online & print)

Citation: Sankararaman, H., T. Ranasinghe, A. Agarwal, A. Sumanapala & H.V. Ghate (2024). The first report of an assassin bug of the genus *Ademula* McAtee & Malloch (Reduviidae: Emesinae) from India and its rediscovery from Sri Lanka. *Journal of Threatened Taxa* 16(9): 25894–25903. https://doi.org/10.11609/jott.9088.16.9.25894-25903

Funding: Self-funded.

Competing interests: The authors declare no competing interests.

Author details: SANKARARAMAN. H is a determined insect collector, interested in the taxonomy and natural history. He works on hover flies (Syrphidae) from India and has described few species new to science. He has documented several groups of insects across India, especially from the biodiversity hotspots. THARINDU RANASINGHE is a researcher at the Wild Island Foundation in Sri Lanka, where he works as a field biologist. His research primarily focuses on Sri Lankan freshwater fishes, insects, and arachnids. He has co-authored around twenty research papers and has described two new fish species. ANUBHAV AGARWAL has been studying insects independently for many years. He also engages in educating about the same to school students, teachers, and stake holders in various habitats. AMILA SUMANAPALA is a postgraduate researcher at University of Colombo studying Odonata taxonomy and biogeography. He has over 15 years of experience exploring the faunal biodiversity of Sri Lanka and research related to ecology and conservation biology. H.V. GHATE is a retired zoologist working on taxonomical problems about bugs and a few other insects.

Author contributions: Ranasinghe and Sumanpala recorded natural history and did photography in Sri Lanka. Sankararaman and Agarwal recorded, photogarphed and collected Indian specimens. H.V. Ghate identified, dissected, prepared images and prepared the first draft. All authors contributed to revision of the first draft and preparation of final draft.

Acknowledgements: We are indebted to the authorities of Modern College, Pune, for the facilities and encouragement to HVG. TR and AS would like to thank Nuwan Chathuranga and Ruvinda de Mel for assistance in the field. HS and AA are grateful to Saravanaraja for his assistance in the field and also for sharing the images of live individuals of Ademula from Padappai, Tamil Nadu. We also thank Mr. Gaurav for allowing us to explore his farm, from where these bugs were collected. Line drawings from photos were prepared by Miss Shruti Paripatyadar and we are thankful for that. We thank Dr. Mr. Yugandhar Shinde, Mr. Digvijay Jadhav and Ms. Shruti Yeola for their assistance in preparation of slides and photography. We are indebted to Dr. Hélcio Gil-Santana (Instituto Oswaldo Cruz, Rio de Janeiro, Brazil) for reading and improving the first draft of this manuscript. Special thanks are due to Dr. Dávid Rédei (National Chung Hsing University, Taichung, Taiwan), for constant support for our work on Emesinae and other bugs. Finally, we thank all the reviewers for useful suggestions for the improvement of this manuscript.

INTRODUCTION

The subfamily Emesinae (Hemiptera: Heteroptera: Reduviidae), commonly called thread-legged assassin bugs, is one of the most remarkable and species-rich subfamilies of the family Reduviidae, as is evident from the monograph by Wygodzinsky (1966) and the catalogue of Reduviidae of the World by Capriles (1990). There are six tribes, about 90 genera, and 950 species of Emesinae (Wygodzinsky 1966; Schuh & Weirauch 2020) and new species continue to be added.

Ademula McAtee & Malloch, 1926 includes small macropterous species distributed in Australian, Ethiopian, and Oriental regions; key to the species described prior to 1966 was published by Wygodzinsky (1966); Capriles (1990) subsequently listed 13 species and the 14th species was added by Rédei (2005). Very recently, Chen et al. (2023) added two more species from southwestern China, so the total number of species of *Ademula* is now 16. The list of all *Ademula* species and their distribution has also been tabulated by Chen et al. (2023). Of the seven species recorded from the Oriental region, only one species, namely *Ademula contaminata* (Distant, 1903), is recorded from Sri Lanka. The genus *Ademula* has not been previously recorded from India (Ambrose 2006; Mukherjee et al. 2020). Following the latest classification (discussed later), the genus *Ademula* is now placed under tribe Emesini (formerly it was under Ploiariolini).

Ademula was erected by McAtee & Malloch (1926) to accommodate two species described simultaneously: *A. reticulata* as the type species of the genus (type locality: Singapore; a paratype from Sandakan, Borneo) and *A. nubecula* (type locality: Sandakan, Borneo); however, only comparative comments with reference to a few other genera like *Tridemula* Horváth, 1914 and *Empicoris* Wolff, 1811 were given by the original authors. A detailed diagnosis of the genus was subsequently given by Wygodzinsky (1966).

During a biodiversity survey in March 2021, one of the authors (TR) documented and photographed an Emesinae species from a garden in Kandumulla, Sri Lanka. Subsequent surveys revealed a few more individuals of the same bug as well as nymphs in other locations (Image 1a–f). Within a short time from the above discovery, two males of the same species were photographed (26 January 2022) and collected after few days, by two of the authors (HS & AA), in southern India. These were studied in detail to establish the identity of the species. This Emesinae species was identified as *Ademula contaminata* based on Wygodzinsky (1966) and confirmed using recent keys for the Oriental species (Rédei 2005; Chen et al. 2023)

Distant (1903a) described *Ploiariola contaminata* from 'Biserat, Jalor' based on material collected during 1901–1902 expedition to the 'Siamese Malay States'; Wygodzinsky (1966) studied a specimen from Peradeniya, Ceylon (= Sri Lanka), preserved at NHM, London, and placed it in a new combination as *Ademula contaminata* and gave the distribution of this species as 'Malaya; Ceylon'. The original description and illustrations given by Distant (1903a) were also consulted and those helped further to confirm the identity of the species. The image of the type available in the database of the Natural History Museum, London (NHM) was also found to be useful; the colouration of forewing of the type is almost identical to what is seen in our material.

Ademula contaminata is described here in greater details, based on two male specimens collected from Padappai, Kanchipuram, Tamil Nadu, India, with several digital photos. Photos of live specimens from India as well as Sri Lanka, with some comments on the natural history, are also provided. Sri Lankan specimens were not collected but bugs were watched for behaviour and photographed.

Although the species has previously been recorded from Sri Lanka, there have been no subsequent reports from the country for more than 120 years – a fact probably related to lack of surveys and lack of taxonomic expertise in this group. This report is therefore the first record of this genus from India and an interesting rediscovery of the species from Sri Lanka.

MATERIALS AND METHODS

In Sri Lanka the various potential habitats for the bugs were explored using a visual encounter survey method. Observations of Emesinae bugs were documented with photographs, primarily using Canon EOS 7D or Canon EOS 7D Mark ii camera, fitted with a Canon EF 100 mm f/2.8 L IS USM macro lens.

In India, small patches of grass and shrub vegetation were being surveyed when these bugs were found. The bugs were collected and preserved in 70% alcohol and subsequently studied and photographed under a Leica Stereozoom MZ6 with attached Canon PowerShot S50. The methods of preparation of genitalia follow those outlined by Ghate et al. (2021).

RESULTS

Material examined: Two males collected from Padappai (12.88 ˚N, 80.01 ˚E), Kanchipuram, Tamil Nadu, India). Date 12.ii.2022; leg. HS and AA. Preserved in Modern College, Pune.

Taxonomic position

Family **Reduviidae** Latreille, 1807

Subfamily **Emesinae** Amyot & Serville, 1843

Tribe **Emesini** Amyot & Serville, 1843 [sensu Standring et al. 2023]

Genus *Ademula* McAtee & Malloch, 1926 (1926: 125); Wygodzinsky & Usinger (1960: 262 new species); Wygodzinsky (1966: 337, diagnosis, key to the species and distribution); Villiers (1970: 818, distribution of the genus, new species 1982: 27 new species); Capriles (1990: 141, catalogued); Ishikawa & Yasunaga (2004: 1, diagnosis, distribution, redescription); Rédei (2005: 128, distribution, new species); Chen et al. (2023: 702, diagnosis, distribution, new species, DNA Barcodes, key to Oriental species)

Ademula contaminata (Distant, 1903):

Ploiariola contaminata Distant, 1903 (1903a: 258, original description, habitus drawing)

Ademula contaminata (Distant): Wygodzinsky (1966: 339, new comb., in key, distribution); Capriles (1990: 142, catalogued); Rédei (2005: 131, in key); Chen et al. (2023: 710, in key)

Genus *Ademula*: diagnostic characters

Diagnostic characters of the genus *Ademula*, as given recently by Chen et al. (2023), are stated verbatim here: "Members of *Ademula* are small-sized and usually pale-coloured species with variable colour patterns on legs and forewings, and can be recognised within the tribe by the following combination of characters: the posterior pronotal lobe has a well-developed lateral carina; the scutellum and the abdominal tergite I each bears a spine-like process; the metanotum is rounded apically or has a small process; the fore tarsus is three-segmented; the fore wing has a single discal cell, and a single vein (M + Cu) is extending basally from the cell". Similarities and differences of *Ademula* with related genera are discussed later.

Redescription of *Ademula contaminata*

Colouration and vestiture: Colour (after preservation). General colour ochraceous with pale or dark brown areas on head, thorax, fore legs, and fore wings. Head uniformly brown, eyes dark brown to black; antennae: first antennomere pale, with subapical dark annulation; remaining antennomeres darker; labium: first visible segment (actual second) very pale, remaining segments dark. Pronotum: disc of anterior lobe dark brown, posterior lobe with median and lateral longitudinal pale brown bands (Image 2a–c); area around scutellum dark brown. Fore legs: coxa pale brown, distal one third darker; femora with three incomplete annulations of dark brown which appear darker on external (posterior) face than on internal (anterior) face; femoral basal dark annulation occupies almost half length of femur, second large one near middle, third and smallest subapical; fore tibiae also possess three annulations of brown that are basal, near middle and apical in position; tarsal segments dark brown to blackish (Image 2e). Mid and hind femora with four dark spots or incomplete annulations, two before middle and two after middle; mid and hind tibiae show one dark, sub-basal dark annulation; mid and hind tarsi dark brown (Image 2f). Abdomen pale brown, segments V and VI with orange tinge. Pygophore brownish.

Body surface mostly dull, some parts of head and pronotum sub shining; all body except wings covered with short and long pubescence or setae, as shown in Images 2 and 3. Mid and hind legs with sparse macrochaetae.

Structure

Head short, broader than long due to very large eyes; ante-ocular slightly longer than postocular portion in lateral view, slightly convex dorsally; ante-ocular with sides parallel in dorsal view; postocular narrowed posteriorly, semiglobular in dorsal and lateral aspects. Eyes very large, occupying almost 50% area of head, as seen laterally, and appearing nearly sub-hemispherical in dorsal view (Image 2d). Labium 4 segmented but first segment not visible hence visible segments are actually second, third and fourth; labium curved, strongly bent between second and third segments; second segment longest and stout, third short and swollen in middle, fourth very slender and longer than third (Image 2b,c). Antenniferous tubercles large, inserted in front of eyes, towards anterior border of head; first antennomere (scape) with long setae. Transverse interocular sulcus curved, situated between eyes, almost at level of middle of eye in dorsal view.

Pronotum short, saddle like, constricted before middle; anterior lobe nearly as wide as long, its sides slightly rounded, disk with roundish or oval depression medially in posterior part; posterior lobe with its sides diverging posteriorly, its surface finely punctate, with short, lateral carina on anterior portion (Image 3a,b). Scutellum and first abdominal tergite with a distinct

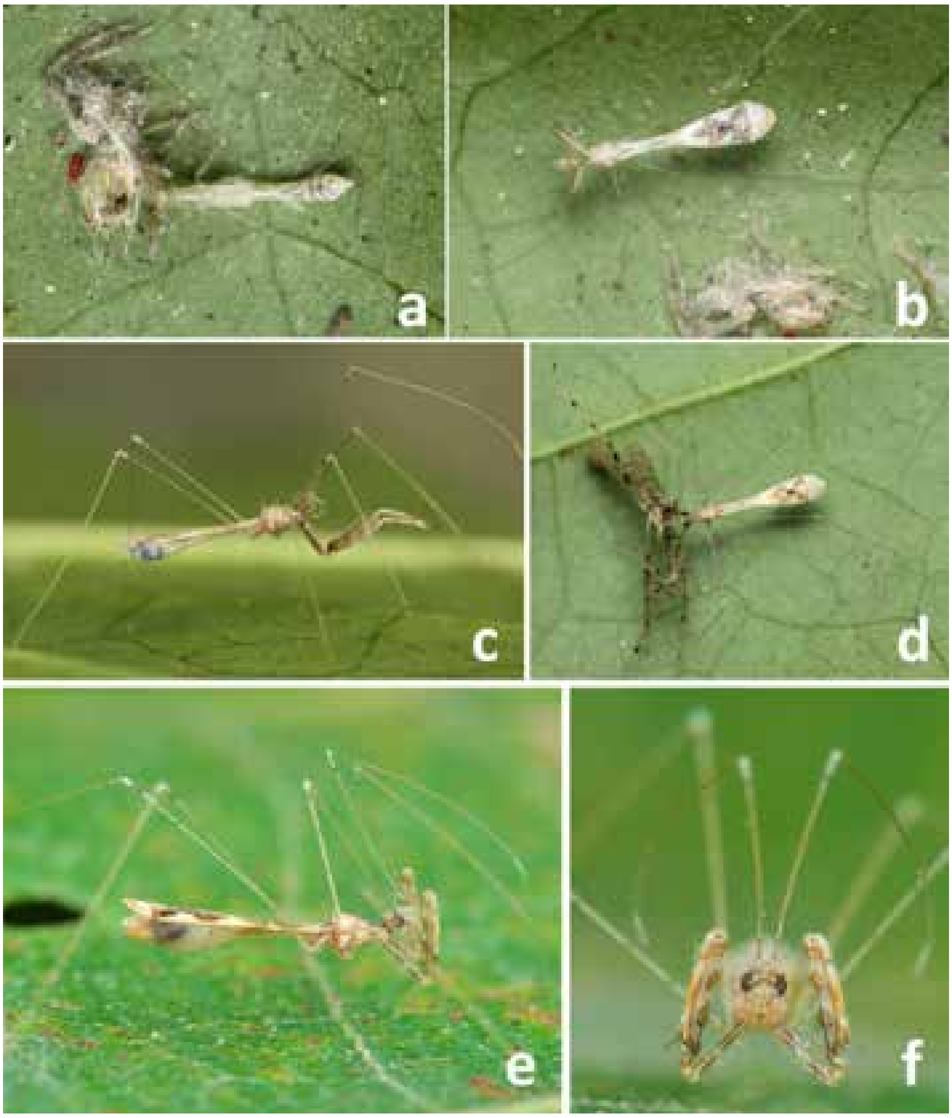

Image 1. *Ademula contaminata* live: a—last instar nymph | b—freshly moulted adult | c—adult | d—adult preying on a limoniid crane fly | a–d all from Kandumulla, Sri Lanka, © Ranasinghe | e—lateral view | f—frontal view| e–f—photographed in India, © Saravanaraja.

spine (Image 2b,f). Forewing smooth, passing apex of abdomen; one large discal cell present, pterostigma reaching apex of wing; venation, and pattern of dark patches as shown in Image 4.

Fore leg slender, its femur with usual two series of spiniferous processes. Posteroventral series, beginning close to base of article, including three relatively thick, long, prominent spiniferous processes and numerous short processes in between, long processes about one third shorter than diameter of femur; first long spiniferous processes close to base appears slightly longer than remaining two, second one situated close by, third farther, beyond middle of femur. Anteroventral series continuous, uninterrupted, starting slightly distal to first long spine of posteroventral series, without long processes. Fore tibia long, thinner than femur, about four-fifths as long as femur, ventrally with series of strong decurved spine-like setae. Fore tarsus three segmented (see inset Image 3c). Claws of equal size. Mid and hind legs very slender, thread-like; hind femora distinctly surpassing apex of abdomen.

Abdomen elongate, narrow at base in lateral and ventral views, wide distally. Seventh tergite short in male, not projecting over pygophore; eighth sternite visible. Pygophore elongate, small, broader at base and narrowed apically, longer than high in lateral view, pygophoral process (superoposterior spine, SP) blunt spine-like as seen in ventral view (Image 5a,b). Parameres (P) short, slender, slightly curved at base, dilated beyond middle, with sparse, simple setae and sharp point at

Image 2. *Ademula contaminata* structure: a—lateral habitus, mm scale | b—anterior half, lateral view | c—head, lateral view | d—head and pronotum, dorsal view of wet specimen | e—fore leg showing colouration | f—mid and hind leg colouration. © H.V. Ghate.

one side in apical region (Image 5e). Phallus slightly sclerotized, dorsally with saddle-shaped sclerotization on phallotheca; vesica arms long and slender, with swollen base and apical thread-like part; articulatory apparatus well developed and sclerotised (Image 5c,d).

Notes on the habitat in India

The specimens were collected from a teak *Tectona grandis* plantation in an undisturbed suburban wild patch, with mixed vegetation of perennial trees and grassland. The bugs were resting on the under surface of teak leaves, in the low-lying branches of the trees, a couple of feet above the ground level. The collected bugs were docile as they were collected during day time. The pale colouration of the bugs made it difficult to spot them when they were resting on the dry leaves. Furthermore, the bugs remained almost flat, keeping their legs and entire body very close to the leaf surface when approached, merging totally with the environment. Some images of live specimen, before those were collected, are available on the following links of iNaturalist (courtesy: Saravanaraja and Anubhav Agarwal), (https://www.inaturalist.org/observations/105676730), (https://www.inaturalist.org/observations/105671338). Habitat pictures are shown in Image 6a,b.

Natural history observed in Sri Lankan population

Both adults and nymphs appear to be arboreal and were observed in well wooded home gardens or forested areas. These bugs are nocturnal and the individuals observed in day time were found resting in abandoned spider webs under the leaves, about 1.5–2.0 m above the ground. If disturbed these bugs walk away from their resting place rather than flying. When resting, both adults and nymphs, usually keep their forelegs retracted and close to the head (Image 1a–f). These emesine bugs seemed to prefer well shaded undergrowth as their habitat. We observed both adults and nymphs in the same location, close to each other, but never on the same leaf.

Individuals observed at night seemed to be active

Image 3. *Ademula contaminata* structure: a—head and thorax in dorsolateral view | b—pronotum, arrow pointing lateral carina | c—fore femur, tibia and tarsus; inset-tarsus. © H.V. Ghate.

and foraging for prey and unlike in the daytime, these usually flew away if disturbed and landed on another leaf close by. One of the individuals recorded at night was observed preying on a limoniid crane fly (most probably *Styringomyia* sp.; Image 1d) which was slightly larger than the bug.

DISCUSSION

According to the keys given recently by Rédei (2005) and Chen et al. (2023), the diagnostic characters of *A. contaminata* are: 'mid- and hind-femora with a subapical annulus and three more annuli along its length; fore femur 10 times longer than its breadth and forewing with numerous large and small dark spots'. All these characters are present in the specimens shown here. The species is distributed widely in Sri Lanka (Image 7) but is known from a single locality in India so far.

There is not much information concerning biology of any species of *Ademula* described so far*,* except for the fact that *A. aemula* Rédei, 2005 was collected from dry, mixed subtropical forest when attracted to light (Rédei 2005) and two recently described species were found resting on underside of leaves and were collected by sweeping with net (Chen et al. 2023). In the present study, the specimens were collected from a similar habitat (Image 6a,b) in India, but during the day. A mummified spider *Myrmaplata plataleoides* (Salticidae) was found in close proximity to *Ademula*, although the bug was not found actually feeding on that spider. The habitats in which Emesinae are found are varied and this fact, along with comments on general bionomics and geographical distribution, has been discussed in detail by Wygodzinsky (1966).

Wygodzinsky (1966) had recognized six tribes under Emesinae: Collartidini Wygodzinsky, 1966; Leistarchini Stål, 1862; Deliastini Villiers, 1949; Metapterini Stål,

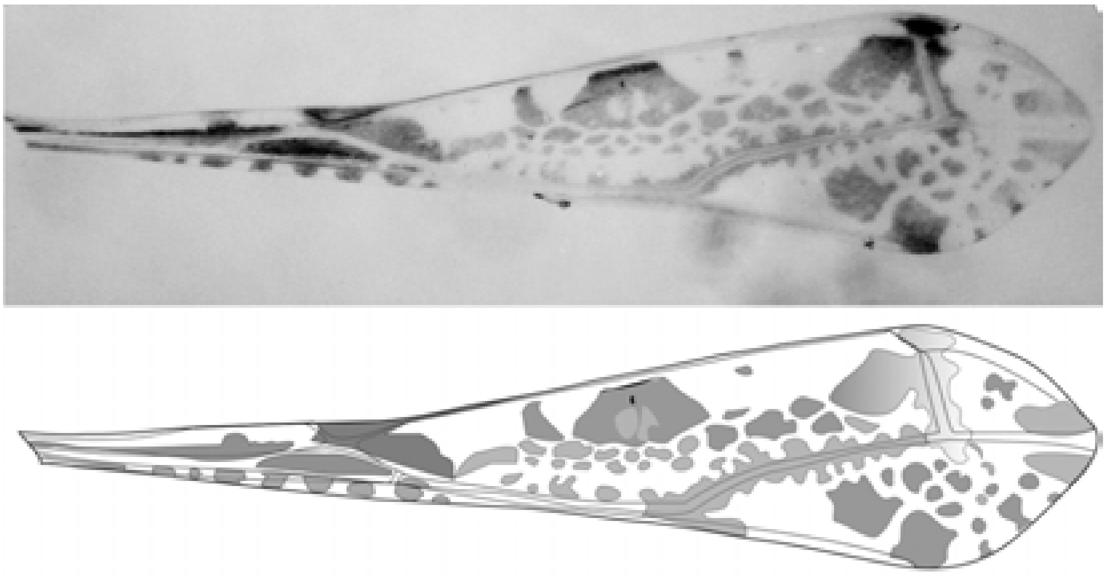

Image 4. *Ademula contaminata* structure: fore wing and its line drawing. © H.V. Ghate, line drawings Shruti Paripatyadar.

1874, Emesini Amyot & Serville, 1843, and Ploiariolini Van Duzee, 1916. Very recently the classification of Emesinae was revised, based on morphological as well as molecular analyses; this new classification has treated the former subfamilies Saicinae Stål, 1859 and Visayanocorinae Miller, 1952 as tribes under Emesinae. This so called "Emesine Complex" now is said to include over 1,000 species and the currently recognized six tribes under Emesinae are: Collartidini Wygodzinsky, Leistarchini Stål, Visayanocorini Miller, Emesini Amyot & Serville, Oncerotrachelini Standring et al., 2023 and Saicini Stål. Former tribes such as Metapterini and Ploiariolini are now treated as synonyms under Emesini; the tribe Deliastini was already treated as a junior synonym of Metapterini (Castro-Huertas et al. 2020; Standring et al. 2023).

Even though Emesinae in India have received considerable attention in the past few years, with new species descriptions as well as redescriptions of a few species, as referred before in Joshi et al. (2022), Sri Lankan Emesinae need detailed redescriptions; only one new species (Ghate et al. 2018) has been added since the work by Villiers (1970).

Earlier we reported and redescribed *Myiophanes greeni* Distant, 1903, and *Onychomesa susainathani* Wygodzinsky, 1966 [now treated as synonym of *O. alata* (Distant, 1903) which was originally described as *Ischnocytes alatus* (Distant 1903b): see Chen et al. 2024], both originally described from Sri Lanka; similarly, we also recently reported from India *Gardena melinarthrum* Dohrn, 1860, *Lutevula hortensia* (Distant, 1906), *Bagauda aelleni* Villiers, 1970 and *Hornylia nalanda* Wygodzinsky, 1966 – all species originally described from Sri Lanka (Kulkarni & Ghate 2016; Ghate & Sarode 2019; Hiremath et al. 2022; Ismavel & Ghate 2024; Ranasinghe et al. 2024; Boyane et al. 2024). Some of these species were also rediscovered from Sri Lanka after a considerable gap (Ranasinghe & Ghate 2022; Ranasinghe et al. 2024). *Ademula contaminata* becomes yet another Sri Lankan emesine recorded in southern India. Extensive surveys in India and Sri Lanka will surely recover more Emesinae, known or new, from both these countries.

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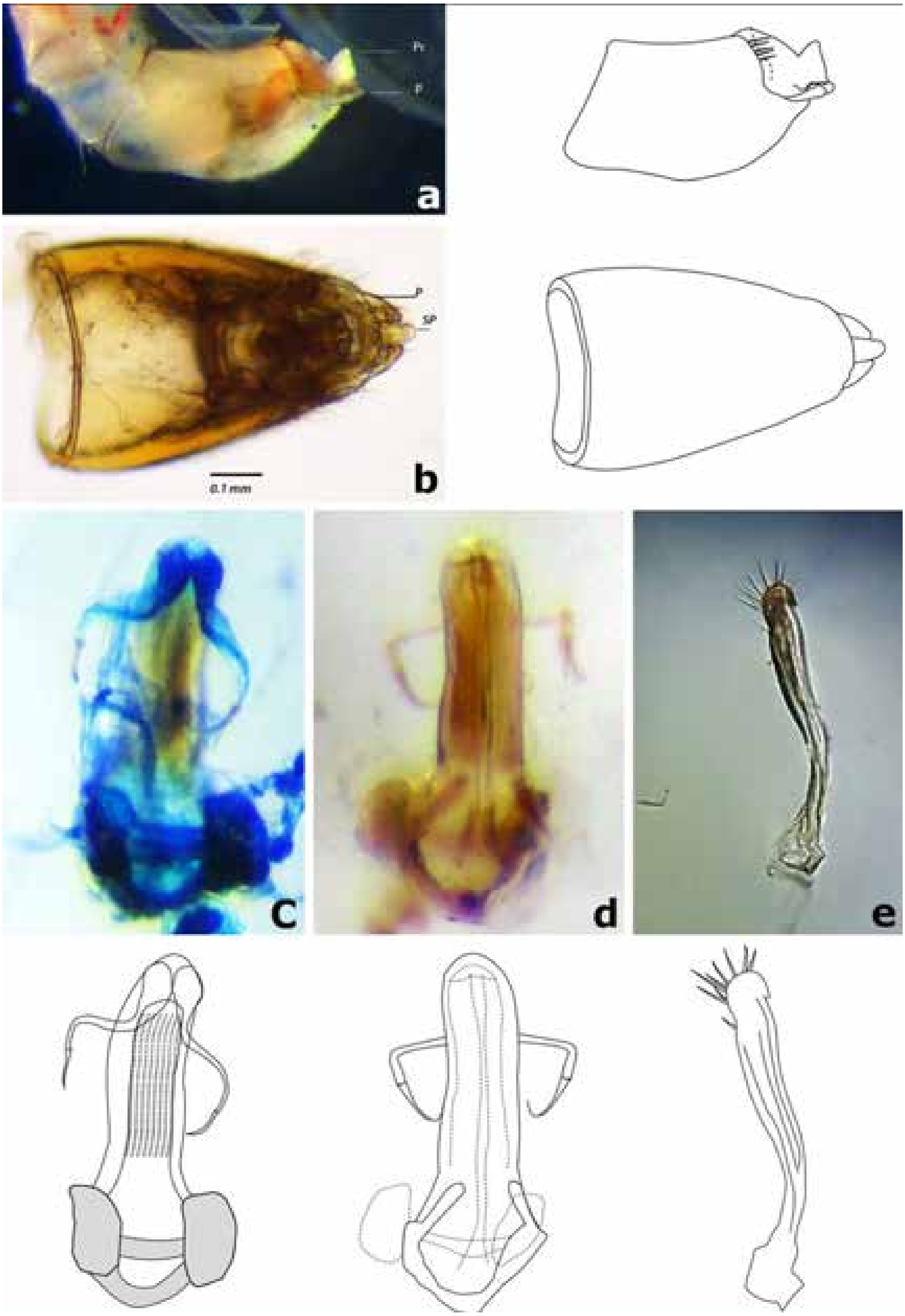

Image 5. ***Ademula contaminata*** **structure: a—pygophore in lateral view and its drawing at right | b—pygophore in ventral view, its drawing at right | c—phallus in dorsal view, its drawing below | d—phallus in ventral view, its drawing below | e—paramere, its drawing below. Abbreviations: P—paramere | Pr—proctiger | SP—superoposterior spine. © H.V. Ghate, line drawings – Shruti Paripatyadar.**

Image 6 a,b. Habitat of *Ademula contaminata* in India. © H. Sankararaman.

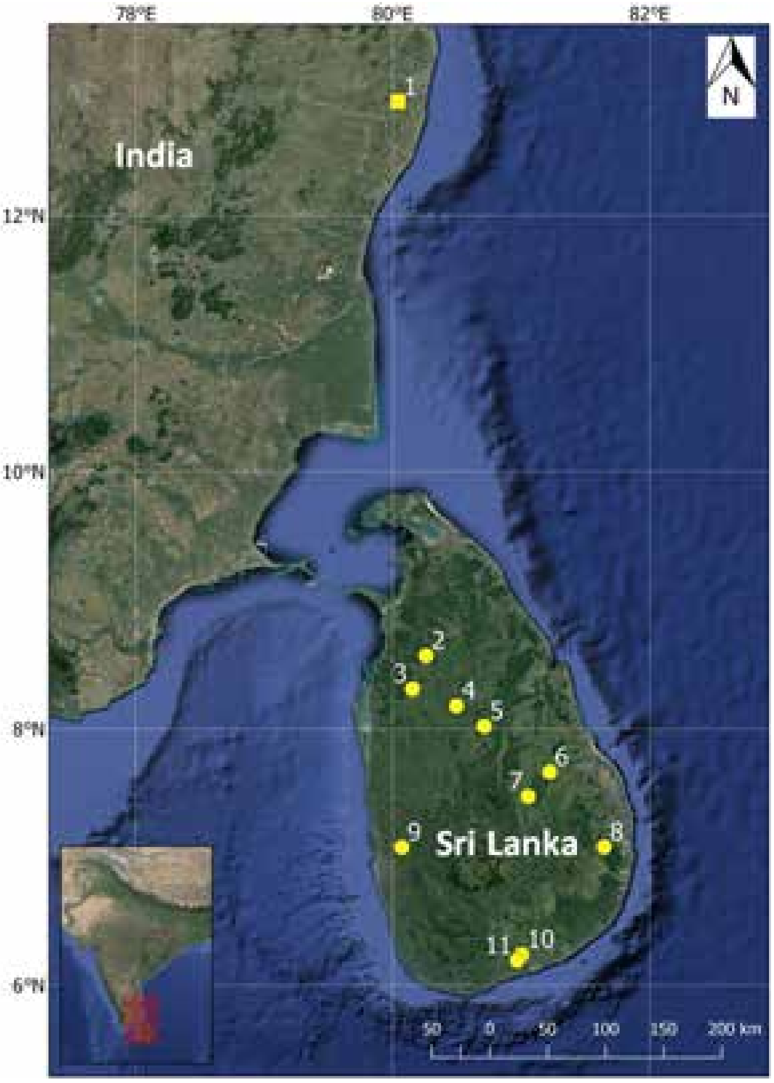

Image 7. Distribution map of *Ademula contaminata* in India ■ and Sri Lanka ● (localities are: 1—Padappai, Tamil Nadu | 2—Thanthirimale | 3—Hunuwilagama | 4—Mahakanumulla | 5 —Digampathaha | 6—Maduru oya | 7—Ulhitiya | 8—Pannalgama | 9—Kandumulla | 10—Madunagala | 11—Ridiyagama.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25904–25912
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.8757.16.9.25904-25912
#8757 | Received 29 September 2023 | Final received 03 September 2024 | Finally accepted 10 September 2024
OPEN ACCESS
COMMUNICATION

Preference and plasticity in selection of host for oviposition in Black Marsh Dart *Onychargia atrocyana* Selys, 1865 (Odonata: Zygoptera: Platycnemididae)

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Abstract: An experimental study was conducted in a natural pond to investigate host plant preference and plasticity in damselfly *Onychargia atrocyana*. The hypothesis was that this species has a host preference for oviposition and also sufficient plasticity to use other hosts in the absence of the preferred host. After mating, tandems were observed landing on plants in search of suitable oviposition substrates. The majority of landings occurred on *Alternanthera philoxeroides*, followed by *Colocasia esculenta* and *Commelina diffusa*. The frequency of landings on *A. philoxeroides* and *C. esculenta* was not significantly different, while landings on *C. esculenta* and *C. diffusa* did differ significantly. In the absence of emergent littoral plants, the damselflies exhibited plasticity in host preference and shifted ovipositional substrate by laying eggs on submerged areas of petioles of free-floating *Eichhornia crassipes*. Females of *O. atrocyana* exhibited a flexible oviposition strategy, transitioning from a combination of emergent and submerged oviposition to primarily selecting emergent oviposition in most cases. Additionally, they divided oviposition events into multiple phases when required to ensure successful reproduction. *E. crassipes* supported a higher rate of oviposition compared to other plants. A multiple regression analysis demonstrated that during submerged oviposition water temperature and pH were significant predictors of the duration of submergence.

Keywords: Damselflies, host preference, Marsh Dancer, natural pond, oviposition strategy, reproduction, water temperature.

Editor: K.A. Subramanian, Zoological Survey of India, Chennai, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Jana, P.K., P.H. Mallick & T. Bhattacharya (2024). Preference and plasticity in selection of host for oviposition in Black Marsh Dart *Onychargia atrocyana* Selys, 1865 (Odonata: Zygoptera: Platycnemididae). *Journal of Threatened Taxa* 16(9): 25904–25912. https://doi.org/10.11609/jott.8757.16.9.25904-25912

Funding: Self funded.

Competing interests: The authors declare no competing interests.

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Author contributions: PKJ—designing and conducting field work, documentation, analysis and interpretation of results, preparation of initial manuscript. PHM—overall supervision, editing and reviewing the draft manuscript. TB—data analysis, interpretation and preparation of final manuscript which was approved by all the authors.

Acknowledgements: We would like to express our sincere gratitude to Vidyasagar University for providing research support.

INTRODUCTION

Odonates such as damselflies primarily rely on visual cues to find suitable places for laying their eggs (Wildermuth 1992). Damselflies that lay their eggs in plant tissue search for appropriate sites while in flight, then they land, choose an optimal location for inserting their ovipositor, and deposit the eggs (Martens 2001; Lambret et al. 2015a). Females are often selective when it comes to choosing an oviposition site (Martens 1992), which is influenced by specific stimuli, as noted by Martens (2001). Understanding this behavior is important, as ovipositional duration is correlated with clutch size (Martens 1992), which in turn determines brood size. The site of egg deposition holds valuable information regarding the habitat requirements and needs of both adult insects and their nymphs (Corbet 1999). The choice of oviposition location by an ovipositing parent is strongly influenced by oviposition site quality. These habitat characteristics are, in turn, influenced by water chemistry and the successional stage (Toivonen & Huttunen 1995; Pietsch 1996). The physico-chemical characteristics of the water in a given habitat play a crucial role in shaping the distribution patterns of damselflies (Ishizawa 2012; Sugiman et al. 2019; Mafuwe et al. 2021).

According to niche theory, the ecological requirements of an odonate species are influenced by both abiotic (physico-chemical environment) and biotic factors (Soberón & Peterson 2005). Factors like temperature (Hershey et al. 2010) and chemical properties such as pH (Gorham & Vodopich 1992; Rychla et al. 2011; Mafuwe et al. 2021) and TDS (Mafuwe et al. 2021) impact species presence and abundance. The presence of floating macrophytes is also crucial for determining odonate assemblages, as some taxa rely on them for oviposition (Schindler et al. 2003). A recent study by Cadena et al. (2023) further emphasized the impact of climate change on the diversity patterns of odonate groups, revealing clear spatial differences. Therefore, investigating the effects of water parameters such as temperature, pH, TDS, etc. is vital in understanding the reproductive strategies of odonates. These parameters provide valuable insights into the ecological dynamics of these organisms and help us comprehend the potential impacts of environmental changes on their reproductive behavior.

Onychargia atrocyana is a common damselfly found in India (Jana et al. 2021) and its reproductive behavior has been studied earlier by Jana et al. (2022). The selection of host plant substrate for oviposition is an important aspect in the reproductive success of damselflies that is not well understood in *O. atrocyana.* The aim of the present investigation is to identify the preferred host plant(s) for oviposition in natural environments, explore the plasticity of the species in shifting to other substrates in the absence of a preferred host, and also to assess the effect of changing water temperature, pH, and TDS on oviposition.

The confinement of this species to specific habitats vulnerable to alteration by human activities or natural processes is a significant conservation challenge. Safeguarding the species requires comprehending the reasons behind their persistence and exploring methods for their preservation or restoration. So, the findings can provide insight into the reproductive ecology of *O. atrocyana,* which might have great implications in the conservation and management of wetland ecosystems as well.

METHODS

The present study was conducted in a man-managed pond located at Madhabchak village (22.2650^{0}N, 87.5464^{0}E) in the Paschim Medinipur District of West Bengal, India. The pond was selected for its diverse aquatic vegetation, which included free-floating hydrophytes like *Spirodela polyrhiza* (L.) Schleid, *Pistia stratiotes* L., and *Eichhornia crassipes* (Mart.) Solms; submerged rooted-floating hydrophyte *Nymphaea alba* L.; and emergent littoral plants like *Alternanthera philoxeroides* (Mart.) Griseb., *Colocasia esculenta* (L.) Schott, and *Commelina diffusa* Burm.f. The identification of hydrophytes was after Cook (1996). To ensure equal surface areas for each vegetation type, separate patches of 1.22 x 1.22 m were set up in the pond, each representing a different plant type. These patches were chosen to have more than 95% coverage of the respective vegetation type. The standard procedure of visual estimation by the quadrat method (Jaccard 1901) was employed to record the percent coverage of hydrophytes within each patch. All observations were conducted during the period from 1 July to 15 September 2022, with observations taking place between 0600 h and 1600 h local solar time (IST).

Landing events of ovipositing pairs were assessed in undisturbed and clear weather conditions by direct observation. To avoid any misinterpretation regarding substrate choice, a 'positive' choice for substrate was considered when a female in tandem exhibited a backward descent behavior from the landing point to reach the submerged part of the plant, followed by palpation of the plant parts and the commencement of egg placement during the oviposition event, as described in Jana et al. (2022). A total of 136 landing events were observed, and 127 landings were taken into consideration for the calculation of the frequency of selecting a particular plant substrate for oviposition. From these, 112 cases were used to measure the clutch size, where females in tandem completed their egg-laying event in a single attempt without changing hosts.

To test the hypothesis that the species has a substrate preference for oviposition, a one-sample binomial test was employed. This test compared the observed landing events on specific plant substrates to an expected probability based on the null hypothesis that no substrate preference exists. A corresponding 95% Clopper-Pearson (exact) confidence interval was also calculated to evaluate the precision of the estimation. When the 95% confidence intervals for the two groups did not overlap it was assumed that there was a significant difference between them, indicating that the true population means were likely to be distinct as suggested by Lambret et al. (2015b). The duration of oviposition was measured with a mobile stopwatch in minutes. Number of eggs deposited was determined by counting eggs on substrate collected 24 h after oviposition under a binocular microscope. The rate of oviposition was calculated following Martens (1992) based on the first 12 cases.

To investigate plasticity and habitat shift from the preferred plant substrate to another substrate in the absence of preferred host plants, observations were also conducted in the same pond from 16 to 25 September 2022. After heavy rains in September, most of the emergent vegetation was submerged, except for *C. esculenta* and *A. philoxeroides*. Petioles of *C. esculenta* and apical parts of *A. philoxeroides* of the entire pond were cut just below the water surface and removed. The *E. crassipes* plants were taller than 0.25 m. To ensure the accurate identification of individual females and avoid potential bias from repeated observations, females were caught during the post-ovipositional rest and marked on the thorax with a permanent alphanumeric code using a red-colored marker after each observation. Based on the above- specified criteria, 30 oviposition events on *E. crassipes* were included in the statistical analysis.

A comprehensive study was conducted weekly to investigate the relationship between fluctuations in water temperature, pH, and total dissolved solids (TDS) with the duration of submerged oviposition.

A total of 32 oviposition events occurring between February and September 2022 were examined within a one-meter radius of the substrate. Water parameters were recorded with the help of a portable water analyzer (WQC-22A).

The submergence period data were exclusively collected during instances of oviposition on *A. philoxeroides*, as other plants were either regularly replaced or not consistently available throughout the year at the water level. Pearson correlation was used to assess the associations between water parameters and the duration of submerged oviposition. Additionally, a multiple regression analysis was performed to examine how well temperature, pH, and TDS predict the duration of the submergence period.

All statistical analyses, including the 95% Clopper-Pearson (exact) confidence interval, one-sample binomial test, Pearson correlation, and multiple regression analysis, were performed using SPSS version 26 (IBM Corp. 2019).

Throughout the study, utmost care was taken to ensure the well-being of the observed organisms. No harm was caused to any living organisms during the entire course of the research.

RESULTS

After mating, tandems of *O. atrocyana* landed on stems of *A. philoxeroides* and *C. diffusa* as well as on the petioles of *C. esculenta* in search of a suitable oviposition site. Then they started descending downwards to reach the water surface for oviposition and the female started probing the vegetation with her ovipositor for a suitable oviposition site. Of the 136 landings (Table 1), 51% landed on *A. philoxeroides* (n = 69), followed by *C. esculenta* (33%, n = 45) and *C. diffusa* (10%, n = 13). Landings were also observed on *E. crassipes* (5%, n = 7) and *P. stratiotes* (1%, n = 2) but egg-laying did not occur perhaps due to lack of suitable submerged plant parts available for palpation and insertion of eggs. Pairs were not observed to land on *S. polyrhiza* or *N. alba* for oviposition. Neither they were seen to palpate on leaves or deposit eggs on dead plants, which indicates that *O. atrocyana* prefers live stems and petioles for oviposition.

There were 127 successful landings where a female palpated after landing. The null hypothesis was that the proportion of *O. atrocyana* landings and palpation on each plant type was equal. The observed proportions of damselflies landing on *A. philoxeroides* and *C. esculenta* were 54% and 35%, respectively. When the confidence intervals were considered, the range for *A. philoxeroides* (45% to 63%) was higher than the range

Table 1. Aspects of oviposition in natural environment.

Types of hydrophytes	Plant	Frequency (%) of landing (n)	Palpated (Yes/ No)	Plant parts palpated	Clutch size. Mean ± SE (Range)	Rate of egg deposition (no. of eggs/m), Mean ±SE (range), n	Type of oviposition
Free- floating	*S. polyrhiza*	-	-	-	-	-	-
	P. stratiotes	1% (n = 2)	No	-	-	-	-
	E. crassipes	5% (n = 7)	No	-	-	-	-
Rooted- floating	*N. alba*	-	-	-	-	-	-
Emergent littoral	*A. philoxeroides*	51% (n = 69)	Yes	Stem	331 ± 8 (227–451)	23.54 ± 0.4 (21.4–26.8), 12	Emergent & submerged
	C. esculenta	33% (n = 45)	Yes	Petiole	430 ± 11 (342–577)	29.2 ± 0.7 (25–33.3), 12	Emergent & submerged
	C. diffusa	10% (n = 13)	Yes	Stem	288 ± 18 (189–416)	25.1 ± 1.2 (16.1–41.9), 12	Emergent & submerged

Table 2. Binomial test with confidence interval and p-value regarding preference for landing of *Onychargia atrocyana* on three hydrophytes.

Hydrophyte	No. of females landed & palpated	Observed proportion	Expected proportion	95% Clopper-Pearson (exact) confidence interval	Binomial p-value
A. philoxeroides	69	0.5433	0.333	45.3–63.2 %	0.375
C. esculenta	45	0.3543	0.333	27.2–44.4 %	0.001
C. diffusa	13	0.1024	0.333	5.6–16.9 %	0.000

for *C. esculenta* (27% to 44%) indicating its preference for *A. philoxeroides* (Figure 1, Table 2). The binomial p-value for landing and palpation (Table 2) also indicates that the proportion of landing on both *C. esculenta* and *C. diffusa* was significantly less as compared to those on *A. philoxeroides*.

In all 127 cases, the females went submerged, of which 15 cases involved the females in tandem ovipositing in multiple substrates. Out of the 127 successful landings, only 112 cases were selected to measure the clutch size, as these females completed their egg-laying in one attempt without switching their host. Among the different substrates, *C. esculenta* petioles exhibited the highest number of eggs laid, followed by *A. philoxeroides* and *C. diffusa*, as depicted in Figure 2 and Table 1. Likewise, the rate of oviposition was also maximum on *C. esculenta* petioles, averaging 29 eggs per minute, compared to other substrates, where it was 23 and 25 eggs per min on the stems of *A. philoxeroides* and *C. diffusa*, respectively, as shown in Figure 3. In all cases oviposition occurred in two phases – emergent and submergent.

In the absence of emergent littoral-associated plants, out of 30, 28 tandem (93%) landed on *E. crassipes,* and only two (7%) though initially landed on *P. stratiotes*, but due to want of oviposition they also landed ultimately on *E. crassipes* (Table 3). Thus, all the 30 tandems landed on the upper portion of the inflated petiole and started backward descending movement, as they normally do. In doing so, females oviposited on the submerged parts of the base (Image 1) in a zigzag manner dragging their male partner all along. Submerged oviposition was seen in only 3% of cases. Moreover, in the absence of sufficient oviposition sites, females did not oviposit in a single attempt but divided the egg- laying process into multiple emergent egg- laying rounds, hopping from one petiole to the other. A female deposited on average 203 eggs in the first attempt which was roughly one- half of the total average number of eggs laid (368). The rate of

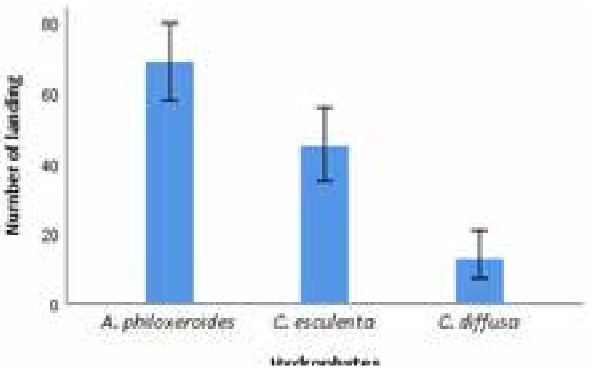

Figure 1. Preference as oviposition substrate by *Onychargia atrocyana* based on a number of landings in a natural habitat with 95% confidence limit.

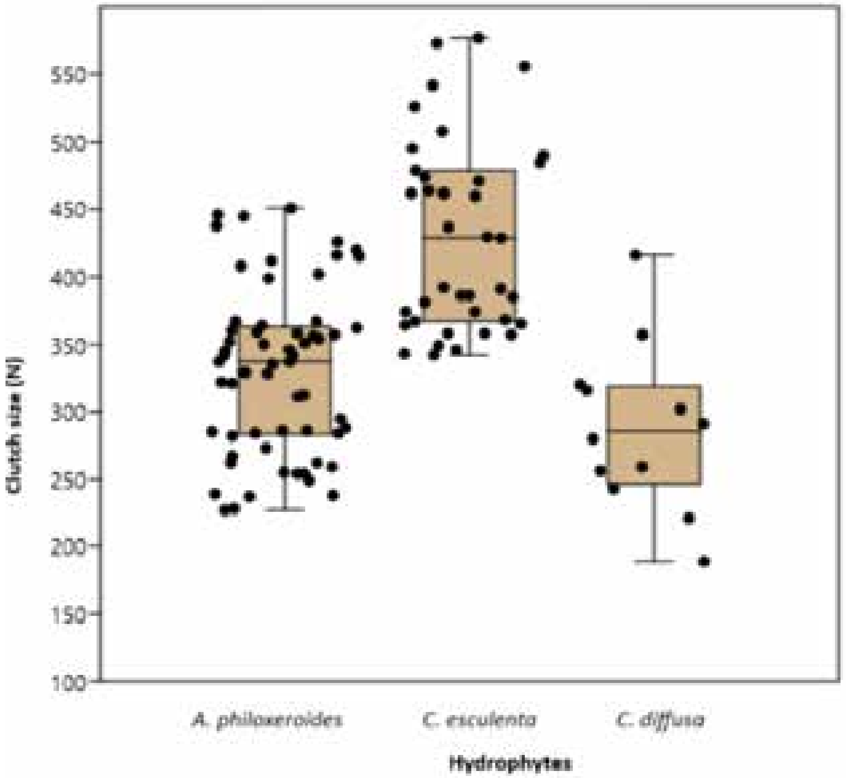

Figure 2. Clutch size of *Onychargia atrocyana* on different hydrophytes.

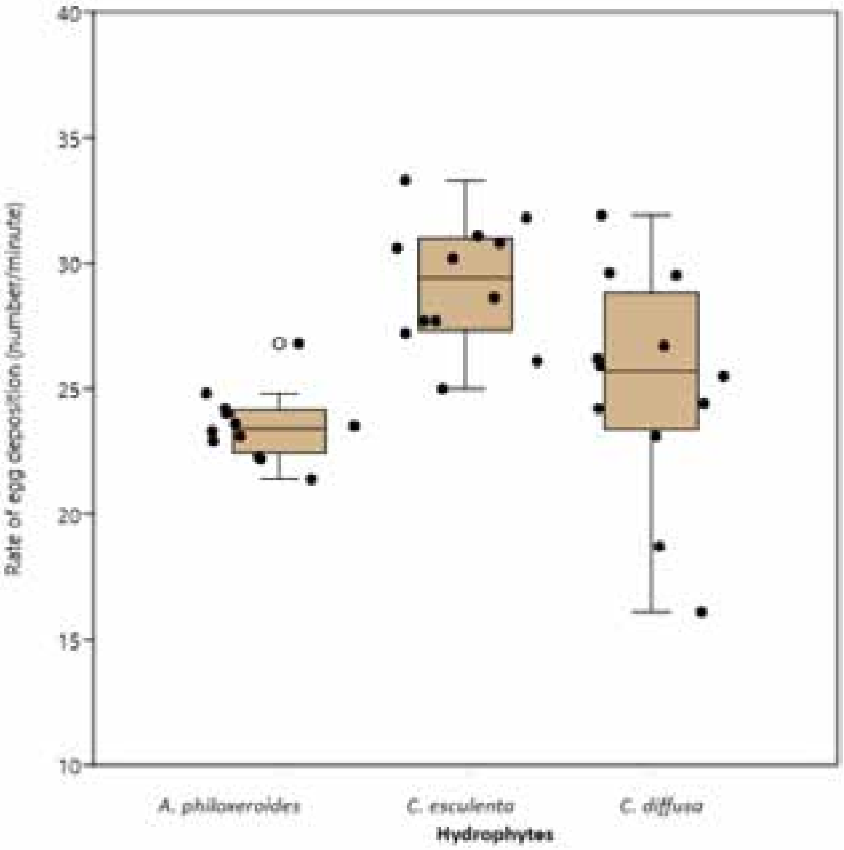

Figure 3. Rate of egg deposition of *Onychargia atrocyana* on different hydrophytes.

Table 3. Aspects of oviposition in an altered environment.

Types of plant	Name of plants	Frequency (%) of landing (n)	Palpated (Yes/No)	Plant Parts palpated	No. of eggs Mean ± SE (range), n	Rate of egg deposition (eggs/m), Mean ± SE (range), n	Type of oviposition
Free-floating	*E. crassipes*	93% (n = 28)	Yes	Petiole	Total eggs 368 ± 11 (198–465), 30		97% emergent & 3% submerged oviposition
					In 1st attempt 203 ± 8 (86–274), 30	31.6 ± 0.9 (26.5–37.3), 12	
	P. stratiotes	7% (n = 2)	No	-	-	-	-

Table 4. Pearson correlation between three water parameters and submergence ovipositional duration (SOD) of *Onychargia atrocyana*.

Factors	M ± SE (Range)	r			
		Temp	TDS	pH	SOD
Temp.	28.93 ± 0.38 (23.8–32.5)	-	0.861**	-0.822**	0.701**
TDS	232.5 ± 3.29 (198–278)	0.861**	-	-0.843**	0.550**
pH	6.64 ± 0.08 (5.2–7.6)	-0.822**	-0.843**	-	-0.380*
SOD	523.3 ± 10.8 (435–636)	0.701**	0.550**	-0.380*	-

** p <0.01 | *p <0.05.

egg deposition on *E. crassipes* during plasticity was on average 32 eggs/min .

Pearson correlation between temperature, TDS, and pH of the water was found to be strongly significant (p <0.01) with each other but the correlation between pH and the other two factors was negative. Likewise, submergence ovipositional duration (SOD) was also found to have a significant positive correlation with water temperature, and TDS but a negative correlation with pH (Table 4). It was also noted that submersion oviposition took place within a temperature range of 23.8–32.5 °C, a pH range of 5.2–7.6, and a TDS level ranging 198–278 ppm. The majority of submergent oviposition occurred within a narrower temperature range of 27.5–30.5°C, a pH range of 6.5–6.9, and a TDS level ranging 223–243 ppm (Figure 4a,b,c). An analysis of the multiple correlations reveals that the predictor water factors have a moderately strong positive relation with SOD (R = 0.783) and the R^2 value explains only 61% of the variability in the duration of submergence by the predictor variables. ANOVA, indicates that the overall regression model is strongly significant (F = 14.807, p <0.001). Results also suggest that temperature and pH are significant predictors of the duration of the submergence period while TDS is not (Table 5).

Table 5. Correlation between water parameters and SOD.

Water parameters	Standardized β	t	R	R^2	ANOVA (F)
Temperature	1.124	4.557**	0.783	0.613	14.807**
TDS	0.138	0.528			
pH	0.659	2.830*			

*p <0.01 | **p <0.001.

DISCUSSION

The findings presented in this study provide insights into the oviposition behavior of *O. atrocyana,* which exhibit its preference for *A. philoxeroides* and *C. esculenta* over other hydrophytes. *C. esculenta* petiole is used only during the rainy season when the water level in the pond rises. It is interesting to note that *O. atrocyana* has a preference for stems and petioles over other parts as oviposition sites. *Platycnemis subdilatata* Selys, 1849*,* a related species, on the contrary, prefers leaves of *Typha angustifolia* (Khelifa et al. 2016). Excessively high substrate stiffness may impede egg laying (Grunert 1995). The role of plant substrate stiffness in the selection of oviposition sites by endophytic zygopteran females has also been demonstrated by Matushkina and Gorb (2007). In *O. atrocyana*, choosing stem or petiole over

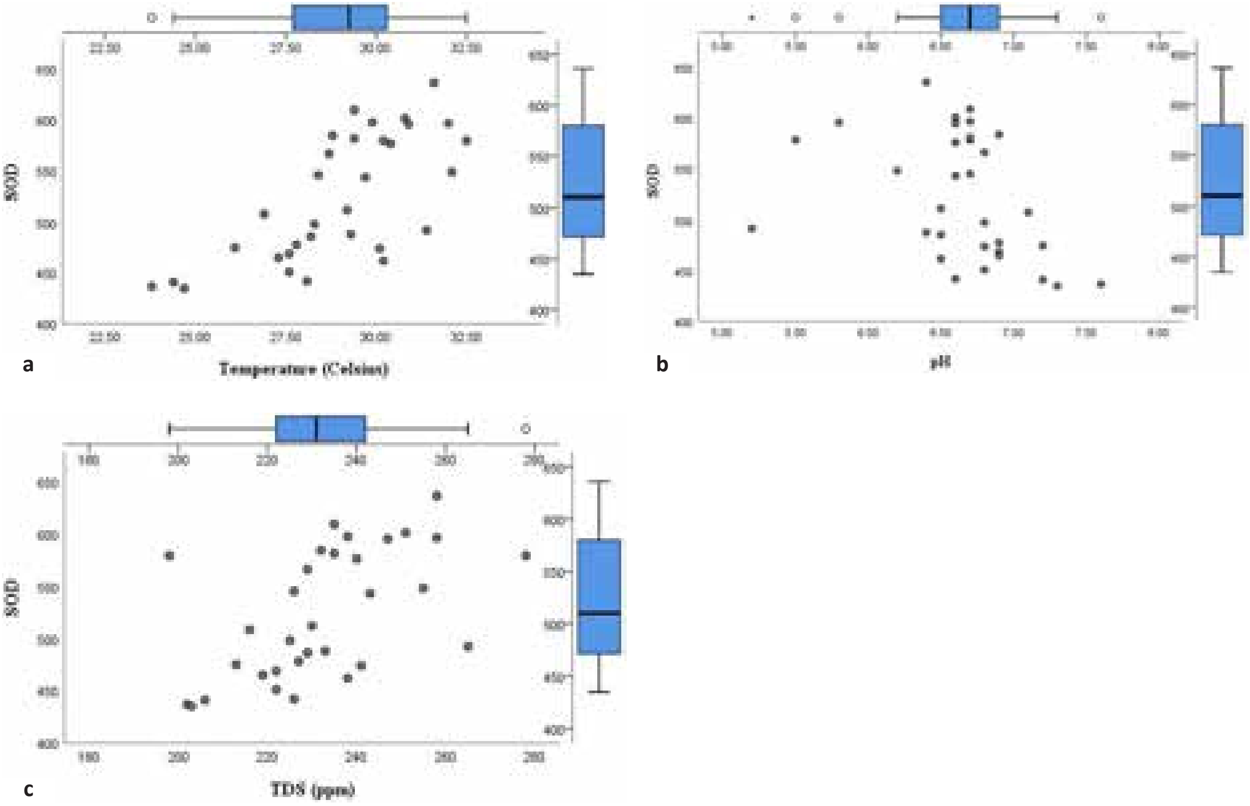

Figure 4. Regression plots showing the relationship between SOD and (a) water temperature, (b) pH, and (c) TDS.


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Image 1. Eggs deposited by an *Onychargia atrocyana* female at the base of the petiole of *Eicchornia crassipes* during its first attempt.

the leaf as a substrate during submerged oviposition might be an effective anti-predator strategy as suggested by Harabiš et al. (2015) who opined that eggs near the water surface are more susceptible to parasitoids and showed higher mortality. The submerged oviposition strategy and selection of oviposition sites both may serve a protective function against abiotic stress like egg desiccation (Fincke 1986; Lambret et al. 2018) and might have evolved as a way to exploit additional oviposition sites in underwater substrates (Miller 1994) as well as to reduce sexual harassment during oviposition (Fincke 1986). The rate of egg deposition also varied among different plants. This suggests that the suitability of an oviposition site depends on the structural suitability of plant parts for the insertion of eggs.

The findings align with previous research by Martens (1992) and Lambret et al. (2015a), all of which have highlighted the influence of substrate characteristics on egg deposition rate. Lambret et al. (2015a) put forward a hypothesis suggesting that a higher egg deposition rate among adults offers advantages in terms of minimizing the duration of oviposition bouts. This reduction in oviposition duration serves to decrease the vulnerability of detection by predators and also leads to an increase in foraging time (Martens 2001). Consequently, a heightened rate of egg deposition on *E. crassipes* can be considered beneficial for *O. atrocyana.* In the absence of emergent plants, this species can shift its oviposition plant and substrate. It prefers the petioles of floating hydrophyte *E. crassipes* only in the absence of stemmed emergent hosts. This indicates habitat plasticity. The species displays remarkable habitat plasticity, as it shifts its oviposition plant and substrate in the absence of emergent plants, demonstrating adaptability in diverse environmental conditions. Females of *O. atrocyana* even alter their oviposition strategy, transitioning from a combination of emergent and submerged oviposition to predominantly selecting emergent oviposition (>96% of cases) and breaking oviposition events into multiple phases when necessary to ensure reproductive success. They quickly adjusted their choice toward an unusual host substrate. Also, such shifts in oviposition sites and changes in strategies are important aspects of their pre-ovipositional parental care which depends on the relative availability of oviposition sites. Though ovipositing tandems were not disturbed by the other conspecific males during emergent oviposition, there might exist undisclosed competition among ovipositing tandems, which could potentially be prevented in submerged oviposition as suggested by Rowe (1987).

In the present study water temperature and pH were identified as predictors of the SOD. These findings conflict with those of Sugiman et al. (2019) who found that in *Pseudagrion pruinosum* (Burmeister, 1839), TDS and water temperature were negatively correlated but pH had a positive correlation. In contrast, Mafuwe et al. (2021) found the distribution of adult and larval platycnemid damselflies was positively correlated with both pH and TDS. Martens (1992) found a minor influence of water temperature on oviposition in *Platycnemis pennipes* (Pallas, 1771) while Ishizawa (2012) observed a strong correlation between the onset of oviposition and ambient temperature, duration of oviposition exhibited a weak correlation with temperature in *Sympetrum frequens* (Selys, 1883). Purse & Thompson (2009), on the contrary, opined that habitat factors such as pH and water temperature were not reliable predictors of oviposition duration in *Coenagrion mercuriale* (Charpentier, 1840). Dolný et al. (2014) demonstrated that the type of submerged plants influences underwater oviposition in Lestidae. These contrasting findings suggest that different species of damselflies exhibit diverse responses to pH, TDS, and water temperature which warrant further research to understand the underlying mechanism.

In view of the present-day changing scenario of natural landscape, it is proposed that water bodies with small patches of *A. philoxeroides*, *C. diffusa*, *E. crassipes*, and *C. esculenta* be established which would not only provide suitable habitat for damselflies like *O. atrocyana* but also help in their conservation.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25913–25919

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8069.16.9.25913-25919

#8069 | Received 19 June 2022 | Final received 06 August 2024 | Finally accepted 09 September 2024

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New records of termite species (Blattodea: Rhinotermitidae, Termitidae) from southern India

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Abstract: There are 133 species of termites so far recorded from southern India and 73 from Kerala. The present study from different habitats in northern Kerala recorded two species new to southern India and one species new to Kerala, taking the total number to 135 for southern India and 76 for Kerala. The newly reported species are *Heterotermes balwanti* Mathur & Chhotani, 1969*, Odontotermes profeae* Akhtar, 1975, and *Microcerotermes annandalei* Silvestri, 1923*. O. profeae* is a new record to the termite fauna of Western Ghats. *O. profeae* and *M. annandalei* are reported for the first time from southern India. *O. profeae* and *M. annandalei* belong to type II feeding group while *H. balwanti* confines to type I feeding group.

Keywords: *Heterotermes balwanti,* Kerala, *Microcerotermes annandalei,* new records, *Odontotermes profeae*, Western Ghats.

Editor: Jobin Mathew, CMS College, Kottayam, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Anushya, A.V. & P.R. Swaran (2024). New records of termite species (Blattodea: Rhinotermitidae, Termitidae) from southern India. *Journal of Threatened Taxa* 16(9): 25913–25919. https://doi.org/10.11609/jott.8069.16.9.25913-25919

Funding: UGC junior/senior research Fellowship (UGC-JRF/SRF).

Competing interests: The authors declare no competing interests.

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Author contributions: Anushya—field work and identification. Swaran—design of method and analysis.

Acknowledgements: Authors acknowledge the UGC, Government of India, for financial support, Kerala State Forest Department for collection permissions and zoology departments, Kannur University Campus Mananthavady and Payyanur College, for the facilities.

INTRODUCTION

Termites are a group of insects that are well known for causing significant harm to woodwork in buildings, agricultural and forest crops, timber and other products of cellulosic origin (Shanbhag & Sundararaj 2013). However, only 12.4% of the described species have been reported as pests (Krishna et al. 2013). Others have only a beneficial role as an integral part of the ecosystem, which is seldom recognized. Identifying the termite species and its feeding preferences in a given area are important considerations for effective and scientific pest management. Thus, taxonomic, ecological, and diversity studies of the pest and other species are equally relevant and a prerequisite to pest management studies.

There are over 3,000 species of termites that have been described, spanning 330 genera worldwide (Krishna et al. 2013). Only 295 species that belong to 52 genera under six families are known from India and 133 species that belong to 37 genera under five families from southern India, of which five genera and 60 species are endemic to southern India (Amina et al. 2013, 2016; Krishna et al. 2013; Rajmohana et al. 2019; Ranjith & Kalleshwaraswami 2021; Joseph et al. 2023). Though taxonomic studies on termites from southern India started way back in 1779 (König 1779) and were enriched by extensive studies of Bose (1984), the scope remains wide open still as evidenced by new species records even in most recent studies like Joseph et al. (2023). The termite fauna of Kerala so far recorded is 73 species under 30 genera and three families, of which two genera and 12 species are endemic to Kerala (Amina et al. 2016, 2020a,b; Mathew & Ipe 2018; Ipe & Mathew 2019; Joseph et al. 2023).

Termites are classified into four feeding groups based on their gut content analysis. Lower termites, mainly the dead wood and grass feeders are included in group I; group II contains higher termites which feed on dead wood, leaf litter and micro epiphytes; group III comprises organic rich soil feeders and group IV includes true soil feeders (Donovan et al. 2001). To which feeding group a termite species belongs, is an indication of its role and importance in the ecosystem and its status as a pest. The present paper discusses part of a taxonomic and ecological study on termites of Northern part of Kerala with three new records of termite species from South India, of which one belongs to feeding group I and two belong to group II.

MATERIALS AND METHODS

Termite samples described in the present paper were collected from different habitats from northern Kerala as part of a detailed study on diversity and seasonality of termites. The specimens were collected using forceps and brush. Samples were preserved in vials containing 70% ethanol and labeled with habitat, collection locality, date and time. Taxonomic observations were made using stereo zoom microscope at 45x magnification. Identification up to species level was made by using Roonwal & Chhotani (1989) and Chhotani (1997). The photomicrographs and measurements were taken by using ZEISS Stemi 305 stereo zoom microscope with Axiocam 208 camera. One sample each of all the species reported are deposited in the National Zoological Collections of the Zoological Survey of India (ZSI), Western Ghats Regional Centre, Kozhikode, Kerala, India. The remaining specimens are kept at the Zoology Museum of Payyanur College, Edat, Kerala, India.

RESULT AND DISCUSSION

Following are the diagnosis of the two species of termites recorded for the first time from southern India and one from the state of Kerala.

Family: Rhinotermitidae

Sub-family: Heterotermitinae

1. *Heterotermes balwanti* Mathur & Chhotani, 1969

Material examined: ZSI/WGRC/I.R.-INV.26917, 23.xi.2019, one colony, India: Kerala, Kasargod, Mavilakadappuram, coastline habitat (12.1917^{0}N & 75.1243^{0}E), coll. A.V. Anushya. KU/PNRC/ZL/520, 21.i.2020, one colony, India: Kerala, Kasargod, Valiyaparamba, coastline habitat (12.1394^{0}N & 75.1449^{0}E), coll. A.V. Anushya.

Diagnosis: Soldier (Table 1 and Image 1) – Head capsule creamy white to yellowish-brown in colour and sub-rectangular in shape. Body is whitish and densely hairy. Fontanelle is minute and leading into a small, brownish tube; situated at base of median groove. Eyes and ocelli are absent. Antennae with 12–14 segments in which, segment 3 is longer than 4 (in the present collection, 2 soldiers had 12 segmented and 4 soldiers had 14 segmented antennae). Labrum triangular shaped with a long and pointed hyaline tip and with a pair of long hairs. Mandibles are dark brown, thin and sabre-shaped with weakly incurved apices. Postmentum is long and club-shaped, waist lying below the middle. Pronotum

Image 1. *Heterotermes balwanti* Mathur & Chhotani, 1969; Soldier, dorsal view. © Authors.

is flat, subreniform, anterior margin outcurved with median emargination and medialy notched, posterior margin with a faint incurving. Worker – Head-capsule sub-squarish, a little broader than length to base of mandibles (length to base of mandibles 0.73–0.85 mm, maximum width 0.7–0.85 mm). Eyes and ocelli are absent. Fontanelle is indistinct. Antennae are 13–14 segmented. Pronotum is flat (length 0.25–0.33 mm, width 0.40–0.55 mm) (modified from Roonwal & Chhotani 1989).

Distribution: India—Odisha, Karnataka (Dharwar), Goa (Krishna et al. 2013), Kerala (Kasargod, present study).

Remarks: *H. balwanti* is listed as a major pest species in India (Krishna et al. 2013; Shanbhag & Sundararaj 2013). The species is endemic to India (Rajmohana et al. 2019) and is reported for the first time from Kerala. From the southern region of India, this species is earlier reported only from the state of Karnataka (Krishna et al. 2013; Ranjith & Kalleshwaraswami 2021). *H. balwanti* belongs to Type I feeding group and it mostly feeds on woodwork in buildings. The species is morphologically similar to *H. malabaricus*, but its smaller size and longer mandibles differs. It is mostly found in the plains of India (Maiti 2006). In the present study it was recorded from coastal plains, feeding on dead wood within the mud tunnel on dried *Cocos nucifera* wood.

Family: Termitidae

Sub-family: Macrotermitinae

2. *Odontotermes profeae* Akhtar, 1975

Material examined: ZSI/WGRC/I.R.-INV.26918, 28.xii.2019, KU/PNRC/ZL/363, 29.xi.2019 two colonies, India: Kerala, Wayanad, Mananthavady, Grass land (11.7659^{0}N & 75.9830^{0}E), coll. K. Jyothi. KU/PNRC/ZL/451, 24.xii.2019, one colony, India: Kerala, Kasargod, Bedur, Coconut plantation (12.2757^{0}N, 75.2949^{0}E), coll. A.V. Anushya.

Diagnosis: Soldier (Table 2 and Image 2) **–** Head capsule brownish-yellow to yellowish-brown, sub-rectangular and sides weakly convex. Abdomen is whitish-yellow, pronotum brownish-yellow. Antennae uniformly coloured with 17-segments, segment 3 is shortest. Labrum triangular shaped; with pointed hyaline tip. Mandibles dark brown in colour and are long, stout and slightly incurved at the distal end. Left mandible with a large anteriorly directed tooth situated a little below middle, right mandible with a minute tooth like projection almost at the level of tooth on left mandible. Post-mentum is sub rectangular; sides almost parallel. Pronotum saddle shaped.

Image 2. *Odontotermes profeae* Akhtar, 1975; Soldier, dorsal view. © Authors.

Table 1. Measurements of soldiers of *Heterotermes balwanti*.

	Measurement of soldier from present study (n = 4)		Measurement of soldier as per (Roonwal & Chhotani 1989)
	Characters	**Soldier (mm)**	**Soldier (mm)**
1	Total body length	3.4–4.2	3.3–4.0
2	Length of head to the base of mandible	1.00–1.15	1.00–1.10
3	Max. width of head	0.71–0.76	0.70–0.75
4	Width at base of mandibles	0.57	-
5	Head index (max. width/length)	0.66–0.71	-
6	Length of mandible	0.84	0.73–0.78
7	Head-mandibular length index (mandible length/head length)	0.73	0.68–0.78
8	Length of postmentum	0.74	0.70–0.88
9	Max. width of postmentum	0.30–0.35	0.30–0.35
10	Min. width of postmentum	0.16–0.19	0.15–0.18
11	Length of pronotum	0.33	0.30–0.35
12	Width of pronotum	0.52	0.50–0.55
13	No. of antennal segments	12–14	12–14

Table 2. Measurements of soldiers of *Odontotermes profeae*.

	Measurement of soldier from present study (n = 4)		Measurement of soldier as per (Chhotani 1997)
	Characters	**Soldier (mm)**	**Soldier (mm)**
	Total body length	7.30–7.43	-
1	Length of head to the base of mandible	2.04–2.29	1.96–2.39
2	Max. width of head	1.87–2.06	1.73–2.00
3	Width at base of mandibles	1.21–1.26	1.06–1.26
4	Head index (max. width/length)	0.89	0.837
5	Index (width at mandible-base/ max. width)	0.612	0.681
6	Length of mandible	1.25–1.30	1.19–1.35
7	Head–Mandibular length index (mandible length/head length)	0.57	0.57
8	Tooth distance from tip of mandible	0.56	–
9	Tooth index (tooth distance/ mandibular legth)	0.45	–
10	Length of postmentum	1.27–1.30	1.28–1.58
11	Max. width of postmentum	0.65–0.74	0.64–0.80
12	Min. width of postmentum	0.55–0.60	–
13	Length of pronotum	0.63	0.60–0.77
14	Width of pronotum	1.24–1.30	1.25–1.33
15	No. of antennal segments	17	17

Worker (Image 3 & 4) – Head capsule yellow to brownish-yellow, post-clypeus and labrum paler than head capsule, antennae basally paler and darker distally, body creamy white to yellowish. Body densely and head moderately hairy. Total body length 4.43–5.20 mm. Head capsule sub–squarish, wider than long (length to base of mandible 1.37–1.45 mm and width 1.50–1.60 mm). Fontanelle is present. Antennae with 19 segments, 3rd segment is shortest. Post-clypeus swollen, divided by a longitudinal median grove into two halves (length 0.30 mm and width 0.60–0.65 mm). Mandibles each with a finger like apical teeth; left mandible with three marginal teeth and right mandible with two marginal teeth. Pronotum saddle shaped (length 0.33–0.60 mm, width 0.84–1.00 mm).

Distribution: Bangladesh; India—Manipur, Nagaland (Krishna et al. 2013), Kerala (Wayanad & Kasargod, present study).

Remarks: *O. profeae* is a fungus growing wood/ litter feeder and belongs to Type II feeding group. Genus *Odontotermes* is the dominant representative of wood destroying termites (Shanbhag et al. 2013). The species is similar to both *O. mirganjensis* and *O. singsiti* in size and pointed tip of labrum, but differs in having a wider head. Earlier reports of the species from India were only from the eastern region (Verma 1984; Maiti et al. 2004). It is reported for the first time from Western Ghats and southern India. It was observed in the present study in grasslands and coconut plantations, where it fed on dead wood and was also collected from the soil.

Family: Termitidae
Sub-family: Termitinae
3. *Microcerotermes annandalei* Silvestri, 1923

Material examined: ZSI/WGRC/I.R.-INV.26919, KU/PNRC/ZL/264, 09.xi.2019, KU/PNRC/ZL/652, 29.ii.2020, three colonies, India: Kerala, Kannur, Puthur, Sacred groove (12.1967^{0}N & 75.2177^{0}E), coconut plantation (12.1979^{0}N & 75.2204^{0}E), coll. A.V. Anushya. KU/PNRC/ZL/122, 02.x.2019, one colony, India: Kerala, Kasargod, Valiyaparamba, coastline habitat (12.1394^{0}N & 75.1449^{0}E), coll. A.V. Anushya. KU/PNRC/ZL/678-679, 03.iii.2020, two colonies, India: Kerala, Kasargod, Bedur, coconut plantation (12.2757^{0}N, 75.2949^{0}E), coll. A.V. Anushya.

Diagnosis: Soldier (Table 3 and Image 5) – Head capsule yellow to brown, sub-rectangular, body creamy white to yellowish. Antennae uniformly pale brown in colour with 13 segments in which segment 3 is shortest. Labrum pale brown, sub-squarish with rounded anterior margin. Fontanelle is small, situated at anterior third of head. Mandibles dark reddish-brown and are short,

Image 3. *Odontotermes profeae* Akhtar, 1975; Worker, dorsal view. © Authors.

Image 4. *Odontotermes profeae* Akhtar, 1975; Worker, mandible. © Authors.

Image 5. *Microcerotermes annandalei* Silvestri, 1923; Soldier, dorsal view. © Authors.

thick, stout and apices strongly incurved. Mandibles coarsely serrated with a tooth like large serration at below middle. Post-mentum is club shaped with a long, slender waist. Pronotum is saddle shaped; anterior margin with deep notch and posterior margin with weak medial emargination. Worker – Head capsule is squarish (length to base of mandible 0.97–1.05 mm). Post-clypeus swollen, length is more than half of its width. Antennae with 13 segments, segment 3 is shortest. Fontanelle is indistinct. Pronotum saddle shaped (length 0.17–0.27 mm, width 0.50–0.57 mm) (modified from Chhotani 1997).

Distribution: Thailand, Myanmar, Malaysia, India—Bihar, Nagaland, Haryana, Odisha, Tripura, Rajasthan (Krishna et al. 2013), Kerala (Kasargod and Kannur, present study).

Remarks: *M. annandalei* is a wood feeder, belonging to Type II feeding group. It is listed as a minor pest species in India (Krishna et al. 2013; Shanbhag & Sundararaj 2013). The species is added to the list of wood destroying termites of Kerala. It is reported for the first time from Kerala as well as from the whole of southern India. It nests in wooden stumps and logs (Bose & Das 1982). Maiti et al. (2000) reported that the species is mostly found in the soil nest from eastern India. In the present study, it was mostly collected from mud tunnels on dead wood materials as well as live trees like *Areca catechu*.

Heterotermes is a genus that contains several species, some of which are dangerous pests, across the tropical regions (Shanbhag & Sundararaj 2013). Only two species of *Heterotermes* were reported earlier from Kerala and the present record of *H. balwanti* makes it three. In the present study, the species was found feeding on dead wood and it is worth noting that it is already reported as a major pest elsewhere (Krishna et al. 2013; Shanbhag & Sundararaj 2013). *Odontotermes* is the largest and most widely distributed termite genus. With 18 species of wood-destroying termites, it is claimed to be the largest genus of wood destroying termites too (Shanbhag & Sundararaj 2013). Kerala has already been home to 16 species of *Odontotermes,* and this study finds one more (*O. Profeae*) bringing the total to 17. The pest status of *O. profeae* has not yet been recorded; however, it was collected from dead wood and soil in the present study. *Microcerotermes* is also a widely distributed genus and one of the largest wood destroying termite (Roisin & Pesteels 2000; Shanbhag & Sundararaj 2013).

Table 3. Measurements of soldiers of Microcerotermes annandalei.

	Measurement of soldier from present study (n = 4)		Measurement of soldier as per (Chhotani 1997)
	Characters	Soldier (mm)	Soldier (mm)
1	Total body length	4.26–4.75	4.08–5.5
2	Length of head to the base of mandible	1.61–1.94	1.57–1.90
3	Max. width of head	0.92–1.19	0.91–1.09
4	Width at base of mandibles	0.62	–
5	Index (width at base of mandible/ max. width)	0.66	–
6	Head index (width/length)	0.57–0.61	0.56–0.60
7	Length of mandible	0.89–1.05	0.90–1.18
8	Head–mandibular length index (mandible length/head length)	0.54–0.55	0.51–0.60
9	Length of postmentum	1.08	0.92–1.19
10	Max. width of postmentum	0.32	0.32–0.33
11	Min. width of postmentum	0.22	0.17–0.27
12	Length of pronotum	0.31	0.30–0.41
13	Width of pronotum	0.66	0.55–0.73
14	No. of antennal segments	13	13

So far, six species have been found in Kerala, (Krishna et al. 2013; Ranjith & Kalleshwaraswami 2021) and the current report makes it seven. The present species, *M. annandalei* is a wood feeding termite with minor pest status and was collected from the mud tunnels on both dead wood and live trees. Of the newly recorded species, *H. balwanti* belongs to feeding group I and the other two species (*O. profeae* & *M. annandalei*) belong to feeding group II.

CONCLUSION

The present study contributes three new species records to the termite fauna of Kerala, in which two species are new to southern India and one species is new to the Western Ghats. The present report updates termite diversity of southern India to 135 species and Kerala to 76 species. The new documentation also adds to the list of wood feeding termite species of Kerala.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25920–25930

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9015.16.9.25920-25930

#9015 | Received 05 March 2024 | Final received 30 August 2024 | Finally accepted 06 September 2024

COMMUNICATION

A study on the association between Tridax Daisy *Tridax procumbens* L. and butterflies at Shivaji University Campus, Maharashtra, India

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Abstract: The objective of the present study was to study butterfly-*Tridax procumbens* interaction and test whether there is any correlation between lengths of corolla tube of the flowers and butterfly proboscis. Most butterflies visit flowers to obtain nectar. A common weed *T. procumbens* is an invasive species and a nectar plant for many butterflies. At Shivaji University campus, we documented a total of 42 species of butterflies belonging to three families (Lycaenidae, Nymphalidae, and Pieridae) of superfamily Papilionoidea visiting flowers of *T. procumbens* for nectar from December 2022 to November 2023. Among these, lycaenids were the most speciose with a total of 21 species, followed by the family Nymphalidae with 12 species, and the family Pieridae with nine species. Although the corolla length of *T. procumbens* flower is considered short, butterflies with both short (Lycaenidae and Pieridae) and long (Nymphalidae) proboscises were observed visiting these flowers for nectar. Seasonal studies carried out here showed that the highest number of butterfly species was recorded during monsoon season, mainly in June, than during other seasons. Among all species recorded, *Eurema laeta* was recorded at the highest temperature 35.8°C with 37% humidity. In the present communication photographs of all 42 butterfly species visiting *T. procumbens* flowers are provided.

Keywords: Butterfly, coat button, corolla tube, flower, humidity, interaction, monsoon, nectar, proboscis, temperature.

Editor: A.J. Solomon Raju, Andhra University, Visakhapatnam, India.

Date of publication: 26 September 2024 (online & print)

Citation: Patil, A.N. & S.M. Gaikwad (2024). A study on the association between Tridax Daisy *Tridax procumbens* L. and butterflies at Shivaji University Campus, Maharashtra, India. *Journal of Threatened Taxa* 16(9): 25920–25930. https://doi.org/10.11609/jott.9015.16.9.25920-25930

Funding: Chhatrapati Shahu Maharaj National Research Fellowship (CSMNRF) 2022, Government of Maharashtra.

Competing interests: The authors declare no competing interests.

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Author contributions: SMG involved in photography, design of the research and write-up of the manuscript. ANP is involved in photography, data compilation and manuscript preparation.

Acknowledgements: The authors are thankful to the Department of Zoology, Shivaji University Kolhapur for providing laboratory facilities and the Chhatrapati Shahu Maharaj National Research Fellowship (CSMNRF) 2022, Government of Maharashtra for financial assistance. We are also thankful to the principal chief conservator of forests (Wildlife), Maharashtra State for necessary permits.

INTRODUCTION

Butterflies (Lepidoptera: Papilionoidea) are one of the most common diurnal groups of flower visitors for taking nectar as main source of their diet (Bawa 1990; Haribal 1992). Being the specialized feeders, they are equipped with a long, hollow, sucking tube called proboscis and is coiled when not in use (Haribal 1992). The feeding of butterflies is not a random phenomenon; it has been shown that they prefer nectar plants having specific chemical composition (Kunte 2000). Hence, it becomes important to study interaction between butterflies and specific species of flowering plants. Several researchers (Tiple et al. 2009; Nimbalkar et al. 2011; Chandra et al. 2013; Sultana et al. 2017; Varalakshmi & Raju 2013; Mukherjee & Hossain 2021; Mallick & Virdi 2024) have studied interaction between butterflies and *Tridax procumbens*.

Tridax procumbens is an annual herbaceous invasive herb that belongs to Asteraceae family used by butterflies for food because this species blooms throughout the year (Nimbalkar et al. 2011; Rathore et al. 2020; Mukherjee & Hossain 2021). This plant is a valuable nectar source for butterflies (Mallick & Virdi 2024). In the present study, 42 species of butterflies feeding on the nectar of *T. procumbens* flowers were recorded. The number of species are significantly higher than species recorded in previous studies (Tiple et al. 2009; Nimbalkar et al. 2011; Chandra et al. 2013; Sultana et al. 2017; Varalakshmi & Raju 2013; Mukherjee & Hossain 2021; Mallick & Virdi 2024). Additionally, abiotic factors (temperature and relative humidity) during the observation period were recorded. This study highlights the significance of *T. procumbens* as a major source of nectar for many butterfly species.

MATERIALS AND METHODS

Field visits were made throughout the day to record visits by butterflies at the study area (Shivaji University Campus, Kolhapur) during December 2022 to November 2023. The visiting butterflies were identified by consulting field guides published by different workers (Haribal 1992; Gunathilagraj 2015; Kunte 2000; Bhakare & Ogale 2015; Kasambe 2016), and the images on the Butterflies of India website (https://www.ifoundbutterflies.org). Temperature and relative humidity were recorded during the observation period by using digital hygrometer. Butterflies were photographed using Canon 550D and Nikon D500 DSLR cameras.

RESULTS AND DISCUSSION

A total of 42 species of butterflies (Table 1) belonging to three families (Lycaenidae, Nymphalidae, and Pieridae), eight subfamilies, and 10 tribes were observed feeding on the flowers of *T. procumbens* at the Shivaji University campus, Kolhapur. Of these, lycaenids dominated (21 species) (Images 1–21) followed by nymphalids (12 species) (Images 22–33), and pierids (9 species) (Images 34–42).

The current study showed that the number of species and the number of individuals of each species visiting the flowers of *T. procumbens* varied seasonally. Table 2 shows that the highest number of butterfly species visited during rainy season (32), followed by winter (14), and summer season (11). The month-wise records (Table 2, Figure 1) showed the maximum number of species in June (19 species) and July (16 species). An almost equal number of species were recorded in October (10 species), November (9 species), and May (8 species). Also, four, five, and three species were recorded in August, September, and December, respectively (Figure 1). *Chilades pandava* (Horsfield, 1829) was not recorded during winter season. *Leptotes plinius* (Fabricius, 1793) was recorded only in February. Most of the butterflies visited the flowers in the morning hours (15 species, 0900–1200 h), followed by morning and afternoon hours (11 species, 0900–1600 h), afternoon hours (8 species, 1200–1600 h), and evening hours (4 species, 1600–1743 h). *Chilades pandava, Talicada nyseus* (Guerin-Meneville, 1843), *Castalius rosimon* (Fabricius, 1775), and *Jamides celeno* (Cramer, 1775) showed foraging activity throughout the day (Table 2). The temperature and relative humidity recorded during the observation period is presented in Table 2. Two species *Catochrysops panormus* (C. Felder, 1860) and *Azanus uranus* (Butler, 1886) were recorded at low temperature (25^{0}C) and high humidity (89%) while *Eurema laeta* (Boisduval, 1836) was recorded at high temperature (35.8^{0}C) and low humidity (37%).

Many studies on butterfly-plant interactions exist (Nimbalkar et al. 2011; Rathore et al. 2020; Khandal & Sharma 2020) including the interactions between butterflies and *T. procumbens* (Tiple et al. 2009; Nimbalkar et al. 2011; Chandra et al. 2013; Sultana et al. 2017; Sharma & Sharma 2018; Khandal & Sharma 2020; Mukherjee & Hossain 2021; Mallick & Virdi 2024). Among these, pollination and nectar feeding relationships are the focus of the current study. In this study, 42 butterfly species were recorded on the flowers of *T. procumbens*. Tiple et al. (2009) recorded 11 species

Table 1. List of butterflies feeding on the nectar of *Tridax procumbens*.

Family	Subfamily	Tribe		Scientific name	Common name
LYCAENIDAE	1. Aphanaeninae	1. Aphaenini	1.	*Spindasis icitis* (Hewiston, 1865)	Common Shot Silverline
			2.	*Spindasis vulcanus* (Fabricius, 1775)	Common Silverline
	2. Polyommatinae	2. Polyommatini	3.	*Freyeria trochylus* (Freyer, 1845)	Grass Jewel
			4.	*Freyeria putli* (Kollar, 1844)	Oriental Grass Jewel
			5.	*Tarucus nara* (Kollar, 1848)	Stripped Pierrot
			6.	*Zizina otis* (Fabricius,1787)	Lesser Grass Blue
			7.	*Lampides boeticus* (Linnaeus, 1767)	Pea Blue
			8.	*Catochrysops strabo* (Fabricius, 1793)	Forget-me-not
			9.	*Chilades pandava* (Horsfield, 1829)	Plains Cupid
			10.	*Leptotes plinius* (Fabricius, 1793)	Zebra Blue
			11.	*Talicada nyseus* (Guerin-Meneville, 1843)	Red Pierrot
			12.	*Azanus ubaldus* (Stoll, 1782)	Bright Babul Blue
			13.	*Nacaduba berenice ormistoni* (Herrich- Schaffer, 1869)	Rounded Six-Line Blue
			14.	*Chilades parrhasius* (Fabricius, 1793)	Small Cupid
			15.	*Zizeeria karsandra* (Moore, 1865)	Dark Grass Blue
			16.	*Castalius rosimon* (Fabricius, 1775)	Common Pierrot
			17.	*Pseudozizeeria maha* (Kollar, 1844)	Pale Grass Blue
			18.	*Catochrysops panormus* (C. Felder, 1860)	Silver Forget-me-not
			19.	*Jamides celeno* (Cramer, 1775)	Common Cerulean
			20.	*Chilades lajus* (Stoll, 1780)	Lime Blue
			21.	*Azanus uranus* Butler, 1886	Dull Babul Blue
NYMPHALIDAE	3. Nymphalinae	3. Junonini	22.	*Junonia lemonias* (Linnaeus, 1758)	Lemon Pansy
			23.	*Junonia almana* (Linnaeus, 1758)	Peacock Pansy
			24.	*Hypolimnas misippus* (Linnaeus, 1764)	Danaid Eggfly
		4. Nymphalini	25.	*Vanessa cardui* (Linnaeus, 1758)	Painted Lady
	4. Danainae	5. Danaini	26.	*Danaus chrysippus* (Linnaeus, 1758)	Plain Tiger
			27.	*Danaus genutia* (Cramer, 1779)	Striped Tiger
			28.	*Tirumala limniace* (Cramer, 1775)	Blue Tiger
			29.	*Euploea core* (Cramer, 1780)	Common Crow
			30.	*Parantica aglea* (Stoll, 1782)	Glassy Tiger
	5. Heliconiinae	6. Vagarantini	31.	*Phalanta phalantha phalantha* (Drury, 1773)	Common Leopard
		7. Acraeini	32.	*Acarea terpsicore* (Linnaeus, 1758)	Tawny Coster
	6. Satyrinae	8. Satyrini	33.	*Ypthima philomela* (Marshall, 1883)	Baby Fivering
PIERIDAE	7. Coliadinae		34.	*Catopsilia pyranthe* (Linnaeus, 1758)	Mottled Emigrant
			35.	*Catopsilia pomona pomona* (Fabricius, 1775)	Common Emigrant
			36.	*Eurema laeta* (Boisduval, 1836)	Spotless Grass Yellow
			37.	*Eurema hecabe* (Linnaeus, 1758)	Common Grass Yellow
			38.	*Eurema brigitta* (Stoll, 1780)	Small Grass Yellow
			39.	*Eurema nilgiriensis* (Yata, 1990)	Nilgiri Grass Yellow
	8. Pierinae	9. Pierini	40.	*Belenois aurota* (Fabricius, 1793)	Pioneer White
			41.	*Cepora nerissa* (Fabricius, 1775)	Common Gull
		10. Leptosianini	42.	*Leptosia nina* (Fabricius, 1793)	Psyche

Table 2. Interaction between butterfly species and *Tridax procumbens* concerning season and abiotic factors.

	Name	Availability of species and abiotic factors	Rainy season				Winter season				Summer season				Foraging time
			Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
1.	*Spindasis icitis*	Presence	+	+	-	-	-	-	-	-	-	-	-	-	1058–1256 h
		Temperature (°C)	33.8	28.4											
		Humidity (%)	41	79											
2.	*Spindasis valcanus*	Presence	-	-	-	-	+	-	-	-	-	-	-	-	1711 h
		Temperature (°C)					28								
		Humidity (%)					72								
3.	*Freyeria trochylus*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	0950 h
		Temperature (°C)	35.7												
		Humidity (%)	37												
4.	*Freyeria putli*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1128 h
		Temperature (°C)		26.7											
		Humidity (%)		84											
5.	*Taracus nara*	Presence	+	+	-	-	-	-	-	-	-	-	-	-	1100–1400 h
		Temperature (°C)	34.5	27.5											
		Humidity (%)	39	81											
6.	*Zizina otis*	Presence	+	+	-	-	-	-	-	-	-	-	+	-	0900 –1400 h
		Temperature (°C)	34.6	27.1									30.8		
		Humidity (%)	39	83									47		
7.	*Lampides boeticus*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1145 h
		Temperature (°C)	32.6												
		Humidity (%)	44												
8.	*Catochrysops strabo*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1344 h
		Temperature (°C)		28.5											
		Humidity (%)		79											
9.	*Chilades pandava*	Presence	+	+	+	+	+	+	-	-	-	+	+	+	0900–1630 h
		Temperature (°C)	32.6	28.4	27.1	26.3	28.1	27.9				30.1	33.3	35.5	
		Humidity (%)	44	79	65	95	34	52				21	26	40	
10.	*Leptotes plinius*	Presence	-	-	-	+	+	+	+	+	+	+	-	-	1140–1340 h
		Temperature (°C)				27.9	27.6	28.5	28.5	28.6	29.1	32.2			
		Humidity (%)				90	82	50	56	43	42	20			
11.	*Talicada nyseus*	Presence	-	-	-	+	+	+	+	+	-	-	-	-	1030–1721 h
		Temperature (°C)				28.9	28.0	28.8	28.1	27.6					
		Humidity (%)				70	72	53	55	46					
12.	*Azanus ubaldus*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1058 h
		Temperature (°C)		28.4											
		Humidity (%)		79											
13.	*Nacaduba berenice ormistoni*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1221 h
		Temperature (°C)		28.4											
		Humidity (%)		79											
14.	*Chilades parrhasius*	Presence	-	-	-	-	-	-	-	-	-	-	-	+	1040 h
		Temperature (°C)												32.5	
		Humidity (%)												45	

	Name	Availability of species and abiotic factors	Rainy season				Winter season				Summer season				Foraging time
			Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
15.	*Zizeeria karsandra*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1005 h
		Temperature (°C)	35.1												
		Humidity (%)	38												
16.	*Castalius rosimon*	Presence	-	+	-	-	-	-	-	-	-	-	+	+	0900–1630 h
		Temperature (°C)		28.3									33.1	35.4	
		Humidity (%)		78									26	35	
17.	*Pseudozizeeria maha*	Presence	-	-	+	-	-	-	-	-	-	-	-	-	1615 h
		Temperature (°C)			27.1										
		Humidity (%)			65										
18.	*Catochrysops panormus*	Presence	-	+	+	-	-	-	-	-	-	-	-	-	1346 h
		Temperature (°C)		25.0	27.7										
		Humidity (%)		89	68										
19.	*Jamides celeno*	Presence	-	-	-	-	+	+	+	+	-	-	-	-	1000–1700 h
		Temperature (°C)					28.3	28.5	27.8	27.6					
		Humidity (%)					81	57	55	46					
20.	*Chilades lajus*	Presence	-	-	-	-	+	-	-	-	-	-	-	-	1152 h
		Temperature (°C)					28.1								
		Humidity (%)					34								
21.	*Azanus uranus*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1346 h
		Temperature (°C)		25.0											
		Humidity (%)		89											
22.	*Junonia lemonias*	Presence	+	+	-	-	-	-	-	-	-	-	+	+	0930 –1400 h
		Temperature (°C)	32.6	28.7									30.8	32.5	
		Humidity (%)	44	78									47	45	
23.	*Junonia almana*	Presence	-	-	-	+	-	-	-	-	-	-	-	-	1247 h
		Temperature (°C)				27.9									
		Humidity (%)				90									
24.	*Hypolimnas misippus*	Presence	-	+	-	-	-	-	-	-	-	-	-	-	1444 h
		Temperature (°C)		29.2											
		Humidity (%)		76											
25.	*Vanessa cardui*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1213 h
		Temperature (°C)	32.6												
		Humidity (%)	44												
26.	*Danaus chrysippus*	Presence	+	-	-	-	-	+	-	-	-	-	-	+	1045–1330 h
		Temperature (°C)	33.5					28.8						33.8	
		Humidity (%)	42					53						40	
27.	*Danaus genutia*	Presence	-	-	-	-	-	+	-	-	-	-	-	-	1032 h
		Temperature (°C)						28.2							
		Humidity (%)						55							
28.	*Tirumala limniace*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1216 h
		Temperature (°C)	32.6												
		Humidity (%)	44												

	Name	Availability of species and abiotic factors	Rainy season				Winter season				Summer season				Foraging time
			Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
29.	*Euploea core*	Presence	-	-	-	-	+	-	-	-	-	-	-	-	1647 h
		Temperature (°C)					27.6								
		Humidity (%)					82								
30.	*Parantica aglea*	Presence	-	-	-	-	+	-	-	-	-	-	-	-	1743 h
		Temperature (°C)					28.3								
		Humidity (%)					75								
31.	*Phalanta phalantha phalantha*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1004 h
		Temperature (°C)	35.1												
		Humidity (%)	38												
32.	*Acarea terpsicore*	Presence	-	-	-	-	-	+	-	-	-	-	-	-	0934 h
		Temperature (°C)						28.5							
		Humidity (%)						57							
33.	*Ypthima philomela*	Presence	+	+	-	-	-	-	-	-	-	-	-	+	1020–1350 h
		Temperature (°C)	32.6	29.2										34.5	
		Humidity (%)	44	76										44	
34.	*Catopsilia pyranthe*	Presence	+	-	-	-	+	-	-	-	-	-	-	-	1000–1217 h
		Temperature (°C)	32.6				27.8								
		Humidity (%)	44				84								
35.	*Catopsilia pomona pomona*	Presence	+	-	-	-	-	-	-	-	-	+	-	-	1103–1230 h
		Temperature (°C)	35.1									32.2			
		Humidity (%)	38									20			
36.	*Eurema laeta*	Presence	+	+	-	-	-	-	-	-	-	-	+	+	0836–1354 h
		Temperature (°C)	35.8	27.56									29.2	35.6	
		Humidity (%)	37	81									50	43	
37.	*Eurema hecabe*	Presence	-	+	+	+	+	+	-	-	-	-	-	-	1000–1547 h
		Temperature (°C)		28.5	27.7	28.9	27.6	27.1							
		Humidity (%)		79	68	71	82	57							
38.	*Eurema brigitta*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1055 h
		Temperature (°C)	32.6												
		Humidity (%)	44												
39.	*Eurema nilgiriensis*	Presence	-	-	-	-	-	+	-	-	-	-	-	-	1000 h
		Temperature (°C)						28.2							
		Humidity (%)						60							
40.	*Belenois aurota*	Presence	+	-	-	-	-	-	-	-	-	-	-	-	1158 h
		Temperature (°C)	36.4												
		Humidity (%)	35												
41.	*Cepora nerissa*	Presence	+	-	-	-	-	-	-	-	-	-	-	+	1034–1108 h
		Temperature (°C)	30.2											35.5	
		Humidity (%)	49											40	
42.	*Leptosia nina*	Presence	-	-	-	-	-	-	-	+	-	-	-	-	1027 h
		Temperature (°C)								27.6					
		Humidity (%)								46					

+—Present | -—Absent

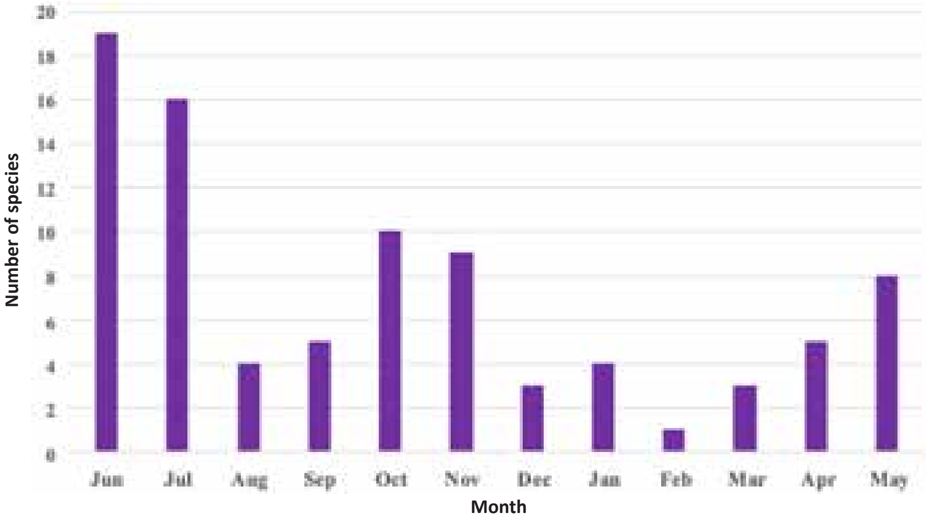

Figure 1. Month-wise number of butterfly species during the study period (December 2022 to November 2023).

of butterflies feeding on the nectar of *T. procumbens* in and around Nagpur. Nimbalkar et al. (2011) recorded a total of 34 species of butterflies feeding on the nectar of *T. procumbens* of which, nine were from Pieridae, four from Lycaenidae, 16 from Nymphalidae, three from Hesperiidae, and two from Papilionidae from Bhor Tahsil, Pune District, Maharashtra, India. Chandra et al. (2013) studied interactions of insects with herbaceous plants and reported 15 species of butterflies feeding on the nectar of *T. procumbens* from different localities of Visakhapatnam. Varalakshmi & Raju (2013) recorded a total of 27 species on *T. procumbens* out of which, five were from Papilionidae, four from Pieridae, 12 from Nymphalidae, five from Lycaenidae, and one from Hesperiidae. Sultana et al. (2017) reported two butterfly species from Pieridae, five from Lycaenidae, and two from Satyridae on *T. procumbens* from protected areas, botanical gardens, and butterfly germ plasm Centre in Bangladesh. Sharma & Sharma (2018) recorded only one Lycaenidae member *Horaga albimacula viola* from different localities of Jammu & Kashmir. Similarly, Khandal & Sharma (2020) recorded only one Hesperiidae species *Coladenia indrani indra* from Ranthambore Tiger Reserve, Rajasthan. Both species were not recorded in the present study because of differences in environmental conditions of the present study site (Maharashtra), Rajasthan, and Jammu & Kashmir. Mukherjee & Hossain (2021) recorded a total of seven butterfly species, all belonging to Lycaenids from Leprosy Mission Campus, West Bengal. Mallick & Virdi (2024) recorded 34 species of butterflies visiting the flowers of *T. procumbens*, of which eight species belonged to Nymphalidae, six species to Lycaenidae, three species to Papilionidae and seven species to Hesperiidae. From all the studies mentioned above, Nimbalkar et al. (2011) and Mallick & Virdi (2024) reported the highest number of 34 small and large butterfly species belonging to different families on T. procumbens. In the present study, 42 butterfly species (21 lycaenids, 12 nymphalids, and 9 pierids) were recorded (Table 1).

Sultana et al. (2017) and Mukherjee & Hossain (2021) noted that in *T. procumbens*, the corolla tube is 8 mm long. Meerabai (2013) documented that butterflies with short proboscis use flowers with 1–10 mm long corolla tubes and butterflies with long proboscis use flowers with 2–43 mm long corolla tube. Different authors (Nimabalkar et al. 2011; Mallick & Virdi 2024) reported that Papilionidae and Nymphalidae butterflies with long proboscis collect nectar from *T. procumbens* flowers. In the present study, Papilionidae butterflies were not recorded but Nymphalidae butterflies with long proboscis collected nectar from *T. procumbens* flowers.

CONCLUSION

The study showed that *T. procumbens* is an important source of nectar during its flowering season for 42 butterflies belonging to Pieridae, Nymphalidae, and Lycaenidae families. But, Lycaenidae represented more species which used this floral source for nectar.

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Image 1. *Spindasis ictis*

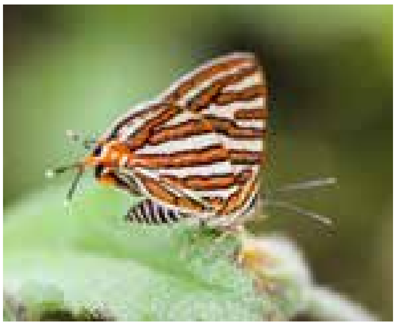
Image 2. *Spindasis vulcanus*


Image 3. *Freyeria trochylus*


Image 4. *Freyeria putli*


Image 5. *Taracus nara*

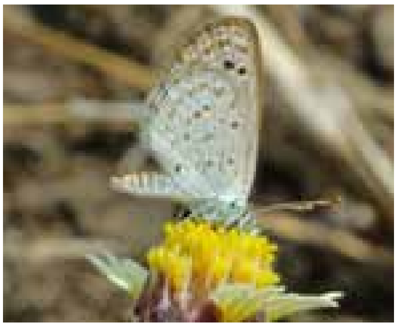
Image 6. *Zizina otis*


Image 7. *Lampides boeticus*


Image 8. *Catochrysops strabo*


Image 9. *Chilades pandava*

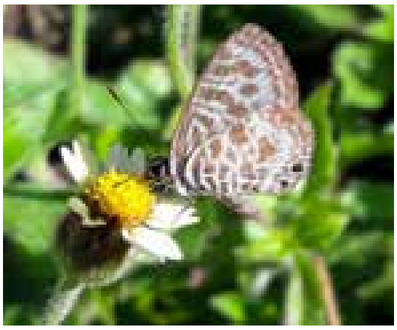
Image 10. *Leptotes plinius*


Image 11. *Talicada nyseus*


Image 12. *Azanus ubaldus*

Image 13. *Nacaduba berenice ormistoni*

Image 14. *Chilades parrhasium*

Image 15. *Zizeeria karsandra*

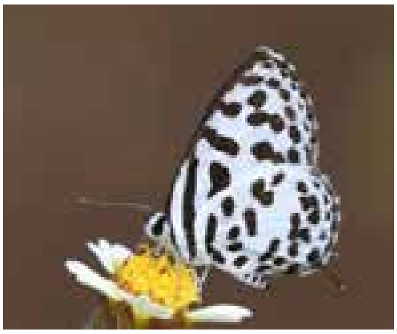

Image 16. *Castalius rosimon*

Image 17. *Pseudozizeeria maha*

Image 18. *Catochrysops panormus*

Image 19. *Jamides celeno*

Image 20. *Chilades lajus*

Image 21. *Azanus uranus*

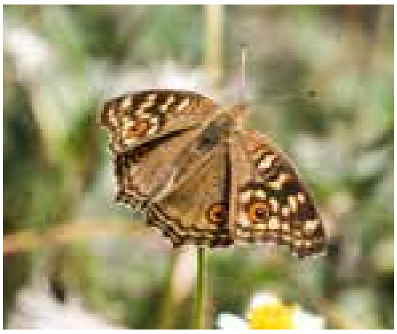

Image 22. *Junonia lemonias*

Image 23. *Junonia almana*

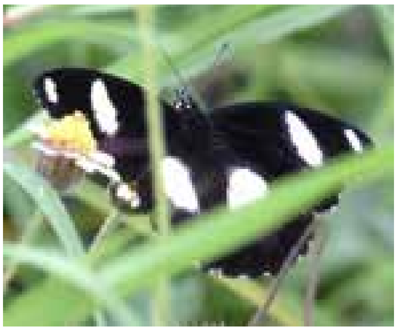

Image 24. *Hypolimnas misippus*

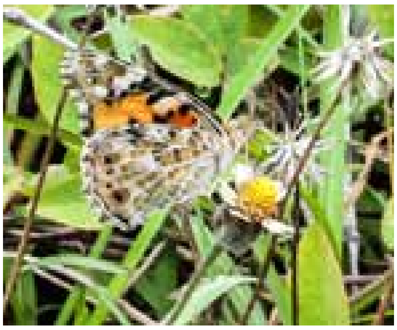

Image 25. *Vanessa cardui*

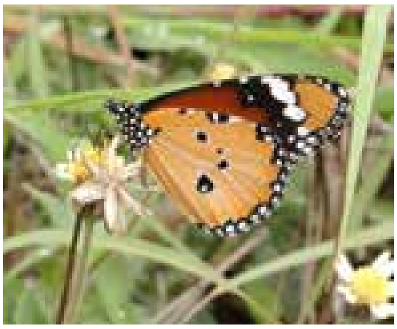

Image 26. *Danaus chryssipus*

Image 27. *Danaus genutia*

Image 28. *Tirumala limniace*

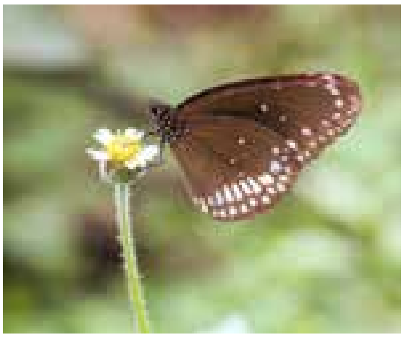

Image 29. *Euploea core*

Image 30. *Parantica aglea*

Image 31. *Phalanta phalantha phalantha*

Image 32. *Acarea terpsicore*

Image 33. Ypthima philomela

Image 34. *Catopsilia pyranthe*

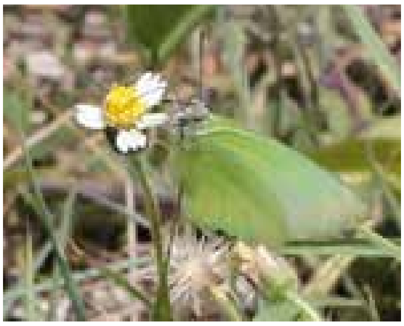

Image 35. *Catopsilia pomona pomona*

Image 36. *Eurema laeta*

Image 37. *Eurema hecabe*

Image 38. *Eurema brigitta*

Image 39. *Eurema nilgiriensis*

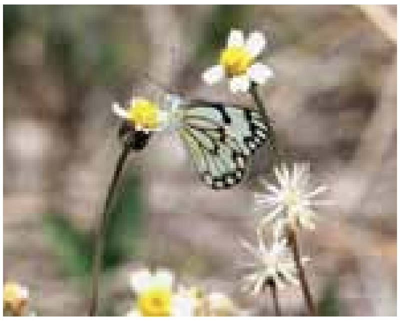

Image 40. *Belenois aurota*

Image 41. *Cepora nerrisa*

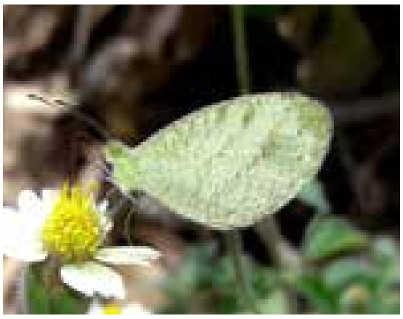

Image 42. *Leptosia nina*

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25931–25934
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.9209.16.9.25931-25934
#9209 | Received 13 June 2024 | Final received 04 September 2024 | Finally accepted 19 September 2024

SHORT COMMUNICATION

Rare Honey Badger *Mellivora capensis* (Schreber, 1776) sighted in Tarai East Forest Division, Haldwani, Uttarakhand, India

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Abstract: The presence of Honey Badger *Mellivora capensis* (Schreber, 1776) is widely distributed but in-depth of ecological understanding this species is still lacking from Asian portion of its global range. The species is listed in Scheduled-I of the Wildlife (Protection) Act, 1972 providing it with the highest level of protection as this is very rare. The current note presents, the first known camera-trap records of this species in Tarai East Forest Division (TEFD), Uttarakhand, India. During the survey exercise, a total 35 camera traps were randomly installed in different habitats (e.g. Natural Sal forest patch, Mixed forests, Sharda River-Canal) in Surai range of the division. As resulted, two images of Honey Badger were captured from the Sharda River bank–Canal habitat of Bagha-I beat, of Surai range. The camera trap study suggests that Honey Badger is rarely sighted in Tarai east sal forest. For protection and management of this species, further need to generate more information and in-depth understanding of their ecological and of population status in around forest habitat of the division.

Keywords: Camera trap, conservation, distribution, GPS, sal forest, Terai Arc Landscape.

The Honey Badger *Mellivora capensis* (Schreber, 1776), also called Ratel, is a mammal widely distributed in Africa (Begg et al. 2016), southwestern Asia, and in the Indian subcontinent. Furthermore, there is no explicit information about the present population of the Honey Badger in Uttarakhand (Kumar et al. 2022). Thus, conservation strategies are difficult to implement, as information on their population status in India is not well documented and their behavioural patterns and social structure are not studied systematically or understood. Though IUCN Red List mentions it under the ‘Least Concern’ category, it is a very rare species and is protected under Schedule 1 of the Wildlife (P) Act 1972.

The Honey Badger is classified under the Mustelidae family, subfamily Mellivorinae. Each paw has five toes, with the hind legs having shorter claws than the forelegs; this assists them with digging and climbing. They stand approximately 25–30 cm high at the shoulder; their skin is loose and tough; this allows the animal to twist and work its way free from either an attacker or from being stuck in a tight space, whilst also providing protection from bites inflicted by other carnivores. They are solitary animals, but a female and her cub can be seen foraging together, and they can hunt in pairs during the mating season (Begg et al. 2005). It lives in a variety of biomes, including mountains, woods, and deserts, and spreads widely throughout South Africa, except the northwestern coastal regions. A study in South Africa suggests that the

Editor: Murali Krishna Chatakonda, Amity University, Noida, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Kumar, P., B.C. Joshi, A.S. Bisht & H. Bagri (2024). Rare Honey Badger *Mellivora capensis* (Schreber, 1776) sighted in Tarai East Forest Division, Haldwani, Uttarakhand, India. *Journal of Threatened Taxa* 16(9): 25931–25934. https://doi.org/10.11609/jott.9209.16.9.25931-25934

Funding: Tarai East Forest Division, Uttarakhand Forest Department.

Competing interests: The authors declare no competing interests.

Acknowledgements: We are grateful to Mr. Sandeep Kumar IFS, ex-DFO Tarai East Forest Division for necessary permission and logistical support. We are also thankful to Mr. Himanshu Bagri IFS, present DFO Tarai East Forest Division for encouragement to publish this research. We thank to Mrs. Sanchita Verma, SDO, R.S. Manral-RO-Surai, R.D. Verma & Baburam Yadav – forester, Mukesh, Sukhvindar & Ravindra – forest guard. We are thankful to field staff of Surai Range, Tarai East Forest Division-Uttarakhand Forest Department for kind cooperation and accommodation in remote locations.

Honey Badgers prefer Eucalyptus plantations to natural habitat types (Kheswa et al. 2018, Allen et al. 2018). Honey Badgers were also reported by researchers in the coastal area of Chilika lagoon, Odisha during a fishing cat survey of the human-dominated landscape (Adhya & Dey 2022). The following studies were reported; it's sightings in different regions of India (Table.1).

A camera trap survey focused on Striped Hyena done in Central Tarai Landscape Nepal documents Honey Badger presence in Sal-dominated Forest (Adhikari et al. 2022). Similarly, a survey done in Bennerghatta National Park, Karnataka, reported the presence of Honey Badger images through camera trapping (Krishnan et al. & 2016). A camera trap survey was conducted to ascertain the presence of tigers and captured the photo of Honey Badger in an opportunistic manner in Simlipal Tiger Reserve (Mishra & Bisht 2023). Here we document the sightings of the Honey Badger from Tarai East forest Division of Uttarakhand.

STUDY AREA

Tarai East Forest Division is a part of the vast Terai Arc Landscape (28°53'24''–31°27'50''N and 77°34'27"–81°02'22" E) and comprises an area of 82,429.0 ha of Terai and Bhabar tracts between the Gola and Sharada rivers (Figure 1). In the Tarai East Forest Division, the Sal Forest is covering a total of 23,080.12 ha (28%) area of the division. It also connects the Nandhaur Wildlife

Table 1. Review of sightings of Honey Badger in India.

	Location	State	Year of study	Reference
1	Bannerghatta NP	Karnataka	2015	Krishnan et al. (2016)
2	Chilika Lagoon	Odisha	2019	Adhya & Dey (2022)
3	Northern Eastern Ghats	Andhra Pradesh	2019	Aditya et al. (2020)
4	Tadoba-Andhari TR	Maharashtra	2016	Chatterjee et al. (2020)
5	Similipal TR	Odisha	2016	Mishra & Bisht (2023)
6	Cauvery WS	Karnataka	2014	Gubbi et al. (2014)
7	Sariska TR	Rajasthan	2009	Gupta et al. (2012)

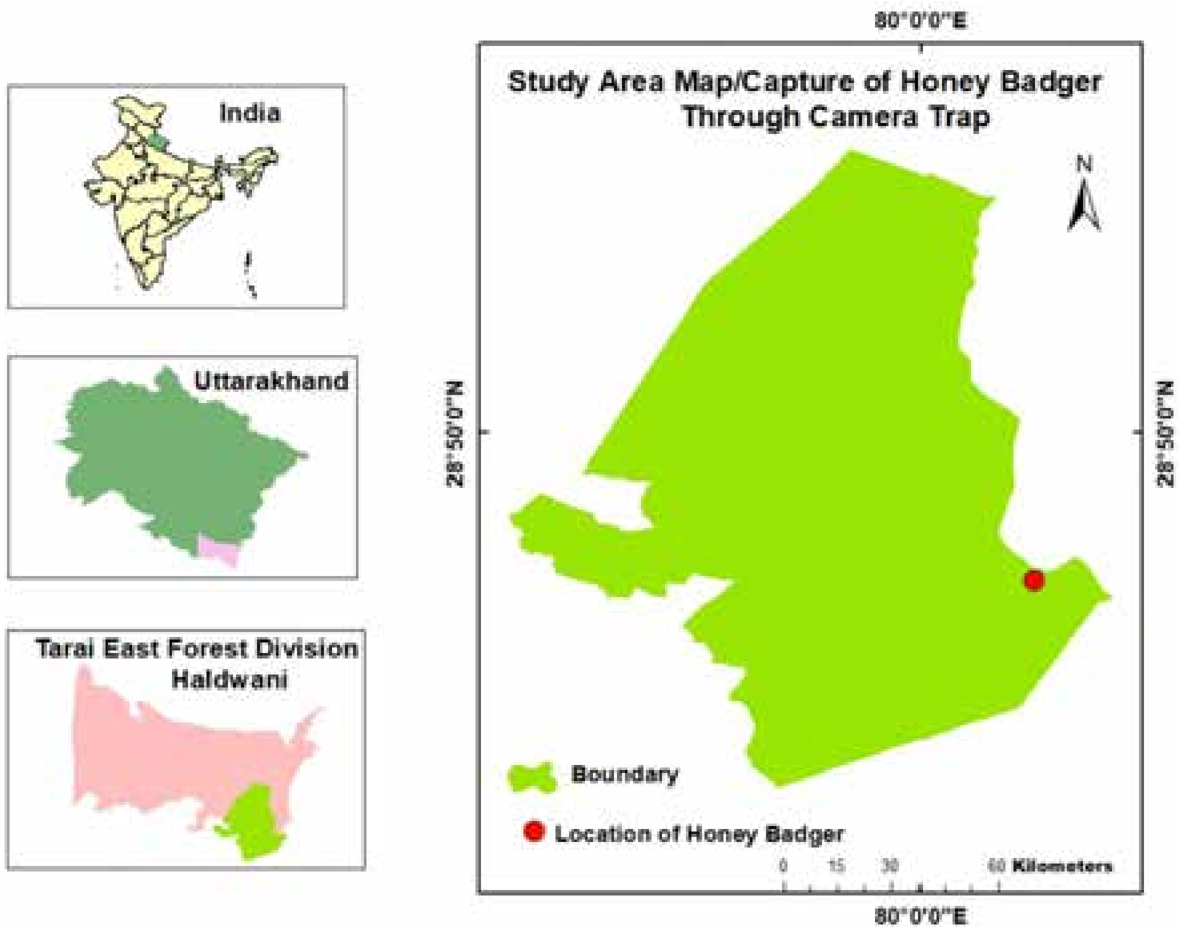

Figure 1. Study Area map showing the location of Honey Badger.

Sanctuary with the Pilibhit Tiger Reserve through the Kilpura-Khatima-Surai corridor. The area is home to very important wildlife species like elephants, tigers, leopards, bears, hyenas, crocodiles etc. Increasing population and dependency on forests, encroachment, overgrazing, poaching etc. are some of the challenges that threaten wildlife and its habitat. The division has covered a total of nine ranges: Kilpura, Khatima, Surai, Gaula, Ransali, Dauli, Barakoli, Kishanpur, and Jaulashal. In this division, Surai range is well known for the presence of 'Royal Bengal Tiger' and a total of 53 individual were reported in Tarai East Forest Division after tiger census (AITE-2022; Qureshi et al. 2023).

RESULTS AND DISCUSSION

As a routine practice under tiger population monitoring, the researchers and staff of the forest department checked the camera trap on 12 January 2024 in which two photos of the camera trap were observed (Image 1 & 2) in Bagha I beat, Surai Range, clicked at 1834 h & 1837 h on 07 January 2024 in the deployed camera trap 13 (CAM 13) which looked like a civet. After matching, the species was identified as a Honey Badger through its morphological characters such as larger size of the skull and mantle color (Menon & Daniel 2003). This is the first photographic evidence of Honey Badger presence in Tarai East Forest Division. This forest division is characterized by Moist Tarai Sal *Shorea robusta* forest (3C/C2C) (Champion & Seth 1968), which provides a rich habitat for Honey Badgers. The age could not be ascertained, but the sex of the Honey Badger was male as the reproductive organ (penis) is clearly visible in the recorded image. The Piliphit Tiger Reserve (PTR) and the Sharda canal of the Indo-Nepal border territories encompass the eastern boundary of Tarai East Forest Division (TEFD), providing possible habitat for the Honey Badger. The Honey Badger sightings and movements have been documented numerous times in the Piliphit Tiger Reserve (PTR) area; being a border area (PTR & TEFD), the Honey Badger's frequent travels have been seen. Camera traps detected its movement for the first time on 07 January 2024, in the TEFD's Surai range. Therefore, it is highly vital to safeguard and conserve their habitats in the area.

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Image 1. Camera trap photo of Honey Badger recorded in Surai Range, Tarai East Forest Division, Uttarakhand.

Image 2. Camera trap photo of Honey Badger recorded in Surai Range, Tarai East Forest Division, Uttarakhand.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25935–25938

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9260.16.9.25935-25938

#9260 | Received 04 July 2024 | Final received 03 August 2024 | Finally accepted 31 August 2024

OPEN ACCESS

SHORT COMMUNICATION

Additional documentation of the Slender Skimmer *Orthetrum sabina* (Drury, 1770) preying on the Pied Paddy Skimmer *Neurothemis tullia* (Drury, 1773) in Nepal

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Abstract: *Orthetrum sabina* is one of the most common dragonflies found in Nepal, but its feeding behavior has not often been reported from there. An example of this species preying on *Neurothemis tullia* is reported from Maidi Lake, Nepal. This observation was made during a field survey of Odonata using direct observation along transects around the lake. It adds to our knowledge of the species' feeding behavior, elaborating the previous findings and providing scope for further ecological studies on Odonata.

Keywords: Dragonfly, feeding ecology, Green Marsh Hawk, Libellulidae, Maidi Lake, Odonata, predator.

Orthetrum sabina (Drury, 1770), commonly known as the Green Marsh Hawk or Slender Skimmer, is a medium-sized dragonfly belonging to the family Libellulidae. The male is medium-sized, greenish-yellow, with bold stripes on the thorax and a pied abdomen. The wings and abdomen have equal lengths of 30–36 mm, with black and reddish-brown spots on the wings, while the eyes are green-mottled with black (Fraser 1936). The female is similar in pattern to the male but differs in the shape of the abdomen. The length of the abdomen is 32–25 mm, while the wings are 31–35 mm. The wing spots and eyes are similar to those of males (Fraser 1936).

Orthetrum sabina has a vast range, being distributed in southern and eastern Asia, Australia, and Micronesia to northern Africa (Mitra 2020). It is widespread within its range and is categorized as 'Least Concern' on the IUCN Red List (Mitra 2020). The species can be seen from an elevation of 0–2,300 m, around various water bodies such as slow-flowing and still water, including ponds, lakes, paddy fields, marshes, and irrigation ditches (Mitra 2020). It can also be seen perching away from waterbodies such as in gardens, on branches, twigs, rocks, and on the ground (Nair 2011). *O. sabina* shows noticeable adaptability to changes in climate and altitude (Fraser 1924). It tolerates high salt content and habitat disturbance or modification (Mitra 2020).

Orthetrum sabina is a voracious predator, feeding on a wide range of insects and even Odonata (including its own species) (Nair 2011). Recently, it was reported feeding on *Neurothemis tullia* in Sri Lanka (Gamage et al. 2023). Previously, Sharma & Oli (2020) mentioned that they encountered the species feeding on *N. tullia* in the Palpa District of Nepal but did not expand on this.

Editor: Albert G. Orr, Griffith University, Nathan, Australia. **Date of publication:** 26 September 2024 (online & print)

Citation: Miya, M.S. & A. Chhetri (2024). Additional documentation of the Slender Skimmer *Orthetrum sabina* (Drury, 1770) preying on the Pied Paddy Skimmer *Neurothemis tullia* (Drury, 1773) in Nepal. *Journal of Threatened Taxa* 16(9): 25935–25938. https://doi.org/10.11609/jott.9260.16.9.25935-25938

Funding: Environmental Education and Science (ENEDAS), Elsterstraße 33, 04109 Leipzig, Germany.

Competing interests: The authors declare no competing interests.

This paper presents *O. sabina* feeding on *N. tullia* Pied Paddy Skimmer, which elaborates on the evidence of the species' feeding behavior.

MATERIALS AND METHODS

The observation was made during the field survey of Odonata in Maidi Lake (one of the lakes in the lake clusters of Pokhara Valley and a Ramsar site) on 30 July 2022 (Image 1). The lake covers an area of 5 ha of water body and a watershed of 160.11 ha. Odonata data was collected by direct observation along transects (Ausden & Drake 2006). Three transects, 200 m each, were laid along the existing trails around the lake to collect data from the end of July to December 2022, once a month, totaling six replications (three other lakes were also surveyed during the project). Each transect was surveyed by walking fixed routes/transects; specimens were seen ahead and 5 m (2.5 m on either side of the transect) were noted (Ausden & Drake 2006; Miya et al. 2021). The study was conducted from 1000 h to 1500 h on sunny days (Pearce-Higgins & Chandler 2020; Batista et al. 2021). The individual feeding on *N. tullia* was photographed with a smartphone (Samsung Galaxy A10) and identified later with the help of field guides (Emiliyamma et al. 2005; Nair 2011). The site map was created using ArcMap 10.8.2, and Image 2 was created using CorelDRAW 9.

RESULTS AND DISCUSSION

This paper illustrates *O. sabina* feeding on *N. tullia* (Image 2). Both species belong to the family Libellulidae. The *O. sabina* started to chew the *N. tullia* from the head, and continued below the body parts while holding it with its forelegs and perching on a herbaceous plant. It didn't fly away even when we approached to take a photograph. Feeding lasted more than 15 mins and was observed about 3 m away from the water body (28.175°N & 84.083°E). *O. sabina* is known to be a predator that even feeds on its own species, and it is not uncommon for it to feed on other species. This particular observation adds to the numerous photographic records of the species preying on other libellulids on the internet. There are photographs in the iNaturalist of *O. sabina* feeding on its own species,

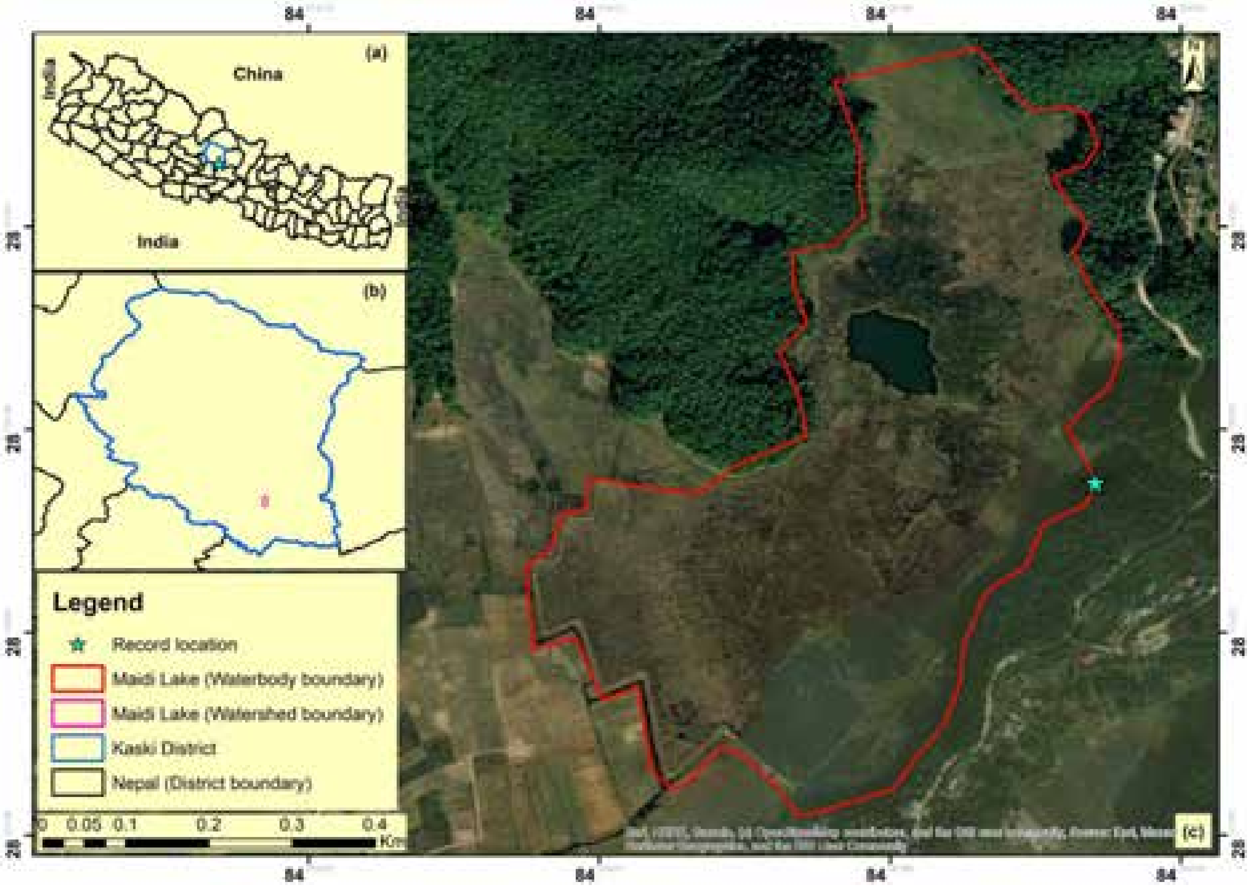

Image 1. The study area map: a—Map of Nepal showing district boundary | b—Map of Kaski District showing watershed boundary of Maidi Lake | c—Record location within the boundary of Maidi Lake.

Image 2. a & b—*Orthetrum sabina* feeding on *Neurothemis tullia* | c—*N. tulia* female | d—Maidi lake.

recorded in Bharatpur, Nepal (Hazenberg 2018) and Indonesia (Jones 2017).

Previous studies have reported *O. sabina* also feeding on smaller Zygoptera (damselflies). This seems less common, presumably because they do not provide sufficient food for the effort. It was reported to feed on *Ischnura senegalensis* in western India (Fraser 1924) and *Asiagrion hisopa* in the Nilgiris, India (Fraser 1936). Similar behavior of preying on other Odonata has been reported in different locations in India, Sri Lanka, Singapore, and Nepal. In their study, Gamage et al. (2023) noted that the species feeding on *N. tullia* in Sri Lanka was similar to our finding. Additionally, the Bird Ecology Study Group (2024) reported *O. sabina* feeding on *Rhyothemis triangularis, Neurothemis fluctuans, and Acisoma panorpoides* in Singapore, and on *Neurothemis fulvia* in India (Jose 2011). Another study by Larsen (1990) documented the species feeding on the *Caprona ransonnettii potiphera* butterfly in India. Similarly, a video on YouTube shows the species feeding on *Rhyothemis variegata* (Karle 2020). Prasad & Biswas (1980) and Thumboor (2017) found the species feeding on *Acisoma panorpoides* in West Bengal and Thrissur, India. Furthermore, Mitra (1999) observed the species feeding on *Agriocnemis pygmaea* and *Ceriagrion coromandelianum* in India. A study in Nepal reported *Neurothemis tullia* feeding on *Ischnura rubilio*, *Brachythemis contaminata* feeding on *Ceriagrion coromandellianum*, and *Orthetrum pruinosum* feeding on *N. tullia* (Sharma & Oli 2022). The observation of *O. sabina* praying on *N. tullia* was encountered during the ectoparasites study of dragonflies and damselflies from Palpa district, Nepal (Sharma & Oli 2020); however, the feeding activity is not highlighted or expanded. Previous literature and the current observation confirm the species' diverse range of larger prey species, providing valuable information for further assessment of the species.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25939–25941
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.9130.16.9.25939-25941
#9130 | Received 08 May 2024 | Final received 17 July 2024 | Finally accepted 17 September 2024

NOTE

First photographic record of the Red Giant Gliding Squirrel *Petaurista petaurista* Pallas, 1766 (Mammalia: Rodentia: Sciuridae) from Sattal, Uttarakhand, India

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Globally, there are 45 recognised species of gliding squirrels classified within 15 genera. The majority (14 genera and 42 species) are found in Eurasia, with a particular concentration in southeastern Asia (Thorington & Hoffmann 2005). In India, 17 species of gliding squirrels have been documented to date (Koli et al. 2013; Sharma & Sharma 2013; Koli 2015; Datta & Nandini 2015; Krishna et al. 2016; Pal et al. 2019). These are primarily found in the Himalayan and northeastern regions, with only two species, the Indian Giant Gliding Squirrel *Petaurista philippensis* and the Travancore Gliding Squirrel *Petinomys fuscocapillus*, inhabiting the Western Ghats (Datta & Nandini 2015). Red Giant Gliding Squirrel *Petaurista petaurista* (RGGS in the later section) is a large, nocturnal folivore, classified as 'Least Concern' by the IUCN Red List (Duckworth 2016). These arboreal squirrels occupy a wide variety of forest habitats across northern South Asia, southern China, and southeastern Asia. Records of their presence in India span Arunachal Pradesh, Assam, Nagaland, Meghalaya, Sikkim, Manipur, Jammu & Kashmir, and Uttarakhand (Choudhury 2013; Duckworth 2016). Their altitudinal range typically falls between 30 and 3,100 m (Molur et al. 2005; Choudhury 2013). Primarily folivorous, RGGS exhibits a diverse diet that includes seeds, fruits, flowers, buds, bark, and lichen (Krishna 2016). They are known to occasionally construct leaf nests and utilise tree cavities and caves for nesting (Krishna et al. 2019). Although this species was reported earlier from other parts of Uttarakhand (Pal et al. 2021), the present communication is the first reporting of RGGS from Sattal with photographic evidence, which is under Bhowali Forest Region of Nainital District, Uttarakhand.

Sattal is a place near the city of Bhimtal in the Nainital district (29.3375^{0}N, 79.5333^{0}E) of the Kumaon region in Uttarakhand state situated at an altitude of 1,370 m (Image 1). The area has an interconnected group of seven lakes, viz.: Garud Tal, Naldamyanti Tal, Hanuman Tal, Sita Tal, Ram Tal, Laxman Tal, and Sukha Tal (Choudhary et al. 2009). The area is covered with dense coniferous trees like oak and pine.

We spotted three RGGS on two oak trees at two different locations (*Quercus* sp.) (Image 2a,b) while travelling along a trail in the forest near Garud Kund, ~1.5 km from the Sattal Lake using Energizer Pro 260 headlamps, Fenix C7 flashlight and binoculars (Model:

Editor: Honnavalli N. Kumara, Salim Ali Centre for Ornithology and Natural History, Coimbatore, India. **Date of publication:** 26 September 2024 (online & print)

Citation: Chetia, H., J. Gupta & M.K. Chatakonda (2024). First photographic record of the Red Giant Gliding Squirrel *Petaurista petaurista Pallas*, 1766 (Mammalia: Rodentia: Sciuridae) from Sattal, Uttarakhand, India. *Journal of Threatened Taxa* 16(9): 25939–25941. https://doi.org/10.11609/jott.9130.16.9.25939-25941

Funding: The study was supported by The Mohamed bin Zayed Species Conservation Fund (Grant Number: 222529776).

Competing interests: The authors declare no competing interests.

Acknowledgements: We would like to express our sincere gratitude to The Mohamed bin Zayed Species Conservation Fund for their generous financial support.

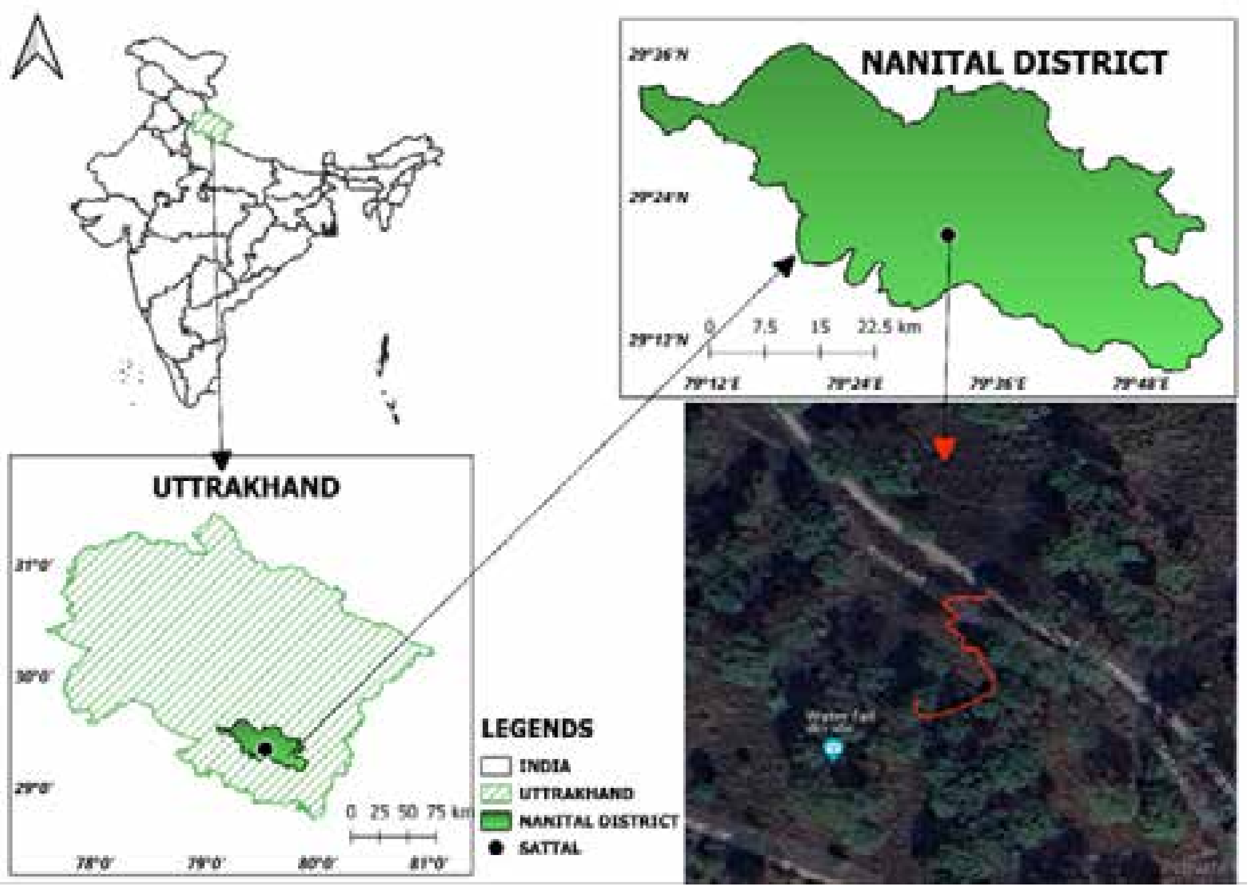

Image 1. Location of Sattal, Nainital (Uttarakhand) along with survey trail.

Solognac Wildlife Binoculars 100, 10 x 42) on 28 March 2024, between 1900–2200 h. We photographed them using a Nikon D500 camera. The first two individuals were recorded at around 1957 h and the other one was recorded at 2100 h. The distance between the two locations was ~700 m. The dorsal colour of the squirrel was reddish-brown with light orangish hair at the base of the patagium. The ventral surface was greyish-white. From the body colouration, it was identified as *Petaurista petaurista albiventer* with the help of standard literature (Thorington et al. 2012). At the time of sighting, the squirrels were actively feeding on tree leaves.

In addition to RGGS, we also sighted Northern Red Muntjak *Muntiacus vaginalis*, Sambar Deer *Rusa unicolor*, Himalayan Goral *Naemorhedus goral*, Yellow-throated Marten *Martes flavigula*, Himalayan Langur *Semnopithecus schistaceus*, and Rhesus Macaque *Macaca mulatta*. We observed forest fires at multiple sites.

Though the observed site falls near the known distribution of RGGS as per the IUCN Red List, the species was not recorded earlier from the present study site. In the Nainital District, the closest location to our current study site, where the species was previously recorded, is about 40 km away. This observation provides valuable insight into the distribution pattern of the species within Uttarakhand. This is crucial for developing effective conservation strategies, as it allows us to identify key habitats and areas that require protection. Consequently, this information will significantly contribute to the species' long-term protection and management efforts.

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Image 2. Red Giant Gliding Squirrel *Petaurista petaurista albiventer* photographed at Sattal, Nainital Uttarakhand.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25942–25944

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8679.16.9.25942-25944

#8679 | Received 09 August 2023 | Final received 03 August 2024 | Finally accepted 31 August 2024

NOTE

Red Pierrot *Talicada nyseus nyseus* (Guérin-Meneville, 1843): an addition to the butterfly fauna of Arunachal Pradesh, India

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The Red Pierrot *Talicada nyseus nyseus* (Guérin-Meneville, 1843) is a butterfly belonging to the blue family Lycaenidae found in the Indian subcontinent. This butterfly is usually noticeable due to their striking patterns and colours. Both the wings are white, with black dots, and a huge section of the hindwings lower edge, which is orange (Bingham 1907). The genus *Talicada* is a monotypic Oriental genus, and the genus is represented by *T. nyseus* (Guérin-Meneville, 1843) which comprised of nine recognized subspecies, including *T. n. nyseus* in southern India (Kunte 2000), Sri Lanka (Seitz 1924), *T. n. khasiana* in Khasia Hills (Evans 1925), *T. n. assamica* in Assam (Larsen 1987), *T. n. metana* in northern Thailand (Pinratana 1981), *T. n. annamitica* in Indo-China (D'Abrera 1986), *T. n burmana* from Shan State of Myanmar to western Thailand (Evans 1925), *T. n. macbethi* in eastern Thailand (Riley 1932), *T. n. delhiensis* in northern India (Kumar et al. 2009), and *T. n. lami* from Hainan Island, China (Philip & Ding 2017). Singh (2005) indicated that due to climate change, the Red Pierrot butterfly has been expanding into the foothills of the Himalaya. As a result, it can now be found from southern India (Kunte 2000) and Kerala (Skaria et al. 1997) to Dehradun (Singh 2005), Delhi (Smetacek 2009), Kumaon Himalaya (Smetacek 2011), Himachal Pradesh (Mahendroo & Smetacek 2011), Chhattisgarh (Singh et al. 2023), and Sikkim (Sharma et al. 2023).

The species is documented to utilize *Kalanchoe blossfeldiana* (Balakrishnan pers. obs. 2017), *K. calycinum* (Davidson et al. 1896; Bell 1918; Robinson et al. 2010), *K. laciniata* (Wynter-Blyth 1957; Kunte 2000), *Bryophyllum delagoense* (Balakrishnan pers. obs. 2017), and *B. pinnatum* (Crassulaceae) (Wynter-Blyth 1957; Kunte 2000) as its common host plants. A thorough examination of the literature did not yield any records of this species in the state of Arunachal Pradesh. Nevertheless, our present survey results revealed the presence of this butterfly species in Arunachal Pradesh, India. A single individual of this species was observed on 12 February 2023, near the Himalayan University, Itanagar (27.04314N, 93.39154E), at an elevation of 201 m, and an additional individual was sighted during the monsoon season on 28 July 2023 in Basar, Leparada District (27.98352N, 94.68769E), at an elevation of 603

Editor: Jatishwor Singh Irungbam, Centrum ALGATECH, Třeboň, Česká Republika.

Date of publication: 26 September 2024 (online & print)

Citation: Upadhaya, R., R. Gogoi, R. Limbu, M.J. Kalita & R. Ahmed (2024). Red Pierrot *Talicada nyseus nyseus* (Guérin-Meneville, 1843): an addition to the butterfly fauna of Arunachal Pradesh, India. *Journal of Threatened Taxa* 16(9): 25942–25944. https://doi.org/10.11609/jott.8679.16.9.25942-25944

Funding: None.

Competing interests: The authors declare no competing interests.

Acknowledgements: The help and support revieved from local people during the study is acknowledged.

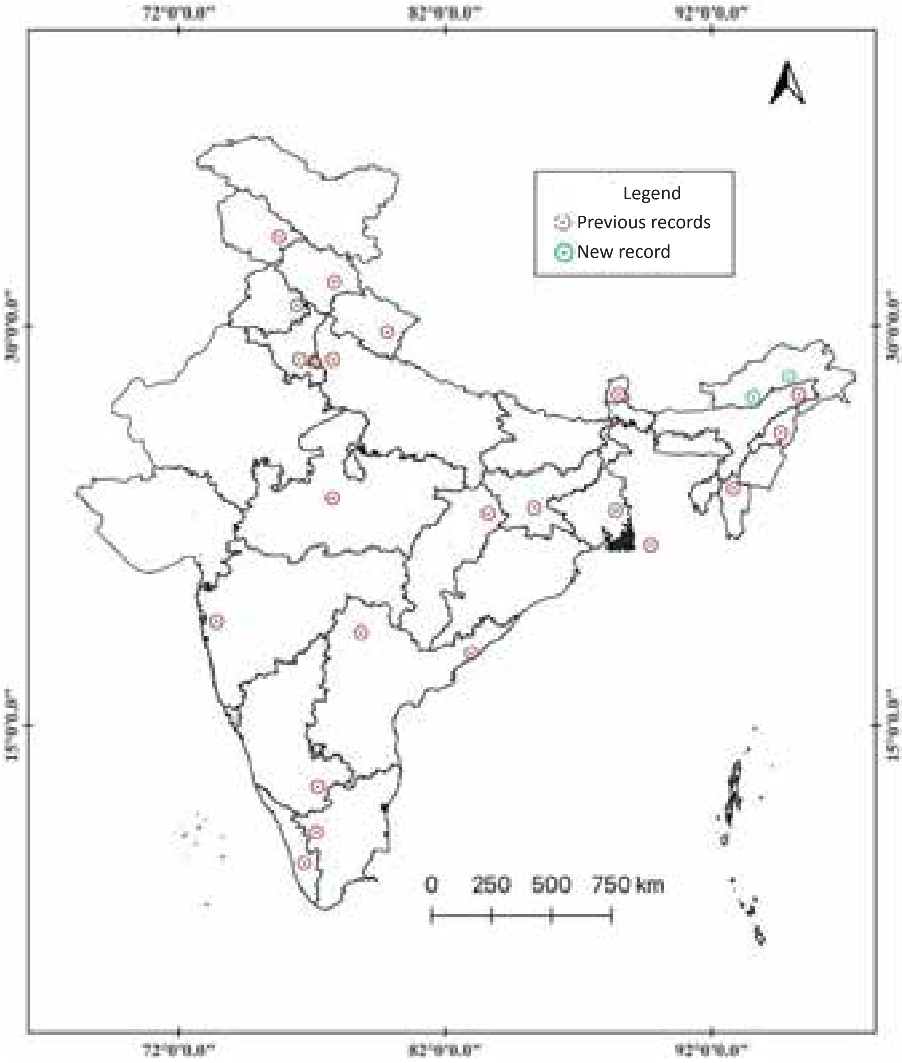

Figure 1. Record of *Talicada nyseus nyseus* (Guérin-Meneville, 1843) from India.

m (Figure 1). However, the observations of both species took place in distinct habitats: one near Himalayan University, characterized by an abundance of herbaceous flora, observed nectaring on *Oxalis corniculata* flowers (Image 1), while the other encountered nectaring on *Mentha* sp. within a kitchen garden in Basar, Leparada (Image 2). Both species were photographed using a Nikon D5600 equipped with a 40 mm kit lens. Identification of the species was confirmed with the help of literature provided by Evans (1925), Wynter-Blyth (1957), and Kehimkar (2016).

Based on earlier observation, this species is observed at elevations up to 2,000 m on the outskirts of woodlands, showing a preference for semi-arid plains, evergreen, & semi evergreen forests, hill stations, and domestic garden (Kunte 2000; Smetacek 2011). Consequently, its presence in Arunachal Pradesh aligns with these habitat preferences. Additionally, the presence of host plants *Kalanchoe* and *Bryophyllum* contributes to the species habitat suitability within the surrounding environment.

The current documentation showcases the first photographic evidence of *T. nyseus nyseus* from Arunachal Pradesh, presenting a new addition to the state butterfly fauna. It is crucial to conduct thorough scientific investigations to obtain further insights into this species, including its distinct host plant preferences, life cycle patterns throughout all seasons and its correlation with floral composition within its habitat, particularly during nectaring activities. As a result, such a report will help to update the distribution of the species in the state.

Image 1 & 2. 1—An adult *Talicada nyseus nyseus*, observed nectaring on *Oxalis corniculata* flowers near Himalayan University, Itanagar, Arunachal Pradesh on 12 February 2023 | 2—An adult *T. n. nyseus*, observed nectaring on *Mentha* sp. within a kitchen garden in Basar, Leparada, Arunachal Pradesh on 28 July 2023.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25945–25948

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9342.16.9.25945-25948

#9342 | Received 31 July 2024 | Final received 16 September 2024 | Finally accepted 21 September 2024

OPEN ACCESS

NOTE

Ranunculus cantoniensis DC. (Ranunculaceae): an addition to the flora of West Bengal, India

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Ranunculus L. is the largest genus of the family Ranunculaceae, comprised of more than 1,700 species (POWO 2024). It is cosmopolitan in distribution, generally occurring in temperate to tropical regions, as well as in high mountain regions of the world (Tamura 1995; Mabberley 2008). They occur in a variety of habitats including dry & damp meadows, forests, shallow & marshy banks of water bodies, and alpine grasslands. In India, Rau (1993) recorded 33 species with one variety, whereas Srivastava (2010) reported 41 species with four varieties of the genus *Ranunculus*. Eight species were reported from West Bengal (Uniyal & Thothathri 1999).

During botanical excursions in 2023 and 2024 in northern part of West Bengal, India, one interesting species of *Ranunculus* L. was collected from the district of Coochbehar. The specimen after critical analysis and perusal of relevant literature (Srivastava 2010; BSI 2024) was identified as *Ranunculus cantoniensis* DC. Authenticated herbarium specimens from CAL, BM, G, GH, P (Thiers 2024) were matched for confirmation of the identity of the species. The specimens were submitted to Ramakrishna Mission Vivekananda Centenary College Herbarium (RKMVCCH). Detailed descriptions along with photographs, habitat details, phenology, and distribution of this species are provided for proper identification.

Earlier literature did not record the distribution of this species from West Bengal in their treatment of Ranunculaceae in India, hence, the species was hitherto unknown from the state (Rau 1993; Uniyal & Thothathri 1999; Srivastava 2010). Therefore, this report is the new distributional record of this herbaceous species from West Bengal.

Taxonomic treatment

***Ranunculus cantoniensis* DC.**, Prodr. 1: 43.1824; M.A. Rau in B.D. Sharma *et al.*, Fl. India 1: 117. 1993; *R. napaulensis* DC. in Prodr. 1: 39. 1824; *R. chinensis* Bunge in Enum. Pl. Chin. Bor.3. 1833; *R. fibrosus* Wall. ex Hook.f. &Thomson, Fl. Ind. 1: 37. 1855; *R. pensylvanicus* auct. non L.f.; Hook.f., Fl. Brit. India 1:19.1872, p.p. (Figure 1; Image 1).

Herbaceous, erect, 13–25 cm tall, branched, hirsute. Leaves trifoliate or trifoliolate, ternatisect, alternate, pubescent, palmately veined; leaflets lobed to partite, rhombic or obliquely trullate; apex acute; base cuneate-attenuate; margin irregularly serrated; 4–8 x 5–7 cm;

Editor: A.J. Solomon Raju, Andhra University, Visakhapatnam India. **Date of publication:** 26 September 2024 (online & print)

Citation: Sarkar, J., S. Mukhopadhyay & B. Roy (2024). *Ranunculus cantoniensis* DC. (Ranunculaceae): an addition to the flora of West Bengal, India. *Journal of Threatened Taxa* 16(9): 25945–25948. https://doi.org/10.11609/jott.9342.16.9.25945-25948

Funding: Ramakrishna Mission Vivekananda Centenary College, Rahara, Kolkata.

Competing interests: The authors declare no competing interests.

Acknowledgements: The authors are grateful to the principal, R.K.M.V.C. College for providing all the necessary facilities in this endeavor. We express our sincere gratitude to the head and the co-coordinator of PG Department of Botany, R.K.M.V.C. College for their support and encouragement. We are also thankful to the anonymous reviewers for improving the manuscript.

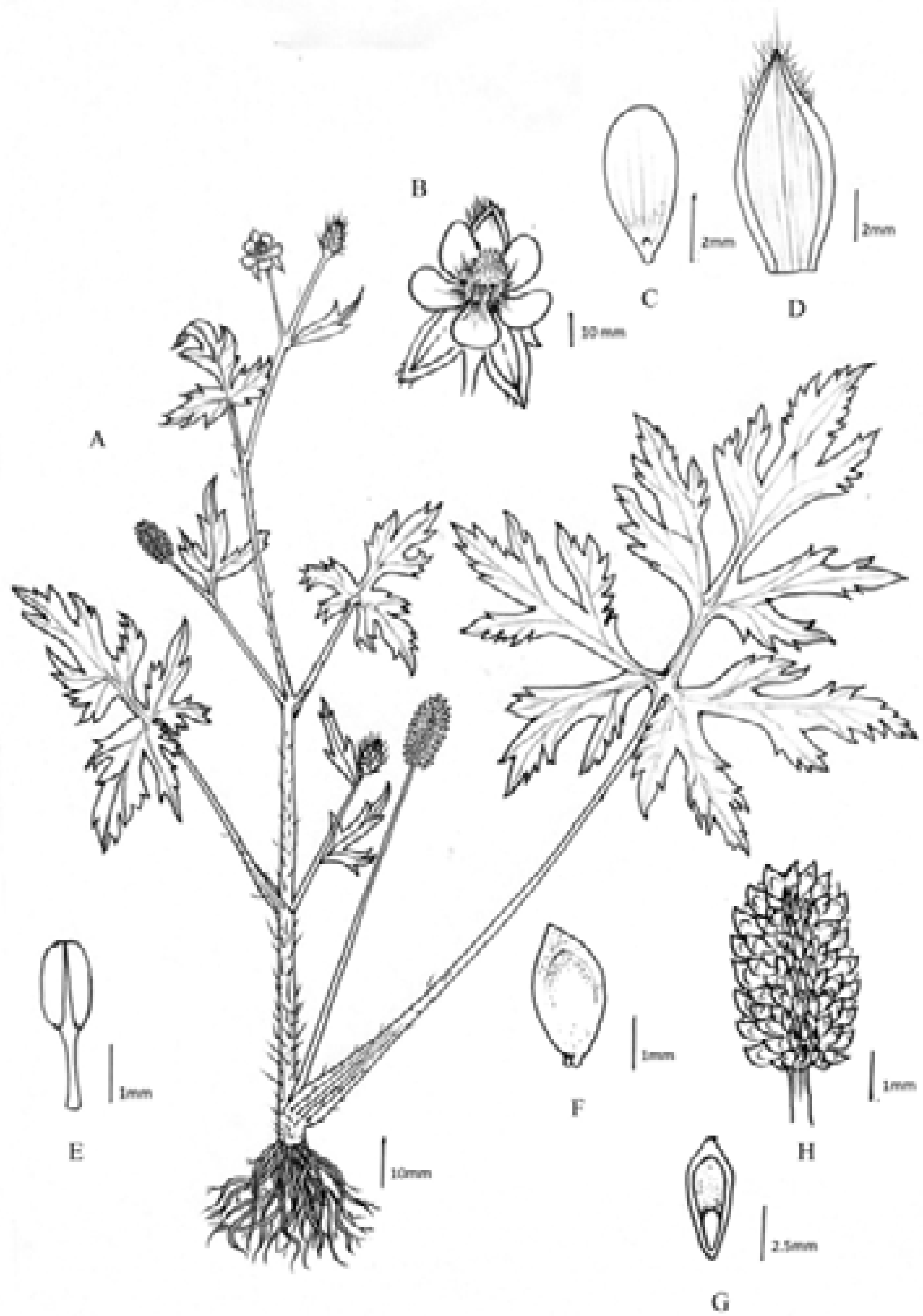

Figure 1. Line drawing of *Ranunculus cantoniensis* DC.: A—Habit | B—Flower | C—Petal | D—Sepal | E—Stamen | F—A single achene | G—T.S. of fruit | H—Etaerio of achenes. © Srijan Mukhopadhyay.

petioles of radical leaves sheathing at base, 3–12 cm long or absent ; petiolules 1–2 cm long. Flowers solitary, terminal, leaf opposed; pedicels 2–5 cm long. *Sepals* 5, ovate or elliptic-oblong, apex obtuse, imbricate, mostly reflexed, adaxially glabrous, abaxially hirsute, green with purple tips, margins translucent, and membranous, c.a. 6–8 x 3 mm. Petals 5, obovate, apex rounded-obtuse, glabrous, yellow, greenish towards the base, 5–7 x 3 mm. Stamens numerous, 3–3.5 mm long; filaments linear, green, ca. 2 mm long; anthers yellow, basifixed, ca. 1.5 mm long. Carpels numerous, green, laterally compressed, obliquely obovate, 3.5 x 2 mm. Stigma white, ca. 0.5 mm shortly beaked. Receptacle sub-globose, narrow, ca 5 x 3 mm, hairy. Achenes numerous, obliquely obovate, compressed, spirally arranged in globose to oblong etaerios, shortly beaked, glabrous

Image 1. *Ranunculus cantoniensis* DC.: A–B—Habit and habitat | C—Branch with flower and maturing fruit | D—Flower | E—Portion of leaf | F—Sepal | G—Petal | H—Stamen | I—Gynoecium | J—Etaerio of achenes | K—A single achene. © Biswajit Roy.

or minutely granular, 3.5–4 x 2–3 mm. Seeds ovoid, flattened, light brown, 2 x 1 mm; apex rounded; base acute; hilum lateral, black.

Flowering and Fruiting: March–December

Distribution: Global*:* Bhutan, China, Japan, Kazakhstan, Kirgizstan, Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Taiwan, Thailand, Uzbekistan and Vietnam,

India*:* Northwestern Himalaya to northeastern India, subtropical to temperate regions. Jammu, Uttar Pradesh, Bihar, Odisha, Sikkim, Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, and West

Bengal (present study).

Specimens examined: West Bengal, Coochbehar, Jhinaidanga, Khalsi (23.309˚N, 88.485˚E; 32.42 m): 23.iii.2024, Roy, Sarkar, & Mukhopadhyay 7395 (RKMVCCH 000631); West Bengal, Coochbehar, Jhinaidanga, Khalsi (23.309˚N, 88.485˚E; 32.42 m): 23.iii.2024, Roy & Karak 7396 (RKMVCCH 000632);

Notes: The investigated taxon was found to be growing under diffused sunlight, in low lying, very moist areas adjacent to cultivated land, and bamboo thickets in association with *Mikania micrantha* Kunth, *Hydrocotyle sibthorpioides* Lam., *Stellaria media* L., *Grangea maderaspatana* (L.) Poir., *Persicaria orientalis* (L.) Spach. Rau (1993), Wang & Gilbert (2001), and Kuo et al. (2005) and Yang & Huang (2008) treated *R. chinensis* Bunge and *R. cantoniensis* DC. as two distinct species. *R. chinensis* Bunge is distinguished from *R. cantoniensis* DC. in having narrower & deep-incised leaflets; the central leaflet being rhombic and ovoid-cylindric or ovoid-aggregrate fruits, whereas ovate leaflets and sub-globose aggregate fruit in the latter. Upon scrutiny of herbarium specimens and literature, Srivastava (2010) revealed this appearance to be continuous gradations in morphology of the leaf, and the etaerios within the broad range of geographic regions of tropical & subtropical Asia, and treated *R. chinensis* Bunge as a synonym for *R. cantoniensis* DC. Among the eight species of *Ranunculus* (Unial & Thothathri 1997), the investigated taxon along with three species of *Ranunculus*, viz. *R. sceleratus* L., *R. muricatus* L., and *R. sardous* Crantz. are known to be distributed outside of Darjeeling District. *Ranunculus muricatus* and *R. sardous* have muricate achenes but the spines are restricted to the margins in *R. sardous.* Moreover, *R. sceleratus* has smooth achenes like in *R. cantoniensis* but the plant is glabrous unlike the latter.

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2024 | 16(9): 25949–25950
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.9419.16.9.25949-25950
#9419 | Received 06 September 2024
OPEN ACCESS
BOOK REVIEW

Flowers of labour – Commelinaceae of India: Book review

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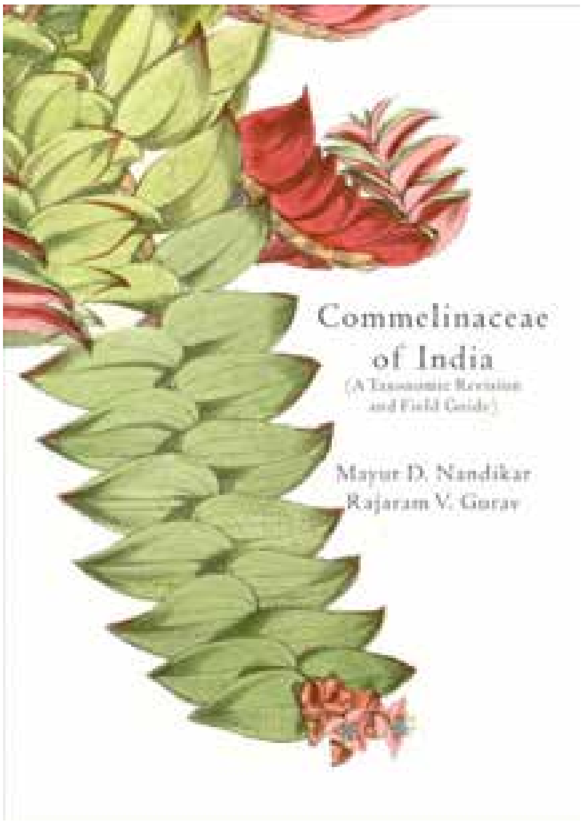
Edition 2024 (2 April 2024), 219 pages + 14 photo-plates
ISBN-13: 978-9334053968
Published by Parambi Plant Research and Education
Foundation, Pune, Maharashtra 411041, India



Commelinaceae
of India
(A Taxonomic Revision
and Field Guide)

Mayur D. Nandikar
Rajaram V. Gurav

The family Commelinaceae Mirb. comprises of 41 genera and 731 species (Faden 2012; Christenhusz & Byng 2016), distributed mainly in the tropics and subtropics, whereas POWO (2024) accepts 36 genera and 774 species. The members of this family are commonly known as "Dayflower". Karthikeyan et al. (1989) recorded 14 genera and 85 taxa from India. Later, Nandikar & Gurav (2020) listed 14 genera and 96 taxa from India, while these authors in the book 'Commelinaceae of India (A Taxonomic Revision & Field Guide)' have reported 15 genera and 130 taxa, of which 30 taxa are endemic. The aim of the book is to provide revision of the Indian Commelinaceae, in a comprehensive way in a single book which was not attempted earlier. This book is the outcome of the hard work, careful observations, and untiring efforts of the first author, which lasted about 14 years (2010–2023). He was awarded Ph.D. in the year 2013 on Indian Commelinaceae. It is a well written, nicely illustrated, well organized, and produced book.

The book contains nine chapters or sections, viz., historical outline of Commelinaceae, methodology, novelties, common & local names, systematic treatment, cultivated & ornamental species, references, index of plant names, and photographs. The section on systematic treatment occupies a major portion of the book. This part begins with morphological descriptions of Commelinaceae members' habit, stem, leaf, inflorescence, stamens, pollen grains, style, capsule, and seed, followed by dichotomous key to the tribes & genera, and genera-wise detailed taxonomic description of all taxa. Every genus provides the number of taxa in the world & in India, complete taxonomic citation with synonyms, type species, etymology, distribution & habitat, and dichotomous key to species & intraspecific taxa. Each species and intraspecific taxa is given a current accepted name with relevant taxonomic references, type details, synonym/s with type details, etymology, detailed morphological descriptions, distribution &

Date of publication: 26 September 2024 (online & print)

Citation: Singh, R.K. (2024). Flowers of labour – Commelinaceae of India: Book review. *Journal of Threatened Taxa* 16(9): 25949–25950. https://doi.org/10.11609/jott.9419.16.9.25949-25950

habitat, chromosome count, IUCN threat assessment, notes, and specimens examined. Coloured photos and line drawing illustrations with scales are provided for many taxa.

Nonetheless, in such a big work, a few discrepancies that went unnoticed by authors are mentioned here. The number of accepted genera, on the page with heading 'About the book' and on page 3 is 15, but in dichotomous key to genera and in systematic treatment the number is only 12 . Similarly, on page 3 the total number of accepted taxa given is 131, but in systematic treatment the number is 126. Authors mention the lectotype for the name *Cyanotis fasciculata* (B.Heyne ex Roth) Schult. & Schult.f. as designated by Arigela et al. (2023), but it was designated by Singh (2022). Similarly, authors have incorrectly mentioned the lectotype designation for the names *Cyanotis decumbens* Wight, *C. dichrotricha* Stocks ex Wight, and *C. thwaitesii* Hassk. Many citations mentioned in the systematic treatment are not included in the references section, like Arigela et al. (2023), Faden (1980), Jameera et al. (2016), Merrill & Dandy (1937), Singh (2022), and Singh & Muguran (2019).

Overall, the book is a praiseworthy, long-awaited contribution to the knowledge of the Indian Commelinaceae and is a must for all botanical institutions, colleges, universities, and for those interested in Dayflowers. The book should also be very useful to foreign countries, especially neighbouring countries and other Asian countries. I congratulate the authors for the great work they have accomplished and succeeded, and they splendidly deserve substantial compliments by the entire botanical fraternity of the country.

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ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

September 2024 | Vol. 16 | No. 9 | Pages: 25791–25950
Date of Publication: 26 September 2024 (Online & Print)
DOI: 10.11609/jott.2024.16.9.25791-25950

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