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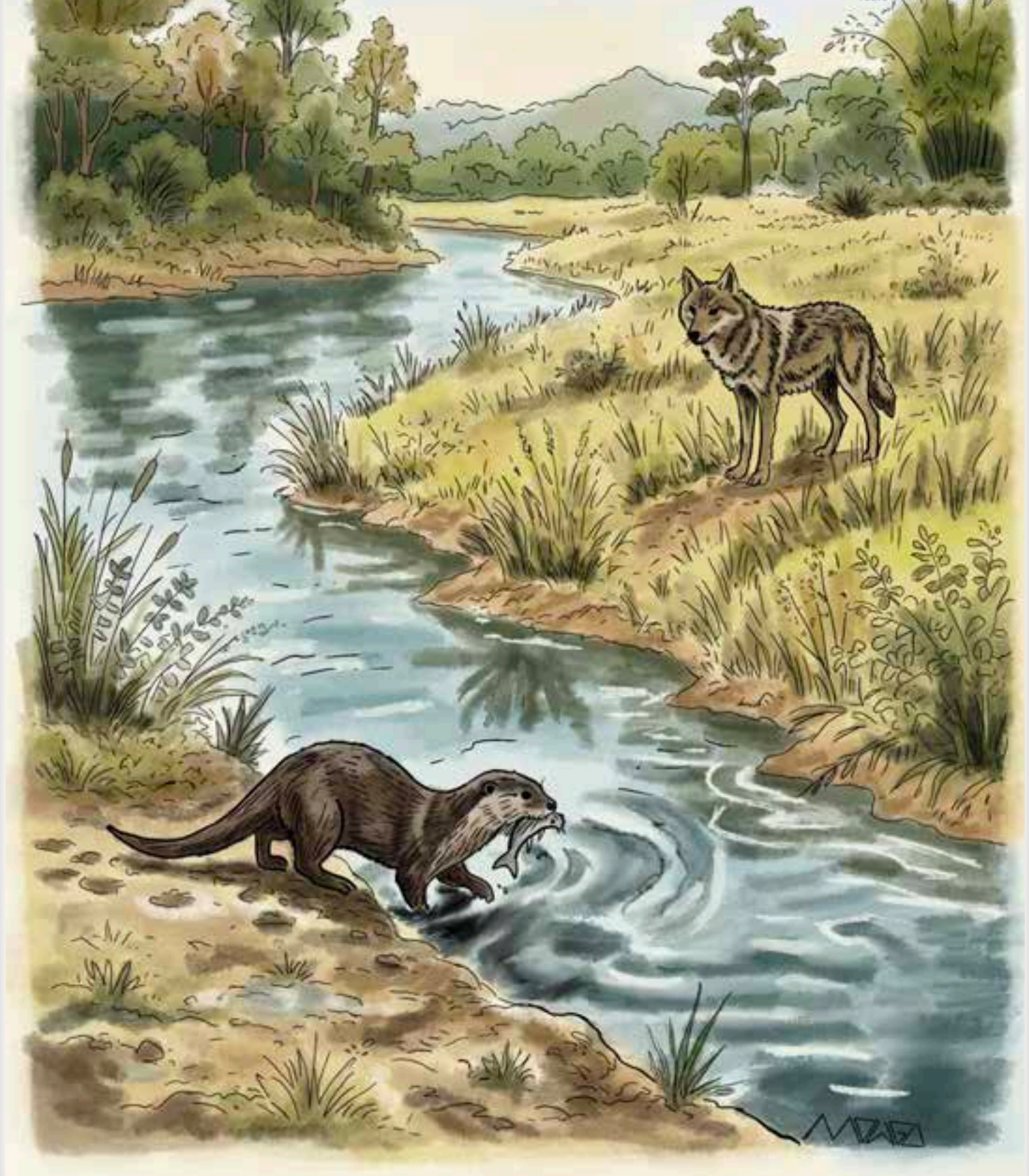

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continued on the back inside cover

Cover: Indian Grey Wolf *Canis lupus pallipes* and Smooth-coated Otter *Lutrogale perspicillata* sharing the territory in Chambal basin. Digital art on Procreate by Aakanksha Komanduri.

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ARTICLE

Knowledge and attitude towards wild carnivores among university students: a study from Kargil Trans-Himalaya, India

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Abstract: Several studies have reflected that the success of wildlife conservation approaches and efforts are determined by local people's knowledge and attitude toward the target wildlife species. It is critical to have a favourable attitude of the local communities towards wildlife for implementing successful conservation efforts that involve public participation. We conducted this study in Kargil Trans-Himalaya, India to understand the knowledge and attitude of local undergraduate and postgraduate students towards wildlife in general, and wild carnivores in particular. To achieve the objectives of this study, an online semi-structured questionnaire was drafted and distributed among student residents of Kargil pursuing their higher education degrees from Kargil and other parts of India. We received a total of 385 responses, and 362 were considered fit for the study. The total knowledge score for the respondents ranged from 3–12 out of 12, with a mean score of 9.68 ± 1.565. With the overall attitude score ranging from 4–12 out of 12, and a mean score of 10.19 ± 1.417, students in higher education from Kargil possess a favourable attitude towards the wildlife of the region. The Spearman's correlation between knowledge and attitude score was weak, $r_s = 0.255$, $p < .001$, $N = 362$. The knowledge and attitudes of local students towards wild carnivore species should be considered for effective long-term conservation efforts. This could be accomplished by timely sustainable conservation education and awareness initiatives. Although this study tries to explore an important factor to be considered in wildlife conservation efforts from a less explored region in the trans-Himalaya, future studies can intensively look into the factors that influence the formation of social attitudes toward wildlife.

Keywords: Biodiversity, cold desert, conservation, environmental awareness, Himalayan Brown Bear, Ladakh, perception, Snow Leopard, social attitudes, wildlife.

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Author details: Iftikar Ali is an environmental scientist and researcher based in Ladakh, India. His research interests include human–wildlife interactions, wildlife conservation, biodiversity, and environmental education. His work primarily focuses on wildlife conservation and human dimensions of biodiversity in the Trans-Himalayan region. Robert John Young is professor of Animal Behaviour and Wildlife Conservation at the University of Salford, UK. His research integrates animal welfare science with in-situ and ex-situ wildlife conservation. His work focuses on animal behaviour, wildlife conservation, bioacoustics, biotelemetry, and the effects of noise on wildlife. His research spans field conservation in Brazil and zoo-based animal welfare across diverse animal species.

Author contributions: IA—conceptualization, methodology, field investigation, data collection, data analysis, project coordination, writing - original, and preparation of manuscript. RJY—supervision, conceptual guidance, methodology review, interpretation of results, critical review and editing of the manuscript.

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INTRODUCTION

Humans have been sharing space with wildlife and competing with them for natural resources throughout history. As the human population is expanding at a rapid pace, demand for natural resources is also increasing, which has resulted in inflated competition for resources and intensified pressure on wildlife (Woodroffe 2000; Conover 2002). As anthropogenic activities expanding across the world, biodiversity suffers a direct loss, and there is a decline in human well-being (Dickman & Hazzah 2016). The exponential increase in the human population has led to an increase in human-wildlife conflicts throughout the world (Woodroffe 2000; Conover 2002). The degradation and fragmentation of wildlife habitats through intensive human use have brought wildlife and humans closer than ever before. Attacks by large predators on humans and their livestock, as well as agricultural damage by large herbivores, have always occurred, but have gained increased attention in recent decades (Inskip & Zimmermann 2009). These occurrences have led to misconceptions and unfavourable notions/emotions about the behaviour of non-charismatic carnivores and large herbivore species in rural areas where people share land and resources with such species (Marchini & Macdonald 2012; Dickman et al. 2014; Castillo-Huitrón et al. 2020).

In the case of emotions and attitudes towards a wild carnivore, physical traits of animal species, as well as human-created "personalities", have elicited a wide range of emotions (Kellert et al. 1996; Kruuk 2002; Prokop & Randler 2018; Castillo-Huitrón et al. 2020). Large charismatic creatures that have historically been viewed as dangerous, yet intelligent, elicit emotions that can lead to protective acts, as has been the case with Lions *Panthera leo*, Tigers *Panthera tigris*, Leopards *Panthera pardus*, Snow Leopards *Panthera uncia*, and different species of Bears *Ursus* spp. (Marchini & Macdonald 2012; Dickman et al. 2014). Knowledge of the behaviour of culturally significant species develops better in rural communities where people are in contact with wildlife regularly than in other locations (Castillo-Huitrón et al. 2020). This allows the anthropomorphising of particular animals, which enhances dread and rejection toward them by labelling them "shy", "noxious", and "monstrous" among other descriptors (Lescureux & Linnell 2010; Castillo-Huitrón et al. 2020). Furthermore, if the existence of an animal causes members of a community to suffer economic losses, their main perspective will be negative, resulting in resentment that may lead to fatal management (Naughton-Treves 1997).

The environmental ethics of the Abrahamic monotheistic faiths—Judaism, Christianity, and Islam, are all based on the concept of stewardship, which implies human responsibility for the preservation of nature (Bhagwat et al. 2011). Further, religions evolved in Asia (Buddhism, Jainism, Hinduism, Taoism, and Sikhism) place a high value on the holiness of nature and its animals, and principles that might elicit environmental awareness and action (Bhagwat et al. 2011). Moral ideals are both derived from and legitimized by religion/faith and they can play a significant role in addressing today's global environmental issues (Mcleod & Palmer 2015). Religion can assist in developing compassion towards an animal/creature, which is the primary ethics of all the faiths but sometimes not valued on an individual level (Mcleod & Palmer 2015).

Community knowledge, engagement, and the impact of conservation measures depend on public attitudes toward conservation. Assessing local people's perspectives can reveal how they will act, whether they will comply with wildlife protection rules, how they will respond to wildlife-related economic losses, and how eager they are to cohabit with wildlife (Megaze et al. 2017). Local community knowledge is regarded as an important component in the expression of feelings toward animals (Castillo-Huitrón et al. 2020). Moreover, local knowledge and emotional ties with animals can be an important factor in identifying strategies to promote environmental awareness (Bowen-Jones & Entwistle 2002).

Individuals' emotional responses to animals are influenced by a variety of factors, including their gender, age, cultural & natural settings, and perceived sensitivity to each species (Johansson et al. 2012). Significant disparities in fear of wildlife species have been discovered among persons with various levels of education; those with higher educational levels are frequently less fearful of wild animals than those with lower educational levels (Røskaft et al. 2003). Understanding the attitude and perception of local people towards wildlife and conservation approaches is necessary to improve favourable human-wildlife interactions (Shrestha & Alavalapati 2006; Vodouhê 2010; Mir et al. 2015; Ciocănea et al. 2016) and how the future of wildlife conservation is shaped (Adams & Hutton 2007; Røskaft et al. 2007; Barua et al. 2013; Lyamuya et al. 2014). In addition, local communities' views and attitudes toward wildlife are essential in resolving conflict problems, which put a negative toll on both the local communities living adjacent to wildlife habitat and on the wildlife species (Naughton-Treves &

Treves 2005). Further, individuals with higher education are likely to have more opportunities to learn about the environment and, in particular, wild animals, which may help individuals realize the ecological advantages given by noncharismatic species reducing their unfavourable preconceptions and beliefs about them (Castillo-Huitrón et al. 2020). Given that values evolve at a youth age (Schwartz 2006), understanding how the younger generation understands and perceives wildlife is critical. These values eventually impact attitude and behaviour related to wildlife and human-wildlife interactions. There is not a single study from Kargil District, India addressing the awareness of wildlife among university students and how they perceive wildlife species. Hence, this study was aimed to fill the gap and targeted respondents studying at the university level to explore and assess their knowledge and attitude towards wildlife of the region in general, and wild carnivores in particular. Although ecological research has expanded in Kargil in recent years, there remains a gap in understanding the social dimensions of wildlife conservation, particularly the attitudes and knowledge of local youth. To assist in implementing concrete, successful, and sustainable conservation efforts in the region, it was felt necessary to conduct this study with the specific objectives: (1) to understand the knowledge and attitude towards wildlife among students from Kargil; (2) to identify the factors and associations, if any, between various respondent categories and knowledge and attitude scores and variables within; and (3) to examine if there is any relationship between knowledge of students and their attitude towards wildlife. Based on the objectives, we hypothesized that: (1) higher knowledge scores are positively associated with more favourable attitude towards wildlife; (2) knowledge and attitude scores significantly vary by demographic variables such as education level, subject background, faith, and gender.

MATERIALS AND METHODS

Study area

Administratively, Kargil is divided into 15 community development (CD) blocks (District Statistics & Evaluation Officer Kargil 2020). But with demographic insights and data available according to the past demarcation of nine CD blocks of the district, we adapted and utilized the data according to the nine CD blocks of the study area (Census of India 2011; District Statistics & Evaluation Officer Kargil 2020) (Image 1).

Kargil is one of the two districts in the newly formed Union Territory of Ladakh, India. Before 2019, it was a district in the former state of Jammu & Kashmir. Often referred to as 'cold desert' in the scientific community, Kargil has a unique floral and faunal assemblage (Pfister 2004), with cold and temperate climatic characteristics. Kargil is home to some of the important and endangered wild carnivore and ungulate species such as Snow Leopard, Himalayan Brown Bear *Ursus arctos isabellinus*, Wolf *Canis lupus*, Fox *Vulpes vulpes*, Pallas's Cat *Otocolobus manul*, Asiatic Ibex *Capra ibex sibirica*, and Ladakh Urial *Ovis vignei* (Pfister 2004). Livestock rearing and sustenance agricultural practices are the main traditional livelihood practices in this region (Barthwal & Mathur 2012). Particularly, in Kargil and Zanskar region, livestock rearing is one of the most important sources of income for agro-pastoral communities (Maheshwari 2016; Maheshwari & Sathyakumar 2020). With a total human population of 140,802 (Census of India 2011) and a geographical area of 14,036 km^2, Kargil is one of the least densely populated districts in India. The human population is distributed along the glacial streams and the three main river valleys (Suru, Drass, and Wakha), which form important tributaries of the Indus river. The majority of the human population in Kargil belongs to the tribal community of the Purigpa and Balti people of Tibetan descent mixed with the Dard, Mon, and other Aryan people (Gellner 2013).

Education in Kargil has undergone a transition phase since the beginning of the 21st century. Until 1998, 95% of Ladakhi (Kargil and Leh district) students failed to complete their high school exams (10^{th} class, as per the education system of India) every year (SECMOL 2022). This reflects that modern education is very new to the region. However, some major steps have been taken by the then state of Jammu & Kashmir, and the government of India to boost the education quality in the region. To improve and provide accessible higher education to the people of the region, the former state of Jammu & Kashmir established the Degree College Kargil by Order No: 138-HE of 1995 dated 31 March 1995 (District Statistics & Evaluation Officer Kargil 2020). The College was founded on 29 June 1995, and the operation of this district's top seat of higher education learning marked the beginning of a new era in the educational development of Kargil's steep, under-developed, and sensitive border region (District Statistics & Evaluation Officer Kargil 2020). The University of Ladakh, established in 2019, is the sole Trans-Himalayan institute of higher learning and research in the Union Territory of Ladakh (University of Ladakh 2020). Both Leh and Kargil are home to the University's administrative offices. The university has

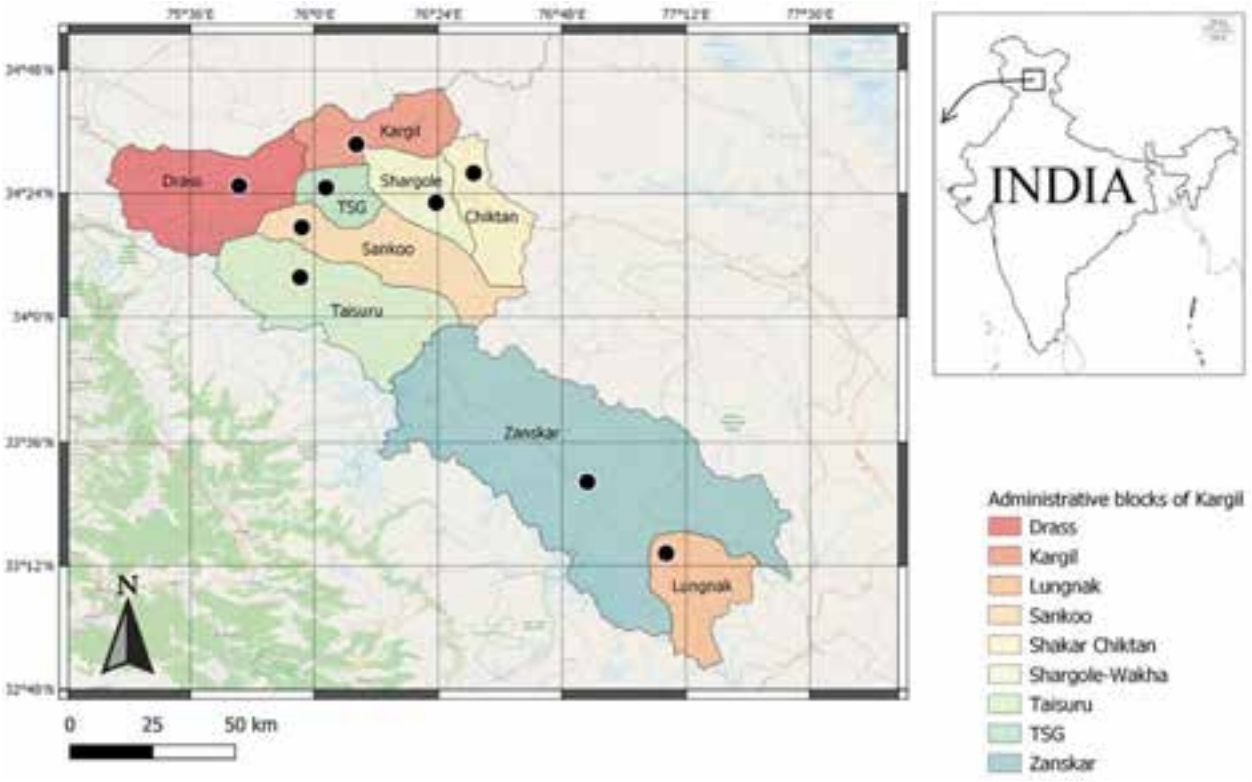

Image 1. Administrative boundary of Kargil District with the demarcation of nine CD blocks boundary and their headquarters.

campuses in both Leh and Kargil, as well as six constituent colleges. In August 2021, to ensure quality education and higher educational requirements for people residing in Ladakh, a bill was passed in the Indian parliament to establish a central university in the Union Territory of Ladakh (The Hindu 2021). Besides the efforts to improve the quality of education, from an early age, many pupils are admitted to renowned Indian colleges to prepare for and participate in competitive postsecondary education (Smith & Gergan 2015). Likewise in the case of Kargil, to pursue quality education students frequently travel to bigger cities like Jammu, Srinagar, Delhi, Chandigarh, and Mumbai.

Kargil has been disregarded in terms of intense wildlife studies and follow-up conservation efforts since it was an armed conflict zone in the late 1990s and early 2000s (Maheshwari 2016). Although human-wildlife interaction is not unique to Kargil, people in this region are particularly vulnerable owing to the high level of reliance on livestock, limited agriculture season, and pasture lands, which restricts conflict mitigation strategies. Understanding human-wildlife interactions require an understanding of how the local communities living adjacent to wild carnivore species' habitat perceive and respond toward the species (Woodroffe 2005).

Methods

Online survey

Nonprobability convenience sampling was adopted for the application of an online survey. The inclusion criteria were students resident of Kargil, aged 18 years or above, and pursuing graduation or higher degree education in Kargil and other parts of India. A preliminary version of the questionnaire was distributed among 40 respondents (mostly students in higher education) to adapt the questions and improve the clarity of the language. The final set of the questionnaire was distributed among the students through executive members of various student organizations in Kargil and other parts of India, emails (colleges and universities), media outlets, and virtual platforms (WhatsApp, Facebook, and Instagram) from 8 November 2021 to 8 December 2021. This is a random technique that ensures the representativeness and equity of the sample (Boso et al. 2021).

The first page detailed the information and purpose of the study. The name, e-mail address, and other contact information of the responsible researcher were available on this page if the respondents needed more information and clarity on the purpose of the study.

This section also highlighted the ethical measures in place to protect the participants' integrity, anonymity, and well-being. The page ended with the consent of the respondent to participate in the study with a 'Yes' or 'No' response. The participants were allowed to proceed further to the completion of the full survey only upon their consent to participate in the research.

Questionnaire design

An online questionnaire form was drafted using the Google Form survey sheet. The questionnaire was divided into three sections. Being one of the three official languages of Kargil (Kargil District - Wikipedia 2021), and a compulsory subject at primary, middle, high, and higher secondary school education levels across Kargil, English was adopted as the medium of language for the questionnaire. We decided to exclude the responses that stated English was not a subject at their higher secondary education level and also, where the respondents stated difficulty in understanding the questionnaire.

Section one of the questionnaire obtained the socio-demographic information (gender, faith, age, CD block of residence, level of education, current place of study, subjects at higher secondary level, environmental science in higher secondary) of the respondents. The section also explored whether the respondent studied English as a subject at their school level to understand the clarity of the questionnaire.

Section two explored the knowledge score of the respondents through 12 sets of questions or statements about the wildlife of Kargil. This section included questions with 'Yes' or 'No' responses or text space to identify wild carnivore species of the region. The pictures of the mammal species that were included to be identified by the respondents were a Red Fox, a Himalayan Brown Bear, a Snow Leopard, and a Wolf. The correct answer to each knowledge question was given a score of '1' and '0' for incorrect responses. Hence the overall knowledge score of the respondent was accumulated to a maximum of 12.

Section three examined the attitude scores of the respondents. This section consists of 12 statements/questions intended to assess the attitude of the respondents towards the wildlife of the region. A favourable response/attitude towards wildlife was scored '1' and a negative response was scored '0'. Hence, the accumulated maximum attitude score for a respondent summed up to 12.

A question was included to find out whether the questionnaire was intelligible to the respondents. One open-ended question was also included in the last section of the questionnaire to explore their experience, further comments on the wildlife of the region, and scope for future studies.

The questionnaire was validated through a pilot test involving 20 students from Kargil in higher education, who matched the inclusion criteria. This pretesting was aimed to assess clarity, language comprehensibility, and content relevance. Based on their feedback, questions were simplified that were hard to understand. While reliability coefficients were not calculated, internal consistency was promoted through clearly defined binary scoring (0 = incorrect/unfavourable, 1 = correct/favourable).

The knowledge section of the questionnaire entirely composed of fact-based questions. Each item was scored as correct (1) or incorrect (0), based on factual accuracy.

Statistical analysis

A one-sample Shapiro-Wilk test was performed to assess the normality of the data. Square root and log transformation were performed on non-normally distributed data to obtain normality. None of the variables satisfied the normality criterion after log and square root transformations. Hence, nonparametric tests were used to guarantee that the findings were reliable.

The Chi-square test (Pearson chi-square, Fisher exact test, likelihood ratio) was used to assess any association between two categorical variables. We used the Kruskal-Wallis test to compare the knowledge and attitude score with more than two independent categories of socio-demographic variables. The Mann-Whitney U test was performed to compare the attitude and knowledge score with two independent paired sociodemographic categories. To evaluate the relationship between the total knowledge and attitude score, we performed a Spearman's correlation test (rho). All the data handling and statistical analysis were performed in Microsoft© Excel and SPSS© 27.

A limitation of this study lies in non-probability convenience sampling approach. The sole use of digital distribution channel may have led to selection bias as those without internet may have left out of the sample. Hence, the findings should be interpreted cautiously.

RESULTS

In total, we received 385 responses. Nine respondents did not consent to participate in the study. A total of 14

additional responses were removed from the final data list. These were the responses that indicated difficulty in understanding the questionnaire (n = 6) and the responses where English was not one of the subjects at their higher secondary education level (n = 8). Hence, a total of 362 responses were considered fit for the final data analysis. The age of the participants ranged between 18 and 33 years with a mean of 23.10 years ± 3.368. The detailed demographic information of the respondents is shown in Table 1.

Knowledge score

The total knowledge score for the respondents ranged 3–12, with a mean score of 9.68 ± 1.565. The accurate responses (in percentage) for the knowledge statement by the respondents are detailed in Table 2.

Identification of species

Identification of different wild carnivore species and their association with various categories of respondents are laid out in Table 3. Fox was correctly identified by 331 respondents. However, it was confused for Wolf *Canis lupus* and common dog *Canis familiaris* by 8.65% (n = 31) of the total respondents. The chi-square test of independence was performed to assess the relationship between various demographic categories of the respondents and the identification of the species. There was a significant relationship between the identification of fox and the students who studied environmental science at the higher secondary school level χ^2 (1, 362) = 3.949, p = 0.047. Students who had environmental science as one of their subjects at higher education level were able to identify the fox more accurately (93.26%) as compared to students without an environmental science background (86.32%).

Bear was the easiest species to be identified by respondents, with 356 (98.3%) respondents correctly identifying the species. It should be noted here that we also considered the responses as accurate, where the Brown Bear was also responded as 'bear' by the participants but excluded responses with Polar Bear *Ursus maritimus*. Six respondents were not able to identify the brown bear correctly, confusing it for the polar bear.

The Snow Leopard was the least identified species by the respondents. It was correctly identified by 255 (70.4%) of the total 362 respondents. The Snow Leopard was confused by the respondents for the common cat *Felis catus*, Cheetah *Acinonyx jubatus*, Tiger, and other cat species in terms of identification. There was a significant relationship between gender and identification of Snow Leopard, χ^2 (2, 362) = 11.128, p = 0.004, with male respondents identifying the species more accurately (75.71%) as compared to female counterparts (58.77%). Three-hundred-and-thirteen of the total 362 respondents were able to identify the wolf correctly. However, 13.5% (n = 49) confused it for the common dog, fox, and Jackal *Canis aureus*.

Knowledge score and various factors

The Kruskal-Wallis test revealed a non-significant difference, H(2) = 3.885, p = 0.143, in the total knowledge score across three gender categories. However, the distribution of the total knowledge score was significantly different, H(3) = 12.724, P = 0.005, across four categories of faith (Islam, mean rank = 185.45; Buddhism, mean rank = 178.93; Bon-chhos, mean rank = 68.35; prefer not to say, mean rank = 183.64). The distribution of total knowledge scores was significantly different, H(3) = 10.626, P = 0.014 across the different levels of education (graduation, mean rank = 175.05; masters, mean rank = 194.25; PhD, mean rank = 236.82; others higher than 10+2, mean rank = 163.71). The distribution of total knowledge score was not the same, H(3) = 10.120, P = 0.018, across the categories of academic subjects of the respondents at the higher secondary education level (Science, mean rank = 191.73; arts & humanities, mean rank = 159.65; commerce, mean rank = 140.20; others, mean rank = 192.85).

To evaluate the difference in knowledge scores among students who studied environmental science as a subject in their higher secondary education level, a non-parametric Mann Whitney U test was performed. Effect size (r) statistic, was calculated using the below formula:

Where Z is the Z statistic from the Mann-Whitney U test, and N is the number of cases. The test revealed a significant difference in knowledge scores among students who studied environmental science as a subject at their higher secondary school level (median = 10, n = 267) and students who did not study environmental science at their higher secondary school (median = 9, n = 95), U = 9978.000, z = -3.159, p = 0.002, r = 0.166.

Attitude score of the respondents

The overall attitude score for the respondents ranged from 4–12, with a mean score of 10.19 ± 1.417. In general, students in higher education possessed a favourable attitude towards the wildlife of the region (Table 4).

A significant difference, H(3) = 20.286, p = <0.001, was observed in the distribution of total attitude score across various categories of faith of the respondents

Table 1. Socio-demographic profile of the respondents to questionnaire about wildlife in Kargil region (N = 362).

		Frequency	Percent (%)
Gender	Male	247	68.2
	Female	114	31.5
	Prefer not to say	1	0.3
Faith	Islam	307	84.8
	Buddhism	38	10.5
	Bon-chhos	10	2.8
	Prefer not to say	7	1.9
Current education level	Graduation	181	50.0
	Masters	91	25.1
	PhD	22	6.1
	Others (higher than 10+2)	68	18.8
Resident (Block)	Kargil	123	34.0
	Zanskar	15	4.1
	Shakar-Chiktan	30	8.3
	Sankoo	68	18.8
	Drass	35	9.7
	Taisuru	30	8.3
	Cha/Lungnak	4	1.1
	Shargole	33	9.1
	TSG	24	6.6
Current place of study	Kargil	158	43.6
	Leh	17	4.7
	Srinagar	22	6.1
	Jammu	59	16.3
	Delhi	38	10.5
	Chandigarh	32	8.8
	Dehradun	5	1.4
	Others (outside Kargil)	31	8.6
Subject in higher secondary (10+2)	Science	252	69.6
	Arts & Humanities	78	21.5
	Commerce	22	6.1
	Others	10	2.8
Environmental Science as a subject in higher secondary	No	95	26.2
	Yes	267	73.8

Table 2. Students' response to knowledge statement/questions.

Question/Statement	Accurate response (%)
Identification of regional wildlife species (fox)	91.4
Identification of regional wildlife species (bear)	98.3
Identification of regional wildlife species (Snow Leopard)	70.4
Identification of regional wildlife species (wolf)	86.5
Kargil has unique and rich biodiversity, due to its special geographical characteristics	91.2
There are many protected areas for wildlife in Kargil	57.7
Wolves are omnivorous animals?	67.1
Kargil (Ladakh) is sometimes referred to as a 'cold desert' in the scientific community	90.6
Each wild carnivore plays an important role in the 'food web'	95.0
The scientific name of the fox is (*Vulpes vulpes* or *Canis lupus*)	75.7
The largest carnivore species of Kargil is (the Brown Bear or Snow Leopard)	66.3
Tigers (*Panthera tigris*) are also found in Kargil	77.9

(Islam, mean rank = 183.09; Buddhism; mean rank = 201.36, Bon-chhos, mean rank = 47.50; prefer not to say, n = 195.43). The distribution of the total attitude score of the respondents was not the same, H(3) = 17.006, p = < 0.001, across four categories of the current level of education (graduation, mean rank = 177.80; masters, mean rank = 189.30; PhD, mean rank = 254.45; others (higher than 10+2, n = 157.32). The distribution of overall attitude score was significantly not uniform, H(3) = 5.523, p = 0.037, across categories of respondents' subjects of study (Science, n = 252; arts/humanities, n = 78; commerce, n = 22; others, n = 10). Further, the Kruskal-Wallis test of the independent sample reflected that the distribution of the total attitude score was significantly different, H(7) = 22.547, p = 0.002, in the categories of the current place of study (Kargil, mean rank = 168.76; Leh, mean rank = 195.00; Srinagar, mean rank = 214.43; Jammu, mean rank = 166.95; Delhi, mean rank = 236.05; Chandigarh, mean rank = 201.36; Dehradun, n = 201.90; others, mean rank = 152.71). Mann Whitney U test revealed a non-significant difference in the total attitude score among students who studied environmental science as a subject in their higher secondary school level (median = 11, n = 267) and students who did not study environmental science in their higher secondary school level (median = 11, n = 95), U = 11466.000, z = -1.476, p = 0.140. The effect size (r = 0.077) of the difference was negligible/very small (Cohen 1988).

Relationship between knowledge score and attitude score

A nonparametric correlation test (Spearman's rho) was performed to explore any relationship between the total knowledge score and the attitude score. Spearman's correlation of knowledge score and attitude score was moderately positive and statistically significant, r_s = 0.255, p < 0.001, N = 362. This correlation though weak, reflected that the increase in knowledge of the wildlife of

the region increases the favourable attitude of students in higher education towards wildlife.

DISCUSSIONS

Although several studies have indicated that females are more afraid of wild animals and have a negative attitude toward them than males (Costello 1982; Klrkpatrick 1984; Kellert & Berry 1987; Arrindell 2000), this study revealed that there was no significant difference in the attitude of university students from Kargil towards wildlife across different gender categories. Although females are more afraid of wild animals, they, on the other hand, place a higher value on wildlife as objects of affection and are more concerned about wildlife exploitation (Kellert & Berry 1987).

The study also revealed that the distribution of the knowledge score was not the same across the different levels of education of the respondents. The knowledge score increased with an increasing level of education. These findings are consistent with the findings of previous researchers who determined that education plays a significant role in influencing knowledge (Fiallo & Jacobson 1995; Pyrovetsi & Daoutopoulos 1997; Gillingham & Lee 1999; Barthwal & Mathur 2012).

The attitude of students towards wildlife

The study also revealed that the distribution of the total attitude score was not the same across categories of the subject of the education of the respondents at the higher secondary education level, students with an educational background with arts and science possess a more favourable attitude than those of commerce and other streams. This could be due to fact that students with arts and science as their main subject have an option for choosing environmental science as a subject in their higher secondary school education level.

The study also informed that the increase in knowledge of the wildlife of the region increases the favourable attitude of students in higher education towards it. This, on some level, confirms past studies that reveal education and awareness can improve attitude and tolerance for wild carnivores (Woodroffe 2005), which may further assist in translating knowledge into positive behavioural changes within the student population and further. Another reason could be, living in close proximity to native species improves awareness of their ecology and behaviour, enabling the development of improved management techniques and responses to them (Røskaft et al. 2003).

The significant correlation, though weak ($r_s = 0.255$, $p < 0.001$) suggests that knowledge may be an important factor that instils a favourable attitudes in humans, but in context to this study it is not the only predictor. This finding also align with existing literature that identifies the importance of other psychosocial variables, such as emotional association with the surroundings, cultural identity, perceived personal risk, or moral values, in determining conservation attitudes (Johansson et al. 2012; Castillo-Huitrón et al. 2020). Another possibility is that individuals' preexisting attitudes affect their acquisition and interpretation of knowledge, instead of the other way around (Khan et al. 2022). Besides, the study did not used any multivariate regression methods to control for potential influencing variables such as gender, education level, or subject background, etc. These variables can be examined in a regression model in future studies to better understand the independent effects of these variables in attitude formation.

In other parts of the Himalaya, such as Suryawanshi et al. (2014) in Himachal Pradesh and Bhatia et al. (2017) in Ladakh, it was found that people with higher education tend to have more positive attitudes toward large carnivores. In those settings, however, direct experiences of livestock loss or perceived risks often moderated those attitudes. In contrast, in our study, students from Kargil living in or outside of Kargil, may have less firsthand experience of human-wildlife interactions, which may partially explain the overall favourable attitudes despite moderate knowledge levels.

There can also be a significant cultural and religious worldview. The majority of respondents in this study identified with Islamic faith, where the concept of stewardship encourages respect for all forms of life, including wild animals. Likewise, Buddhist principles of non-violence (Ahimsa) in neighboring regions like Zanskar may contribute to conservation-positive attitudes. Furthermore, as Kargil is a geopolitically sensitive and historically underserved border region, wildlife may be viewed less as a threat and more as a symbol of regional identity and ecological uniqueness.

The statistical analyses shows some variation in knowledge scores across religious groups, but this needs to interpreted cautiously. Religious identity alone is unlikely to have any effect on factual ecological knowledge. Rather, these differences may be indicative of larger socio-cultural factors, such as access to education, geographic concentration, and community values & interest on the environment. These pathways could be explored further in future studies more explicitly through qualitative or ethnographic approaches.

Table 3. Association between categories of respondents and identification of species.

Respondent categories	Variables	Fox					Bear					Snow Leopard					Wolf				
		Ci (%)	Ii (%)	Asso.	df	Sig. (p value)	Ci (%)	Ii (%)	Asso.	df	Sig. (p value)	Ci (%)	Ii (%)	Asso.	df	Sig. (p value)	Ci (%)	Ii (%)	Asso.	df	Sig. (p value)
Gender	Male	92.31	7.69	5.328* (G^2)	2	0.07	98.38	1.62	0.042 (G^2)	2	0.979	75.7	24.3	11.128 (G^2)	2	0.004	87.04	12.96	0.542 (G^2)	2	0.762
	Female	90.35	9.65				98.25	1.75				58.78	41.22				85.09	14.91			
	Prefer not to say	0	100				100	0				100	0				100	0			
Faith	Islam	91.86	8.14	5.128 (G^2)	3	0.163	98.7	1.3	6.183 (G^2)	3	0.103	71.66	28.34	12.023 (G^2)*	3	0.007	85.99	14.01	0.492 (G^2)	3	0.921
	Buddhism	92.11	7.89				100	0				71.05	28.95				89.47	10.53			
	Bos-chhoss	70	30				90	10				20	80				90	10			
	Prefer not to say	100	0				85.72	14.28				87.5	12.5				85.72	14.28			
Block resident	Kargil	90.24	9.76	8.139 (G^2)	8	0.42	98.38	1.62	4.759 (G^2)	8	0.783	65.04	34.96	5.911 (G^2)	8	0.657	85.37	14.63	17.458 (G^2)*	8	0.026
	Zanskar	93.34	6.66				100	0				60	40				80	20			
	Shakar-Chiktan	96.67	3.33				100	0				73.34	26.66				83.34	16.66			
	Sankoo	92.65	7.35				97.06	2.94				73.53	26.47				85.3	14.7			
	Drass	85.72	14.28				97.14	2.86				80	20				74.29	25.71			
	Taisuru	83.34	16.66				96.67	3.33				76.67	23.33				100	0			
	Lungnak	100	0				100	0				50	50				100	0			
	Shargole	96.97	3.03				100	0				72.73	27.27				90.91	9.09			
	TSG	87.38	12.62				100	0				70.84	29.16				95.84	4.16			
Current education level	Graduation	93.37	6.63	2.364 (G^2)	3	0.5	99.45	0.55	4.288 (G^2)	3	0.232	71.27	28.73	6.623 (G^2)	3	0.085	90.06	9.94	10.534 (G^2)*	3	0.015
	Masters	91.21	8.79				97.71	2.29				67.04	32.96				85.72	14.28			
	PhD	86.37	13.63				100	0				90.91	9.09				95.46	4.54			
	Other	88.24	11.76				97.06	2.94				66.18	33.82				75	25			
Current place of Study	Kargil	92.41	7.59	4.078 (G^2)	7	0.771	99.37	0.63	5.436 (G^2)	7	0.607	62.66	37.34	21.189 (G^2)*	7	0.003	82.09	17.91	3.699 (G^2)	7	0.814
	Leh	94.12	5.88				100	0				64.71	35.29				78.58	21.42			
	Srinagar	81.82	18.18				100	0				77.28	22.72				84.21	15.79			
	Jammu	89.83	10.17				98.31	1.69				64.41	35.59				90.74	9.26			
	Delhi	89.47	10.53				94.74	5.26				86.84	13.16				81.25	18.75			
	Chandigarh	93.75	6.25				96.875	3.125				78.13	21.87				85.72	14.28			
	Dehradun	100	0				100	0				100	0				100	0			
	Others	93.55	6.45				96.77	3.23				87.1	12.9				85.19	14.81			
Subject in Higher Secondary	Science	92.46	7.54	4.433 (G2)	3	0.218	98.41	1.59	1.415 (G^2)	3	0.702	72.23	27.77	4.552 (G^2)	3	0.208	88.1	11.9	2.660 (G^2)	3	0.447
	Arts	89.74	10.26				97.44	2.56				64.11	35.89				80.77	19.23			
	Commerce	81.82	18.18				100	0				63.64	36.36				86.37	13.63			
	Others	100	0				100	0				90	10				90	10			
EVSin 10+2	Yes	86.32	13.68		1	0.053 (Ꝑ)	96.84	3.16		1	0.188 (Ꝑ)	72.63	27.37	0.297 ($\chi 2$)	1	0.586	82.11	17.89	2.091 ($\chi 2$)	1	0.148
	No	93.26	6.74				98.88	1.12				69.66	30.34				88.02	11.98			

G^2—Likelihood ratio | Ꝑ—Fisher exact | χ^2—Pearson chi-square | EVS—Environmental science as a subject | *—significant at 0.05 | Ci—Correct identification | Ii—Incorrect identification | Asso.—Association.

Table 4. Students' response to attitude statement/questions.

Question/ Statement	Favourable response (%)
Do you think there should be more emphasis on the wildlife-related curriculum/subjects in schools?	92.5
There should be more protected areas in Kargil to conserve and protect biodiversity?	90.3
Local people living in areas adjacent to wild carnivores should be educated and awareabout wild carnivores?	88.7
Wild carnivores should be protected even if it incurs a loss of some livestock	82.9
Would you be interested or thrilled to see a snow-leopard in wild?	91.2
It is Important to protect wild carnivores of Kargil	75.4
I feel relieved and comforted when there are efforts to protect the wildlife of Kargil	94.2
Conservation of the wild carnivores is necessary for human survival	91.7
Curriculum/subjects focusing on local and global wildlife should be included in school education	95.5
In geographically challenging regions, like Kargil, the wise use of natural resources isnecessary	96.7
Every student especially in higher education must have good basic knowledge of the wildlife of his/her region	90.9
We should respect and strive to protect all living beings, including wild carnivores as an integral part of the ecosystem	95.0

CONCLUSIONS

Students from Kargil in higher education possessed good knowledge and information of their local wild carnivores and have a favurable attitude towards them; 78.3% of the respondent studied environmental science at their higher secondary education level, this shows students' interest in understanding and exploring more about the natural environment. Several studies (Kellert 1985; Røskaft et al. 2007; Suryawanshi et al. 2014; Bhatia et al 2017) have revealed that people with higher levels of education and awareness have higher levels of tolerance towards wild carnivores, and other non-charismatic species. Considering knowledge as an important component of human emotions (Castillo-Huitrón et al. 2020), we recommend that the perception and emotions of wild carnivores among local students can be improved by organizing regular awareness campaigns and programs in schools and higher education institutions across Kargil. This approach can also assist in shaping the need to translate knowledge into positive behaviour change of local communities towards wildlife.

Studies had also indicated that education and awareness can improve attitude and tolerance for wild carnivores (Woodroffe 2005), however, educating people who have a negative attitude about large carnivores due to a lack of interest in knowing more about them might be challenging (Bath & Majic 2001; Kaczensky 2003). Better direct experiences, such as understanding the importance of species in tourism and their aesthetic values, can help alleviate fear and promote favourable attitudes toward wildlife (de Pinho et al. 2014). Implementing proper livestock compensation schemes by considering the tangible and intangible cost of livestock loss (e.g., loss of sleep due to worry) by the local communities, setting up proper livestock insurance programs, and promoting eco-tourism could be some of the positive steps in reducing poor attitudes and perceptions towards wildlife and can also serve as initial steps in enhancing their interest in knowing more about species of the region.

The study also reflected that students with environmental science as a subject at their higher secondary education level possess more knowledge about the wildlife of the region. Although environmental sciences, as a subject is taught at a higher secondary school level across Kargil within science and arts stream as an optional subject, we recommend prioritizing the subject at a higher secondary school level to promote knowledge and awareness of wildlife of the region in specific and Environment as a general.

The findings of this study carry important conservation implications. The weak correlation between knowledge and attitudes suggests that awareness campaigns should not focus solely on factual knowledge but also engage with local values, emotions, and lived experiences. Conservation programs targeting youth in Kargil and similar trans-Himalayan landscapes should be designed to reinforce positive perceptions, integrate traditional ecological knowledge, and build platforms for direct and empathetic engagement with wildlife. Additionally, religious and community leaders can be strategic allies in shaping conservation messaging that resonates with local belief systems.

Future research could intensively look into the factors that influence the formation of social attitudes toward wildlife.

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ARTICLE

Avian community structure in a human-impacted forest landscape: insights from Amangarh Tiger Reserve, Uttar Pradesh, India

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Abstract: Habitat degradation and loss due to anthropogenic pressures are the primary threats to biodiversity, particularly in tropical forests. Monitoring bird communities provides valuable insights into the environmental status of both natural and human-modified ecosystems. In this study (February–April 2021), the point count method was used to assess avian species richness, diversity, and density in Amangarh Tiger Reserve (ATR)—a human-impacted forest area, aiming to understand its ecological importance and conservation potential. A proportionately stratified random sampling strategy was used for point count surveys across multiple habitat types. Species were identified, counted, and categorised by feeding guilds, and diversity indices were calculated. Bird density was calculated using Distance 7.3 software. A total of 110 bird species were recorded, indicating noteworthy species richness. Mixed forest exhibited the highest diversity, richness, and density (2029.7 birds/km², 95% CI: 1732.2–2378.2), likely due to its structural complexity. In contrast, teak plantations supported the lowest bird diversity, likely due to monoculture and low structural complexity. The riverbed had the lowest richness and density (1038 birds/km², 95% CI: 245.9–4381.1). Insectivores were the most abundant group, suggesting good ecological integrity of the region. This study highlights the ecological value of ATR for avian conservation, particularly the role of habitat heterogeneity and its mixed forests. Long-term monitoring is necessary to guide conservation planning and maintain the stability of bird communities in human-impacted landscapes such as ATR.

Keywords: Avian density, avian diversity, avian richness, biodiversity, birds, community ecology, distance sampling, feeding guilds, habitat heterogeneity, point count.

Abbreviations: ATR—Amangarh Tiger Reserve | CR—Carnivore | EN—Endangered | FR—Frugivore | GR—Granivore | IN—Insectivore | LC—Least Concern | NC—Nectivore | NT—Near Threatened | OM—Omnivore | PI—Piscivore | VU—Vulnerable.

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Author contributions: VPS conceived the study, designed the study, conducted the fieldwork, analysed the data, and prepared the initial manuscript. SR contributed to study design and conducted the fieldwork. MA contributed to study design and field supervision. SK contributed to statistical analysis, writing, supervision and manuscript review. AK contributed to study design, Supervision, data interpretation, and critical revision of the manuscript.

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INTRODUCTION

Birds are a highly diverse and widely distributed group of vertebrates, with more than 11,000 species found globally (BirdLife International 2023; Clements et al. 2023; Rheindt et al. 2025). India harbours remarkable avian diversity, supporting around 12% of the world's bird species (Praveen & Jayapal 2025). This remarkable avian diversity can largely be attributed to India's diverse landforms, vast altitudinal gradient, and highly varied climatic conditions, which give rise to a wide range of vegetation types and environments in the country. Birds inhabit a diverse range of environments and play a crucial role in ecosystem functioning, including pollination, seed dispersal, pest control, and nutrient cycling, making them vital components of biodiversity (Sekercioglu 2006).

Forest landscapes are undergoing rapid changes due to various anthropogenic activities, leading to modifications in vegetation structure and loss of biodiversity (Morris 2010; Haddad et al. 2015; Brancalion et al. 2025; Yang et al. 2025). Monitoring human-impacted forest landscapes is crucial for understanding the effects of these disturbances on natural ecosystems and for implementing effective corrective measures. Due to their sensitivity to environmental changes and wide distribution, birds are effective and reliable indicators of environmental health and stability and are frequently used to monitor ecosystem health (Canterbury et al. 2000; Mansfield et al. 2024; Naveen et al. 2026; Njuguna et al. 2026). Monitoring bird communities provides valuable insights into ecological dynamics and the impacts of anthropogenic pressures on natural ecosystems in a specific area; therefore, understanding the structure of bird communities is crucial for long-term environmental conservation (Gregory & Van Strien 2010; Byju et al. 2026). Species richness, abundance, and community composition are key characteristics of communities that ecologists often examine (Magurran 2004). Another important approach to understanding bird community structure is based on their feeding guilds and habitat use (Thiollay 1995; Clough et al. 2009). A guild is a fundamental concept in avian ecology, referring to a group of bird species that coexist within a community by utilising similar types of environmental resources (Balestrieri et al. 2015). Different guilds exhibit distinct tolerance thresholds and resource utilisation strategies that are shaped by the specific environmental conditions they inhabit. These variations are largely governed by multiple biotic and abiotic factors, including food availability, vegetation structure, habitat complexity, and the presence or absence of predators and competitors. Such ecological parameters play a crucial role in determining the distribution, abundance, and functional roles of guild members within an ecosystem (Katuwal et al. 2016; Mathibalan et al. 2026).

Despite their importance in monitoring the health of ecosystems, there is a notable lack of comprehensive scientific studies on birds in the human-impacted forests, especially in the Terai Arc Landscape. This landscape harbours exceptionally rich avifauna — for example, 330 species recorded in Dudhwa National Park (Javed & Rahmani 1998), and over 400 species in Terai Arc protected areas (Safi et al. 2024). However, most ornithological accounts from the Terai region have been limited to species checklists or opportunistic sightings, documenting presence but not quantifying population densities or spatial patterns. Consequently, robust studies estimating bird abundance using standardised methods, such as point counts or line transects, remain scarce, leaving critical gaps in conservation planning (Kidwai et al. 2013). Amangarh Tiger Reserve (ATR), which forms a multiple-use zone of the Corbett Tiger Reserve, is subject to various anthropogenic pressures, including livestock grazing, fuelwood extraction, and the collection of non-timber forest products by locals (Reza et al. 2024). Despite high anthropogenic pressures, ATR remains a significant forest landscape, serving not only as an important area for tiger conservation but also as a refuge for a wide range of other wildlife species, including avifauna, mammals, reptiles, and insects (Reza et al. 2024). Important mammalian species of ATR include Leopard *Panthera pardus*, Rusty-spotted Cat *Prionailurus rubiginosus*, Asian Elephant *Elephas maximus*, Sambar *Rusa unicolor*, and Chital *Axis axis*, among others. Considering its ecological value, it is an ideal site for initiating bird monitoring and ecological studies. The present study aims to assess the bird community structure in the ATR, focusing on species richness, diversity, abundance, and density. The research seeks to enhance the understanding of the bird community of the region and contribute to broader conservation initiatives.

Study Area

The study was conducted in the ATR, spanning over an area of 80.60 km^2. The reserve is located in the Bijnor district of Uttar Pradesh (Image 1). The ATR was originally part of Corbett National Park before the state of Uttar Pradesh was bifurcated. Following the bifurcation of Uttar Pradesh, a major part of Corbett National Park became part of Uttarakhand, while the

Amangarh range remained within the state of Uttar Pradesh. In 2012, the Amangarh range of Bijnor Forest Division was designated as a buffer zone of the Corbett Tiger Reserve, thereby integrating the area into the tiger reserve. Biogeographically, ATR is part of the regional subdivision (Terai Bhabar tract) of the Upper Gangetic Plains, a low-lying land stretch along the sub-Himalayan Shivalik ridges (Rodgers & Panwar 1988). The prominent vegetation in the Terai region is tropical moist deciduous forest (Champion & Seth 1968; Rodgers & Panwar 1988). The ATR vegetation can be further categorised into the following types: Sal-dominated forest, Teak plantation, mixed forest, grassland, and scrubland. The terrain is mainly plain with a mean elevation of 290 m (ranging 246–373 m), rarely becoming undulating in certain areas. The area has three major seasonal rivers and many small water channels, which become active during the monsoon and feed water to the area.

A land cover map of the ATR was prepared using a Landsat 8 (ESRIGRID; projection, UTM; datum, WGS 1984; cell size 30 m) operational land imager (OLI) image acquired on 11.iii.2021. The OLI data were processed using ArcGIS Pro 10.8.2 software (Esri, 2021), and through supervised classification, six distinct habitat types were identified within the study area (Image 2).

Methods

The study was conducted between February and April 2021, using the Point Count method (Verner 1985) to collect data for bird diversity, community structure, and abundance estimates. This method involved monitoring birds at established fixed point count stations across various habitats within the study area. Point counts were conducted by a team of two to three observers at 0600–1100 h and 1500–1900 h, as bird activity is highest during these times (Rutt et al. 2023; Singer et al. 2025). After reaching a point count station, the team waited quietly for five minutes to allow birds disturbed by their presence to resume normal activity. This acclimatisation period minimised person-induced bias and ensured random distribution of birds around the point count station. Data were collected for all birds seen around the point count station over a 10-minute observation period. Data on bird species, flock size, and radial

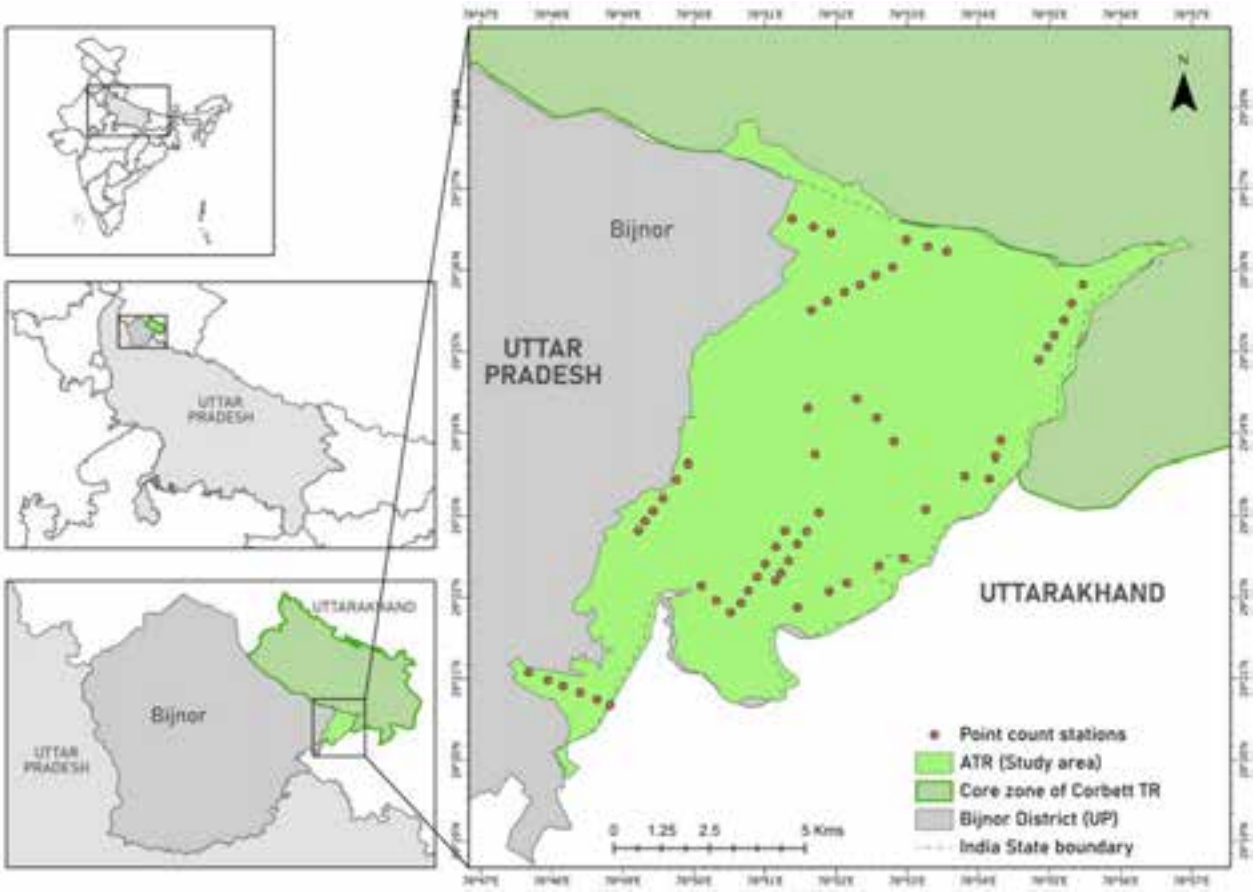

Image 1. Map of Amangarh Tiger Reserve and locations of point count stations.

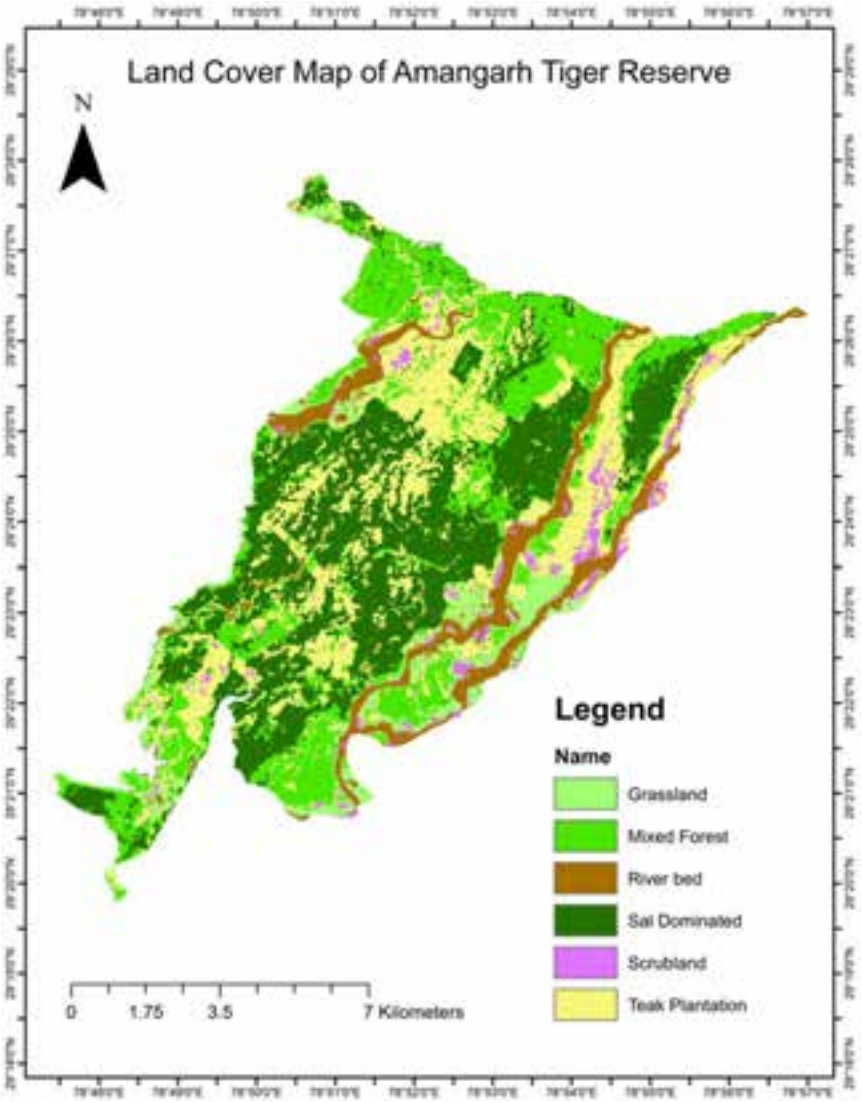

Image 2. Map showing land use land change of Amangarh Tiger Reserve.

distance (using an IR range finder) from the points were collected. Each point count station was monitored six times during the study period, three times during both evening and morning hours. Species identifications were performed by experienced observers using Grimmett et al. (2011) and Grewal et al. (2016).

A total of 60 points were laid using a stratified random sampling strategy across these six habitat types. The number of points in a particular habitat type was almost proportional to the area under that habitat type (Table 1). A minimum distance of 400 m was maintained between two adjacent points to ensure that bird detections from different points are statistically independent.

Bird density was determined using the software DISTANCE 7.3 (Thomas et al. 2010). Models with different combinations of key functions and series expansions were tried and the final model for the analysis was chosen based on Akaike's information criteria (AIC) values (Akaike 1974; Burnham & Anderson 2002), and chi-square statistics were used to determine the 'goodness of fit' of each function (Burnham et al. 1980; Buckland et al. 2001). Species diversity (Shannon-Wiener) and richness (Margalef) indices were calculated using software Past 4.03 (Paleontological Statistics Software package for education and data analysis, Hammer et al. 2001), while relative abundance and species occurrence were calculated using the following formulas:

$$\text{Relative abundance of a species} = \frac{\text{Total individuals of a species}}{\text{Total individuals of all species}} \text{ X } 100$$

$$\text{Occurrence of a species} = \frac{\text{Number of times a species recorded}}{\text{Total effort}} \times 100$$

Sixty point-count stations were monitored six times each, yielding a total effort of 360 point-count occasions. As data satisfied the assumptions of normality, a one-way ANOVA was performed to determine differences among habitat types for richness and diversity indices. Feeding guilds were determined using dietary information from EltonTraits 1.0 (Wilman et al. 2014). Species were categorised based on the predominant food items in their diet and grouped into major feeding guilds such as insectivores, frugivores, granivores, etc. In cases where no single food category was clearly dominant, species were classified into combined guilds.

Limitations of the study: The findings of the study should be interpreted in light of certain limitations. First, field surveys were conducted for a limited period and did not encompass all the seasons, particularly the monsoon season. As bird communities often exhibit seasonal variations in species composition and abundance due to migration and resource availability, the observed patterns may not fully represent avian diversity and population dynamics within the study area. Second, although distance sampling methods were employed to estimate bird density, detection probability may have varied among habitats. While the distance sampling framework accounts for imperfect detection and attempts to correct biases, residual errors associated with observer ability, vegetation density, species-specific detectability, and environmental conditions may still influence density estimates. Despite these limitations, the study provides valuable baseline information on avian diversity, community structure and density and establishes a foundation for future long-term and year-round monitoring efforts.

RESULTS

Avian diversity and ecological traits

A total of 110 species (109 identified and one unidentified) were recorded during the study, representing 14 orders and 45 families. The Passeriformes were the largest order, containing 61 bird species. Among families, Muscicapidae, with 10 species, emerged as the most species-rich family, followed by Picidae (9 species), Accipitridae (6 species), and Columbidae (6 species). The highest number of species was recorded in mixed forest (70 species), followed by Sal-dominated forest (61 species), while the minimum number of species (21 species) was recorded in riverbed (Table 2).

Table 1. Proportion of different habitat types and sampling efforts in Amangarh Tiger Reserve.

Habitat type	Land cover area percentage (%)	No. of point count stations	Percentage of point count stations
Dry river	6.06	2	3
Grassland	5.26	2	3
Mixed forest	22.53	15	25
Sal dominated forest	32.10	24	40
Scrubland	10.16	4	7
Teak plantation	23.09	13	22

Among the recorded species, one species—Egyptian Vulture *Neophron percnopterus*—is 'Endangered'; two species—Great Hornbill *Buceros bicornis*, and Great Slaty Woodpecker *Mulleripicus pulverulentus* are 'Vulnerable'; two species—Cinereous Vulture *Aegypius monachus* and Red-breasted Parakeet *Psittacula alexandri*—are 'Near Threatened'; and the rest (104 species) are 'Least Concern'.

Categorisation of birds according to their feeding guilds showed that the majority of bird species belong to insectivores (n = 52, 46.85%), followed by omnivores (n = 20, 18.02%), frugivores (n = 12, 10.81%), granivores (n = 9, 8.11%), carnivores (n = 8, 7.21%), nectarivores (n = 2, 1.80%), and piscivores (n = 1, 0.90%). Five species belonged to multiple feeding guilds (Image 3).

Bird density

Based on AIC values, the hazard-rate model with simple polynomial adjustment was selected for bird density estimation. The estimated bird density in the study area was 1,471 birds/km² (95% CI: 1313.6–1647.2), while the cluster density was 926.19 clusters/km² (95% CI: 828.7–1035.2), with a mean cluster size of 1.6 individuals and an effective detection radius (EDR) of 44.78 m (Table 3). Estimates of relative abundance and occurrence indicated that the Plum-headed Parakeet *Psittacula cyanocephala*, Rose-ringed Parakeet *Psittacula krameria*, and Yellow-throated Sparrow *Gymnoris xanthocollis* were the most common and abundant bird species in the study area (Table 4). The estimates of bird density in different habitat types showed that mixed forest had the highest density (2,029.7 birds/km², 95% CI: 1732.2–2378.2), followed by scrubland (1,928.6 birds/km², 95% CI: 1325.9–2805.1), whereas the lowest density (1,038.0 birds/km², 95% CI: 245.94–4381.1) was recorded in riverbed (Table 2).

Table 2. Density, diversity, and richness of birds across different habitat types in Amangarh Tiger Reserve.

Habitat type	No. of species recorded	EDR ± SE (m)	Density per sq km	95% Confidence interval	Diversity	Richness
Mixed forest	68	42.04 ± 0.83	2,029.7	1732.2, 2378.2	3.06	9.59
Sal dominated	60	44.50 ± 0.83	1,291.5	1075.2, 1551.3	2.47	8.29
Teak plantation	42	42.39 ± 1.06	1,243.2	985.35, 1568.7	1.88	6.48
Scrubland	32	47.68 ± 1.91	1,928.6	1325.9, 2805.1	2.79	5.29
Grassland	23	62.77 ± 2.89	1,082.0	663.40, 1764.9	2.64	4.34
River bed	20	50.74 ± 3.38	1,038.0	245.94, 4381.1	2.67	4.22

Table 3. Avian group density, average cluster size and overall density of birds in Amangarh Tiger Reserve.
D—estimate of density of birds | DS—estimate of density of clusters | EDR—effective detection radius | E(S)—estimate of expected value of cluster size.

Parameter	Point estimate	Standard error	Percent coef. of variation	95% Confidence interval	
DS	926.19	51.845	5.6	828.67	1035.2
E(S)	1.5882	1.71E-02	1.07	1.5551	1.622
D	1471	83.842	5.7	1313.6	1647.2
EDR	44.785	0.49015	1.09	43.834	45.757

Bird species diversity and richness

The overall Shannon-Wiener diversity and Margalef richness were 1.81 ± 0.06 SD and 2.72 ± 0.12 SD, respectively. Among the different habitat types, mixed forest had the highest diversity (3.06) and richness (9.59), while the lowest diversity (1.88) and richness (4.22) were recorded in teak plantations and riverbed, respectively (Table 2). An analysis of variance (ANOVA) revealed statistically significant differences among habitat types for species richness ($F(5,54) = 7.938$, $p = 1.16e-05$) and species diversity ($F(5,54) = 9.214$, $p = 2.19e-06$).

DISCUSSION

This study provides insights into the avian species richness, density, and feeding guilds of the ATR, emphasising the ecological significance of this human-impacted landscape for biodiversity conservation. The observation of 110 bird species (109 identified and one unidentified) within a relatively small area (80.60 km²) reflects considerable species richness, underscoring the importance of habitat heterogeneity in supporting avian biodiversity (Pineda-Diez de Bonilla et al. 2012). The availability of diverse habitat types, such as mixed forests, scrublands, and grasslands, provides a broad array of ecological niches, allowing various bird species with different habitat preferences and ecological requirements to thrive.

The presence of multiple feeding guilds (i.e., considerable functional diversity) can also be related to high habitat heterogeneity and the availability of diverse habitat types. The dominance of insectivores can be attributed to their adaptability and the high availability of insect prey in tropical landscapes (Pineda-Diez de Bonilla et al. 2012; Panda et al. 2021; Ahmad & Khan 2022**).** Abundance and diversity of insectivorous birds are also recognised as sensitive indicators of environmental health, as they rely on the complexity of vegetation and abundant insect populations (Kellermann et al. 2008). Empirical and experimental studies often associate these traits with greater temporal stability of ecosystem functions such as productivity, pest control, and nutrient cycling (Tilman 1996; Hooper et al. 2005; Nyffeler et al. 2018). Their high abundance in the ATR suggests that the area maintains a healthy trophic structure.

Results of diversity, richness, and density highlight the ecological value of mixed forest habitats, where the highest value of all three indices were recorded, likely due to their structural complexity. Various studies suggest that the abundance of forest birds is primarily driven by two distinct structural components: regenerating vegetation (a developing cohort of saplings, shrubs, and closing canopy) and legacy vegetation (retained biological structures such as large-diameter trees, snags,

Table 4. Relative abundance, occurrence, IUCN Red List status, and feeding guilds of birds recorded in Amangarh Tiger Reserve.

Order	Family	Common name	Scientific name	Relative abundance	Occurrence	IUCN Red List status	Feeding guild
Accipitriformes	Accipitridae	Changeable Hawk-Eagle	*Nisaetus cirrhatus*	0.03	0.28	LC	CR
		Cinereous Vulture	*Aegypius monachus*	0.06	0.56	NT	CR
		Crested Serpent Eagle	*Spilornis cheela*	0.38	3.61	LC	CR
		Egyptian Vulture	*Neophron percnopterus*	0.03	0.28	EN	CR
		Griffon Vulture	*Gyps fulvus*	0.03	0.28	LC	CR
		Crested Honey Buzzard	*Pernis ptilorhynchus*	0.03	0.28	LC	CR
		White-eyed Buzzard	*Butastur teesa*	0.06	0.56	LC	CR
Anseriformes	Anatidae	Green-winged Teal	*Anas crecca*	2.08	1.11	LC	OM
Bucerotiformes	Bucerotidae	Indian Grey Hornbill	*Ocyceros birostris*	3.44	23.33	LC	FR
		Great Hornbill	*Buceros bicornis*	0.29	1.39	VU	FR
		Oriental Pied Hornbill	*Anthracoceros albirostris*	0.23	1.11	LC	FR
Charadriiformes	Burhinidae	Indian Stone Curlew	*Burhinus indicus*	0.09	0.83	LC	CR
	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	0.2	1.94	LC	IN
		Yellow-wattled Lapwing	*Vanellus malabaricus*	0.35	3.06	LC	IN
Columbiformes	Columbidae	Common Emerald Dove	*Chalcophaps indica*	0.03	0.28	LC	FR
		Eurasian Collared Dove	*Streptopelia decaocto*	0.14	0.83	LC	GR
		Oriental Turtle Dove	*Streptopelia orientalis*	1.53	11.67	LC	GR
		Red Collared Dove	*Streptopelia tranquebarica*	0.09	0.83	LC	GR
		Spotted Dove	*Spilopelia chinensis*	3.07	28.06	LC	GR
		Yellow-footed Green Pigeon	*Treron phoenicopterus*	1.04	3.33	LC	FR
Coraciiformes	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	0.09	0.83	LC	PI
	Coraciidae	Oriental Dollarbird	*Eurystomus orientalis*	0.03	0.28	LC	IN
		Indian Roller	*Coracias benghalensis*	0.67	5.56	LC	IN
	Meropidae	Blue-bearded Bee-eater	*Nyctyornis athertoni*	0.06	0.56	LC	IN
		Blue-tailed Bee-eater	*Merops philippinus*	1.39	10.28	LC	IN
		Chestnut-headed Bee-eater	*Merops leschenaulti*	0.2	1.94	LC	IN
		Asian Green Bee-eater	*Merops orientalis*	2.17	17.5	LC	IN
Cuculiformes	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	0.06	0.56	LC	OM
Galliformes	Phasianidae	Grey Francolin	*Ortygornis pondicerianus*	0.4	1.67	LC	GR
		Indian Peafowl	*Pavo cristatus*	0.03	0.28	LC	OM
		Red Junglefowl	*Gallus gallus*	0.29	1.67	LC	OM
Gruiformes	Rallidae	White-breasted Waterhen	*Amaurornis phoenicurus*	0.03	0.28	LC	OM
Passeriformes	Acrocephalidae	Blyth's Reed Warbler	*Acrocephalus dumetorum*	0.32	1.11	LC	IN
	Aegithinidae	Common Iora	*Aegithina tiphia*	0.06	0.56	LC	IN
	Alaudidae	Ashy-crowned Sparrow-Lark	*Eremopterix griseus*	0.38	2.22	LC	GR
	Campephagidae	Indian Cuckooshrike	*Coracina macei*	0.06	0.28	LC	IN
		Long-tailed Minivet	*Pericrocotus ethologus*	0.38	0.56	LC	IN
		Rosy Minivet	*Pericrocotus roseus*	0.09	0.28	LC	IN
		Small Minivet	*Pericrocotus cinnamomeus*	0.09	0.56	LC	IN
	Chloropseidae	Golden-fronted Leafbird	*Chloropsis aurifrons*	0.03	0.28	LC	OM
	Cisticolidae	Ashy Prinia	*Prinia socialis*	0.09	0.83	LC	IN

Order	Family	Common name	Scientific name	Relative abundance	Occurrence	IUCN Red List status	Feeding guild
		Grey-breasted Prinia	*Prinia hodgsonii*	0.09	0.83	LC	IN
	Corvidae	House Crow	*Corvus splendens*	0.03	0.28	LC	OM
		Large-billed Crow	*Corvus macrorhynchos*	0.38	3.06	LC	OM
		Rufous Treepie	*Dendrocitta vagabunda*	0.64	5.83	LC	OM
	Dicaeidae	Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	0.09	0.83	LC	NT+FR
		Thick-billed Flowerpecker	*Pachyglossa agilis*	0.03	0.28	LC	NT+FR
	Dicruridae	Black Drongo	*Dicrurus macrocercus*	0.61	5	LC	IN
		Greater Racket-tailed Drongo	*Dicrurus paradiseus*	0.17	1.67	LC	IN
		Hair-crested Drongo	*Dicrurus hottentottus*	1.65	13.06	LC	IN
		White-bellied Drongo	*Dicrurus caerulescens*	0.17	1.67	LC	IN
	Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	0.03	0.28	LC	GR
	Fringillidae	Common Rosefinch	*Carpodacus erythrinus*	0.55	1.94	LC	GR
	Hirundinidae	Grey-throated Martin	*Riparia chinensis*	0.12	0.56	LC	IN
	Leiothrichidae	Jungle Babbler	*Argya striata*	3.5	13.33	LC	OM
	Locustellidae	West Himalayan Bush Warbler	*Locustella kashmirensis*	0.17	0.56	LC	IN
	Monarchidae	Indian Paradise Flycatcher	*Terpsiphone paradisi*	0.09	0.83	LC	IN
	Motacillidae	Grey Wagtail	*Motacilla cinerea*	0.03	0.28	LC	IN
		Tawny Pipit	*Anthus campestris*	0.06	0.56	LC	IN
		Paddyfield Pipit	*Anthus rufulus*	0.03	0.28	LC	IN
	Muscicapidae	Black Redstart	*Phoenicurus ochruros*	0.23	2.22	LC	IN
		Blue Whistling Thrush	*Myophonus caeruleus*	0.09	0.83	LC	OM
		Bluethroat	*Luscinia svecica*	0.09	0.83	LC	IN
		Grey Bush Chat	*Saxicola ferreus*	0.12	0.83	LC	IN
		Indian Robin	*Copsychus fulicatus*	0.26	2.5	LC	IN
		Oriental Magpie-Robin	*Copsychus saularis*	0.9	8.61	LC	IN
		Pied Bush Chat	*Saxicola caprata*	0.52	5	LC	IN
		Red-breasted Flycatcher	*Ficedula parva*	0.06	0.28	LC	IN
		Siberian Stonechat	*Saxicola maurus*	0.12	1.11	LC	IN
		White-rumped Shama	*Copsychus malabaricus*	0.03	0.28	LC	IN
	Nectariniidae	Crimson Sunbird	*Aethopyga siparaja*	0.12	1.11	LC	NC
		Purple Sunbird	*Cinnyris asiaticus*	1.71	12.22	LC	NC
	Oriolidae	Black-hooded Oriole	*Oriolus xanthornus*	0.87	7.5	LC	OM
		Indian Golden Oriole	*Oriolus kundoo*	0.09	0.56	LC	OM
		Maroon Oriole	*Oriolus traillii*	0.06	0.56	LC	FR
	Paridae	Cinereous Tit	*Parus cinereus*	0.93	8.06	LC	IN
	Passeridae	Yellow-throated Sparrow	*Gymnoris xanthocollis*	6.94	33.61	LC	GR
		House Sparrow	*Passer domesticus*	0.06	0.28	LC	OM
	Phylloscopidae	Blyth's Leaf Warbler	*Phylloscopus reguloides*	0.03	0.28	LC	IN
		Hume's Leaf Warbler	*Phylloscopus humei*	0.06	0.28	LC	IN
	Pycnonotidae	Black Bulbul	*Hypsipetes leucocephalus*	0.2	0.56	LC	FR+IN
		Black-crested Bulbul	*Rubigula flaviventris*	0.17	1.11	LC	FR+IN
		Himalayan Bulbul	*Pycnonotus leucogenys*	0.61	2.22	LC	FR+IN
		Red-vented Bulbul	*Pycnonotus cafer*	2.17	9.17	LC	OM
		Red-whiskered Bulbul	*Pycnonotus jocosus*	3.21	15	LC	OM

Order	Family	Common name	Scientific name	Relative abundance	Occurrence	IUCN Red List status	Feeding guild
	Sittidae	Chestnut-bellied Nuthatch	*Sitta cinnamoventris*	0.2	1.39	LC	IN
		Velvet-fronted Nuthatch	*Sitta frontalis*	0.06	0.56	LC	IN
	Stenostiridae	Grey-headed Canary-flycatcher	*Culicicapa ceylonensis*	0.12	1.11	LC	IN
	Sturnidae	Brahminy Starling	*Sturnia pagodarum*	0.84	3.33	LC	OM
		Chestnut-tailed Starling	*Sturnia malabarica*	0.32	0.83	LC	OM
		Common Myna	*Acridotheres tristis*	3.64	19.17	LC	OM
	Turdidae	Orange-headed Thrush	*Geokichla citrina*	0.06	0.56	LC	IN
	Zosteropidae	Indian White-eye	*Zosterops palpebrosus*	0.4	2.5	LC	IN
Pelecaniformes	Threskiornithidae	Red-naped Ibis	*Pseudibis papillosa*	0.2	1.11	LC	OM
Piciformes	Megalaimidae	Brown-headed Barbet	*Psilopogon zeylanicus*	2.28	20	LC	FR
		Coppersmith Barbet	*Psilopogon haemacephalus*	0.09	0.83	LC	FR
Piciformes	Picidae	Brown-capped Pygmy Woodpecker	*Yungipicus nanus*	0.14	1.11	LC	IN
		Fulvous-breasted Woodpecker	*Dendrocopos macei*	0.09	0.83	LC	IN
		Great Slaty Woodpecker	*Mulleripicus pulverulentus*	0.38	1.67	VU	IN
		Greater Flameback	*Chrysocolaptes guttacristatus*	0.17	1.39	LC	IN
		Himalyan Flameback	*Dinopium shorii*	0.2	1.67	LC	IN
		Black-rumped Flameback	*Dinopium benghalense*	0.55	5	LC	IN
		Rufous Woodpecker	*Micropternus brachyurus*	0.17	1.67	LC	IN
		Streak-throated Woodpecker	*Picus xanthopygaeus*	0.35	3.33	LC	IN
		White-naped Woodpecker	*Chrysocolaptes festivus*	0.12	1.11	LC	IN
Psittaciformes	Psittaculidae	Plum-headed Parakeet	*Psittacula cyanocephala*	32.65	174.44	LC	FR
		Rose-ringed Parakeet	*Alexandrinus Krameri*	8.39	42.22	LC	FR
		Alexandrine Parakeet	*Palaeornis eupatria*	0.06	0.28	LC	FR
		Red-breasted Parakeet	*Psittacula alexandri*	0.38	1.67	NT	FR
Unidentified	Unidentified	Unidentified		0.06	0.28		

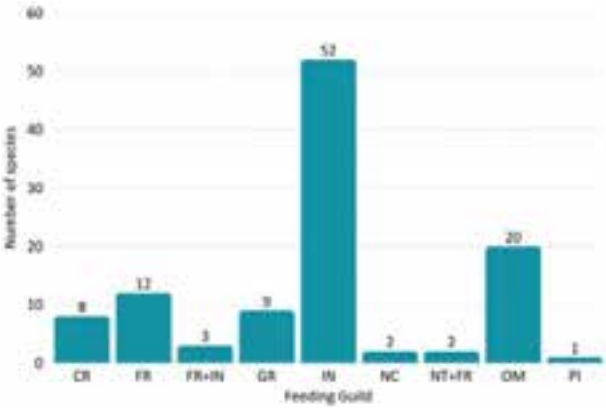

Image 3. Number of bird species belonging to different feeding guilds in Amangarh Tiger Reserve.
CR—Carnivore | FR—Frugivore | GR—Granivore | IN—Insectivore | NC—Nectivore | OM—Omnivore | PI—Piscivore.

and understory remnants) (Balestrieri et al. 2015, 2017; Czeszczewik et al. 2015; Basile et al. 2021). Mixed forests are structurally heterogeneous systems characterised by the regenerating understory layers (seedlings, saplings, and shrubs) and mature overstory trees (Gray et al. 2005; Hanle et al. 2020). Due to their high vegetation diversity, they offer more foraging opportunities, nesting sites, and microhabitats than other forest types. Additionally, vegetation complexity creates edge habitats, which tend to harbour more bird species due to the overlap of species from adjacent habitat types (Wiens 1989; Diaz 2006). Numerous studies have also highlighted that increased vegetation structure and plant diversity are strongly associated with richer and more abundant bird communities (Monkkonen 1994; Hobson & Bayne 2000a,b; Machtans & Latour 2003; Archana et al. 2024).

In contrast, the teak plantation had the lowest

diversity, and the riverbed had the lowest richness and density. Teak plantations are typically monocultures with poor understory and low vegetation heterogeneity. Such structurally simplified and deciduous habitats offer fewer resources and nesting opportunities, leading to reduced avian diversity (Hartley 2002; Waltert et al. 2004). Additionally, teak forests (in the Terai) tend to lack native floral diversity, which can result in a decline in associated faunal communities, particularly specialists that depend on diverse plant-insect interactions. Riverbeds exhibited the lowest richness and density, likely because dry riverbeds generally have sparse or low vegetation (gravel, sand, and few shrubs) and no tall vegetation, offering few perches, nesting substrates, or cover. Additionally, open riverbed ground has an extreme microclimate (intense sun, heat, wind), and exposure to predators further reduces bird survival. Despite low bird richness and density, riverbeds contribute to landscape heterogeneity, further boosting the landscape-level diversity.

The abundance of generalist species, such as the Plum-headed Parakeet, in ATR indicates that some native birds are capable of adapting to human-modified environments, particularly when essential habitat features, such as food and nesting substrates, are retained. However, this also highlights the need to monitor less adaptable, specialist species, which may decline under increasing anthropogenic pressures.

Although this study establishes ATR as an ecologically important area for bird conservation, it also underscores the need for long-term monitoring to better understand temporal changes in bird communities and the impacts of human activities on biodiversity. Long-term studies would provide deeper insights into breeding patterns, seasonal migration, habitat utilisation, and the resilience of avian populations in the face of environmental change.

The present study provides quantitative estimates of avian densities within a largely understudied region of the Terai Arc Landscape. In addition, it establishes essential baseline information on the structure and composition of local bird communities and gives a comprehensive species checklist for ATR. The study also highlights the role of habitat heterogeneity in maintaining avian diversity, revealing both the conservation value of mixed forests and the limitations of monoculture teak plantations.

Based on the study findings and supporting field observations, several site-specific management interventions are recommended for ATR. Anthropogenic pressures such as livestock grazing, fodder, and fuelwood collection should be regulated to minimise habitat degradation and facilitate habitat recovery. Livestock grazing may be managed through rotational grazing practices and the promotion of stall feeding. Restoration of degraded forest patches through the planting of native mixed forest species should be prioritized to enhance structural complexity, improve resource availability, and support a diverse bird community. The management of riverine vegetation along streams and seasonal watercourses is equally important, as these habitats provide essential foraging, nesting, and refuge sites for numerous bird species. Furthermore, reducing dependence on forest resources through the promotion of alternative energy sources, energy-efficient cocking stoves, and livestock breed improvement initiatives could help in reducing fuelwood and fodder extraction pressures. Collectively, these measures would contribute to maintaining habitat heterogeneity and help conserve biodiversity in the area.

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ARTICLE

Long-term dynamics of breeding waterbirds in relation to habitat structures in a tropical irrigation wetland: evidence from Vettangudi Bird Sanctuary, Tamil Nadu, India

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Abstract: Wetlands are critical habitats for breeding waterbirds, yet many are undergoing rapid ecological change due to hydrological alteration, land-use changes, and increasing anthropogenic pressures. We assessed long-term changes in breeding waterbird assemblages in Vettangudi Bird Sanctuary, an irrigation tank in Tamil Nadu, using data from eight breeding seasons (2012–2026). Total breeding waterbird abundance showed high interannual variability with no significant long-term trend. Nest abundance declined over time, from 396 nests in 2012–13 to as low as 163 in 2018–19, with only partial recovery to 190 in 2025–26. Breeding species richness declined, from 11 nesting species in 2016–17 to three species in 2025–26. The breeding community was dominated by Asian Openbill and Black-headed Ibis, while several species, like egrets and herons, showed declining trends or zero nesting in later years. In land-use and land-cover (LULC) analysis, water extent showed a significant negative relationship with breeding diversity during nest initiation (August: $\rho = -0.74$, $p = 0.035$), while no significant associations were observed during peak nesting (December). Nesting abundance showed a weak positive association with dense vegetation cover in both August ($\rho = 0.43$, $p = 0.30$) and December ($\rho = 0.52$, $p = 0.20$). Despite recent increases in water extent and vegetation cover, nesting abundance and species richness declined, suggesting that habitat extent alone does not determine breeding suitability. The observed declines are likely linked to changes in habitat quality, nesting substrate availability, particularly the removal of mature *Parkinsonia aculeata* trees, coupled with the increasing dominance of *Neltuma juliflora*. Hence, prioritising targeted conservation, long-term monitoring and management of stable hydrological conditions and nesting trees, and minimising disturbance during the breeding period, are key to sustaining breeding waterbird populations in such vulnerable, human-influenced wetlands.

Keywords: Colonial nesting, conservation management, habitat change, heronry, irrigation tanks, land use land cover, LULC, protected area, Sivagangai, wetland ecology.

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Author contribution: BH: Conceptualisation, writing, editing and supervision; MH: writing, editing, data management and maps; RN: data collection and curation; RV: writing.

INTRODUCTION

Globally, wetlands play a critical role in maintaining ecological balance by supporting diverse biological communities. Colonial and solitary waterbirds depend on wetlands for feeding, roosting, nesting substrates, and suitable hydrological conditions throughout the breeding cycle. Consequently, changes in wetland condition can directly influence breeding success, population persistence, and community composition of waterbirds. Despite their ecological importance, wetlands globally are declining at an alarming rate due to human-driven land-use changes, altered hydrological regimes, and climate-related impacts, which collectively contribute to waterbird population decline (Wang et al. 2023; Kundu et al. 2024).

In India, these pressures are further intensified by agricultural expansion and development, resulting in the loss and fragmentation of wetland habitats (Rashiba et al. 2022; Kundu et al. 2024). Such changes directly influence waterbird assemblages by altering habitat availability and suitability, ultimately affecting their distribution and breeding success (Charalambous et al. 2024).

The breeding ecology of waterbirds is particularly sensitive to habitat conditions. Hence, habitat selection, especially during breeding cycles, is largely shaped by hydrological conditions, availability of food resources, and access to suitable nesting sites (Li et al. 2019). Hydrological regimes influence prey accessibility, colony isolation, and nest survival, while vegetation structure determines the availability and suitability of nesting sites for colonial breeding species (Frank et al. 2021). In tropical regions, rainfall patterns further influence these processes, which regulate water levels, vegetation growth, and resource availability, leading to inter-annual variability in breeding populations (Byju et al. 2025a; Gonzalez & Fletcher 2025). Recent studies increasingly emphasize that habitat quality and structural heterogeneity may be more important determinants of breeding success than habitat extent alone (Mott et al. 2023; Charalambous et al. 2024).

Advances in remote sensing have enabled the quantification of long-term wetland habitat dynamics through land-use and land-cover (LULC) analyses (Pontieri et al. 2025). Open-water extent, vegetation structure, and canopy structure, which are directly relevant to nesting and foraging requirements of waterbirds, are important habitat variables that, with long-term breeding data, enable the assessment of how changes in water availability and dense vegetation cover relate to variation in waterbird abundance and nesting patterns (Wani et al. 2021; Zhang et al. 2023).

In peninsular India, irrigation tanks, which were originally constructed for water storage and agriculture, have evolved into significant ecological habitats sustaining diverse avifaunal assemblages (Mathibalan et al. 2026). In Tamil Nadu, several studies have highlighted the importance of such wetlands in supporting breeding colonies of waterbirds, particularly heronries consisting of mixed-species nesting aggregations (Frank et al. 2021; Byju et al. 2025b). Nevertheless, long-term assessments of waterbird breeding in these systems remain scarce, particularly studies linking breeding patterns with habitat change.

Vettangudi Bird Sanctuary, located in the Sivagangai District of Tamil Nadu, is one such irrigation tank system. Despite its ecological importance, studies on avifauna in Vettangudi have been limited to documenting species occurrence and breeding records (Subramanya 2005; Chandrasekaran et al. 2014; Mahesh et al. 2018), with no specific works on long-term changes in breeding waterbird assemblages in relation to vegetation and water extent. Understanding these relationships is particularly important because the sanctuary has undergone substantial habitat modifications over recent decades, including changes in vegetation composition, water availability, and management interventions.

Hence, the present study aimed to: 1. assess the breeding assemblage of waterbirds and species composition over the long term; 2. evaluate temporal trends in species richness and nesting abundance of breeding waterbirds; 3. examine the relationship between nesting patterns and habitat characteristics, particularly changes in LULC. We hypothesized that breeding waterbird assemblage structure and nesting abundance are influenced not only by the extent of water and vegetation, but also by habitat quality attributes such as vegetation heterogeneity, nesting substrate availability, hydrological stability, and anthropogenic disturbance. Therefore, increases in habitat extent alone may not necessarily translate into greater waterbird breeding population or nesting abundance.

MATERIALS AND METHODS

Study area

Vettangudi Bird Sanctuary in the Sivaganga District, Tamil Nadu (10.098° N, 78.539° E), covers approximately 40 ha and comprises three village freshwater irrigation tanks— Periyakollukudi (13.5 ha), Chinnakollukudi (6.2

ha), and Vettangudi (14 ha). Our study was conducted in the main waterbird-breeding tank of Periyakollukudi Tank, hereafter referred to as the Vettangudi Sanctuary.

The tank is largely rain-fed from the north-east monsoon (October–December; 330–390 mm), with supplementary rainfall from the south-west monsoon (June–September; up to ~300 mm). The adjacent paddy fields and the Vaigai River provide additional foraging habitats. Vegetation within the tanks is dominated by *Neltuma juliflora*, *Acacia nilotica*, *Parkinsonia aculeata*, and parts of the surrounding area are also invaded by *Neltuma chilensis* (BirdLife International 2026).

Data collection

Waterbird surveys were conducted over eight breeding seasons from July to January (2012–13, 2015–16, 2016–17, 2017–18, 2018–19, 2019–20, 2021–22, and 2025–26). The peak breeding season of colonial waterbirds in Tamil Nadu coincides with the northeast monsoon (Byju et al. 2025a). The study site was visited once a month during morning hours (0700–1100 h). Data collection was conducted following both direct count and block count methodologies (Bibby et al. 2000). Waterbirds were surveyed from three selected vantage points, chosen based on waterbird presence and nesting within the tank (Image 1). The perimeter counting method was employed to enumerate visible nests and to monitor foraging flights from the colony edge for nest counts (Dodd & Murphy 1995). Observations were performed using binoculars (10×50 Nikon) and spotting scopes (14 × 70 Vanguard).

Statistical analysis

We considered peak seasonal nest counts and waterbird abundance counts for data analysis. Temporal trends were assessed using the non-parametric Mann–Kendall test (MK) (Mann 1945; Kendall 1975). The magnitude of change was estimated using Sen's slope estimator, which provides the median rate of change per unit time (Sen 1968). Trend analyses were conducted for (i) total breeding waterbird abundance (summed peak counts) and (ii) species-wise counts. Only species with ≥5 observations were included in species-level analysis. Statistical significance was evaluated at $\alpha = 0.05$.

Interannual variation in species composition was assessed using hierarchical cluster analysis based on Bray–Curtis dissimilarity (Bray & Curtis 1957). Clustering was performed using the agglomerative average linkage (UPGMA) method (Sokal & Michener 1958). A combined dendrogram and heatmap were used to visualize

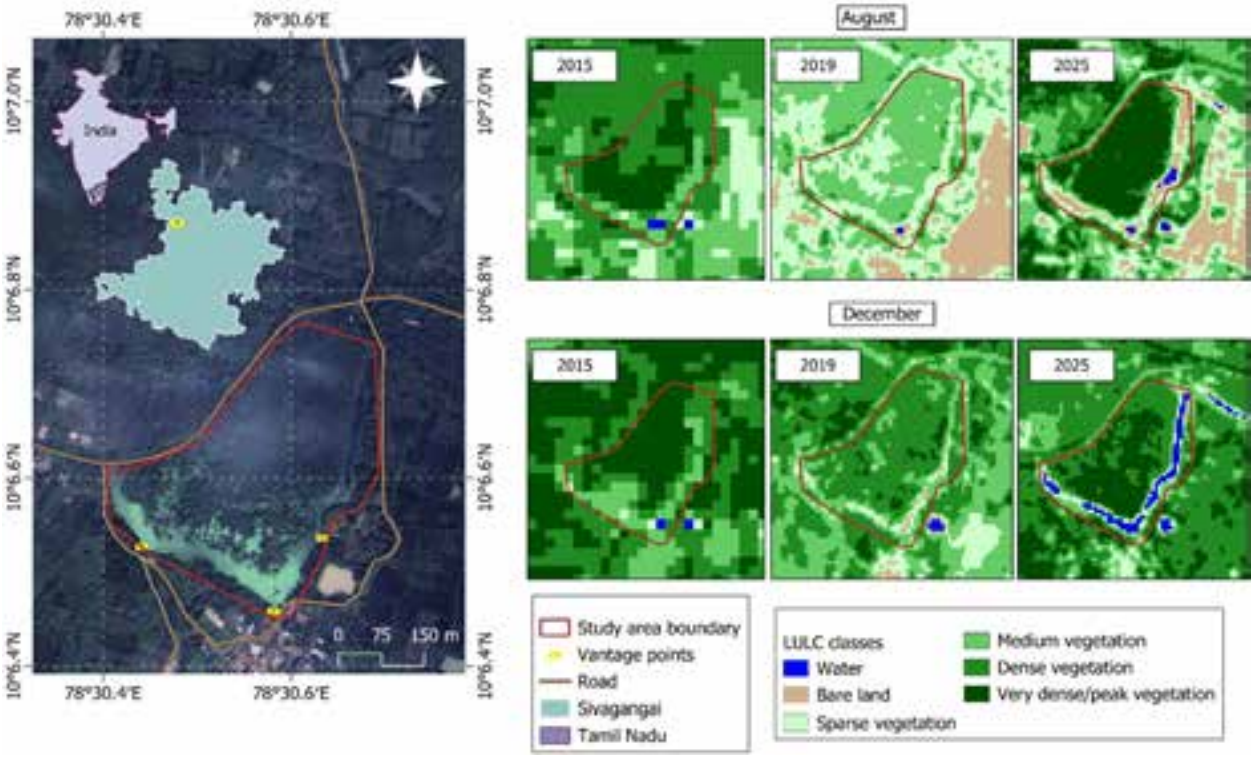

Image 1. Map showing the vantage points in the study area with the representative LULC maps of the early (2015), mid (2019) and recent (2025) study years.

similarity patterns across years.

All statistical analyses and plots were performed using R software version 4.5.1 (R core team 2026).

Land use/Land cover analysis

LULC classifications of the study area were derived from satellite imagery for August (nesting initiation) and December (peak breeding) across the study years 2012, 2015, 2016, 2017, 2018, 2019, 2021, and 2025 (which corresponds to the breeding season, as 2012 August and December are 2012–13 and similar for the other years). Surface reflectance imagery from Landsat 7 ETM+ (30 m resolution) was used for 2012, while Landsat 8 OLI/TIRS Collection 2 Level–2 data (30 m resolution) were used for 2015, 2016, 2017, and 2018. Sentinel–2 MSI Level–2A data (10 m resolution) were used for 2019, 2021, and 2025. Due to limited image availability, scenes with up to 80% cloud cover were included where necessary. Cloud, shadow, and cirrus pixels were masked using the QA_PIXEL band. Supervised classification was performed separately for each dataset in QGIS (version 3.44.1) to derive five classes: water, bare land, sparse vegetation, medium vegetation, and dense vegetation. These variables were selected because they represent key habitat attributes known to influence colonial breeding waterbirds. Water extent was defined as the total surface area (ha) classified as open water within the study area. Vegetation extent was defined as the total area (ha) occupied by moderate and dense vegetation classes. Water extent reflects hydrological conditions and potential foraging habitat; moderate vegetation represents habitat heterogeneity with shrubs, small trees, and developing nesting substrates, while dense vegetation represents mature nesting trees used by colonial nesting species. Class-wise area was calculated using pixel-based area estimation. The total area for each class was derived by summing pixel areas and converting to hectares. Based on functional relevance to breeding waterbirds, three variables— water extent, moderate vegetation, and dense vegetation were selected for subsequent statistical analysis.

Representative LULC maps were generated for 2015, 2019, and 2025 using surface reflectance imagery from Landsat 8 OLI/TIRS Collection 2 Level–2 (2015; 30 m resolution) and Sentinel–2 MSI Level–2A (2019 and 2025; 10 m resolution). Years were selected based on data availability and minimal cloud cover (less than 10%), with intervals of 3–4 years to represent early, mid, and recent periods. The classified outputs for LULC analysis were clipped to the study area boundary and validated using satellite imagery and field data.

Breeding waterbird diversity was quantified using the Shannon diversity index (H'), which incorporates both species richness and relative abundance (Shannon 1948; Magurran 2004).

To evaluate the relationship between habitat characteristics and breeding waterbird species diversity and nest abundance, Spearman's rank correlation coefficient (ρ) was used. This non-parametric method was selected due to the small sample size and the absence of normality assumptions in ecological datasets (Zar 2010). Analyses were conducted separately for August and December to distinguish between habitat influences on breeding patterns.

Limitations of the study

The analysis is based on non-continuous sampling years due to logistical constraints and restricted field access during the COVID–19 period, which restricts the ability to capture continuous interannual variability. Nest and breeding waterbird abundance was derived from single peak counts per season and therefore does not account for turnover or failed nesting attempts within the breeding period. In the LULC analysis, differences in spatial resolution between Landsat (30 m) and Sentinel–2 (10 m) imagery may influence the detection of fine-scale features, with coarser Landsat data more likely to contain mixed pixels in heterogeneous areas.

RESULTS

Waterbird and nest abundance patterns

A total of 25 waterbird species were recorded in the sanctuary. Among them, 11 waterbird species nested in the first year and reduced to three species in the last year of study. Total waterbird abundance increased from 2012–13 (n = 648) to 2016–17 (n = 990), followed by a sharp decline in subsequent years and again reached higher values in 2025–26 (n = 967) (Image 2). Total waterbird nests showed an overall declining trend. The highest number of nests was recorded in 2012–13 (396 nests), decreased to 190 in 2025–26, with inter-annual fluctuations in between (Image 3).

Species-wise abundance showed an overall increase in Asian Openbill *Anastomus oscitans* (n = 500 in 2025–26), the highest among all species. Black-headed Ibis *Threskiornis melanocephalus* abundance also increased, with a peak in 2025–26 (n = 300). Little Egret *Egretta garzetta* reached a peak of 150 individuals in 2016–17, followed by a sharp decline in later years. Species like Indian Cormorant *Phalacrocorax fuscicollis* and Little

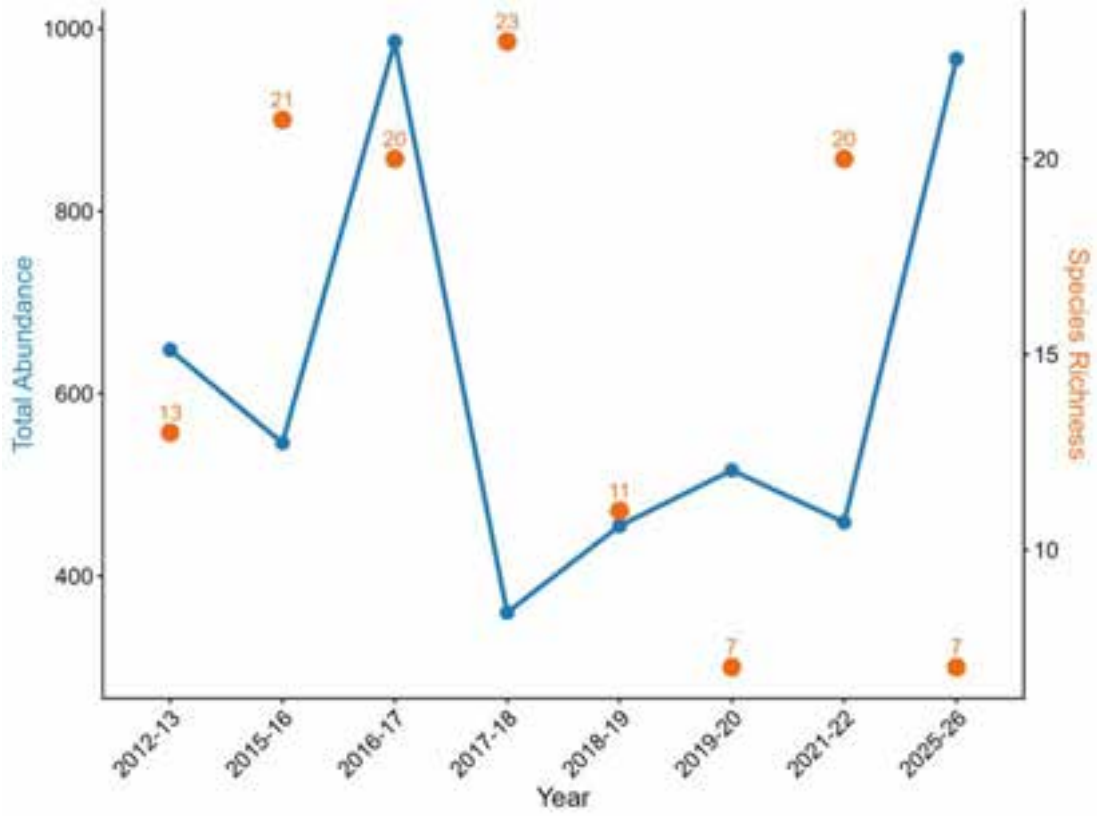

Image 2. Total waterbird abundance and overall waterbird species richness across study years in Vettangudi Bird Sanctuary.

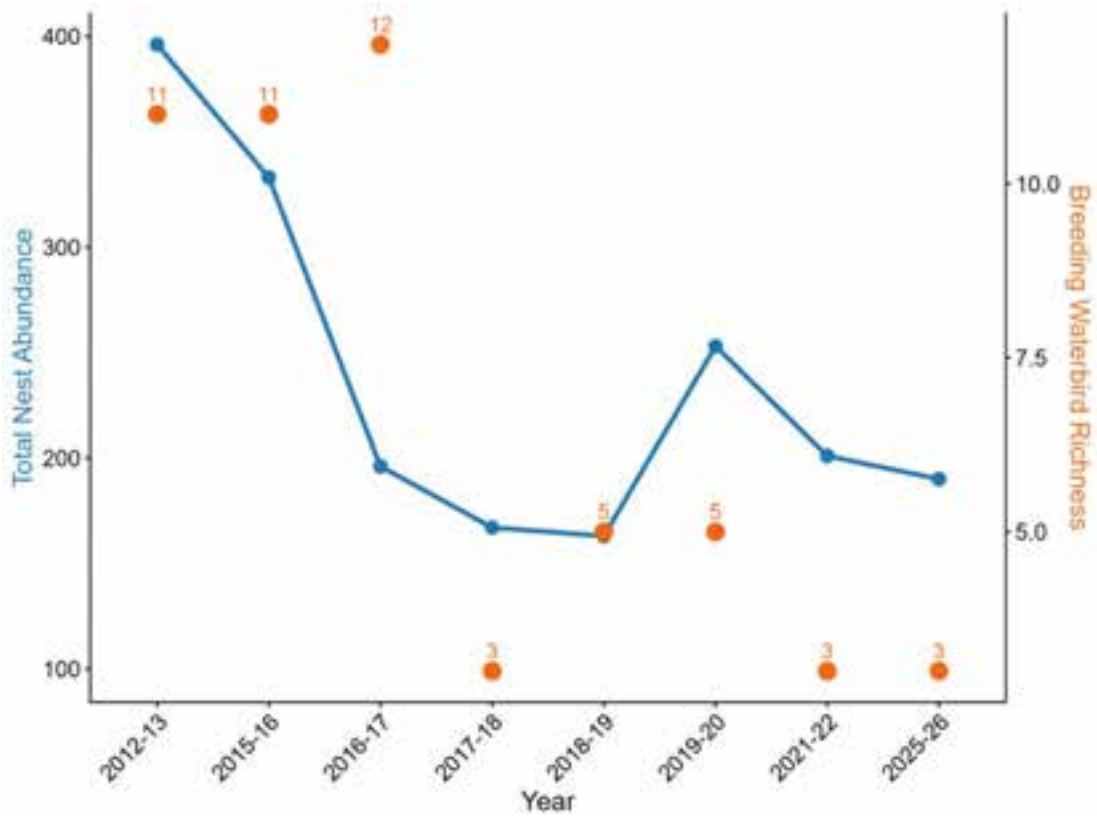

Image 3. Total nest abundance and richness of breeding waterbirds across study years in Vettangudi Bird Sanctuary.

Table 1. Shannon-Weiner diversity index values calculated for the breeding waterbirds.

Year	Shannon index
2012–13	1.701
2015–16	1.320
2016–17	1.772
2017–18	0.376
2018–19	1.310
2019–20	0.984
2021–22	0.532
2025–26	0.878

Table 2. Spearman correlation analysis of nest abundance and breeding waterbird diversity with the habitat characteristics.

Nest abundance	August		December	
	Rho	p value	Rho	p value
Water	-0.061	0.884	-0.282	0.498
Moderate vegetation	0	1	-0.595	0.132
Dense vegetation	0.428	0.299	0.523	0.196
Breeding waterbirds diversity	August		December	
	Rho	p value	Rho	p value
Water	-0.741	0.035	-0.245	0.557
Moderate vegetation	0.38	0.359	0.166	0.703
Dense vegetation	-0.238	0.582	0.023	0.976

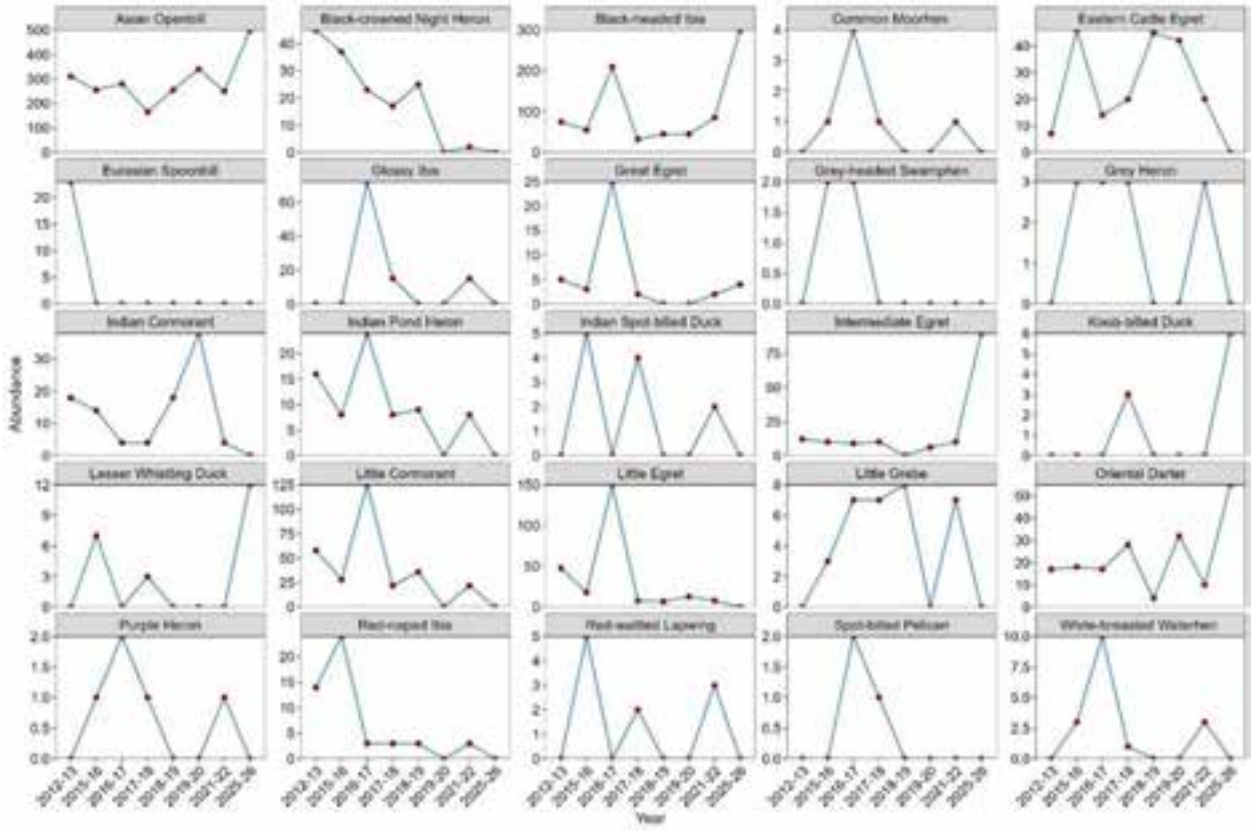

Image 4. Abundance of individual waterbird species recorded across years in Vettangudi Bird Sanctuary.

Cormorant *Microcarbo niger* did not nest in 2025–26 (Image 4).

Similarly, Asian Openbill nests were the highest, peaking at 210 in 2015–16, but declined in 2025–26. Black-headed Ibis exhibited a marked increase in nesting in 2025–26 (120 nests). Several species exhibited a complete absence of nesting in later years (after 2016–17) despite earlier occurrence. Little Egret nested from 2012–13 to 2016–17 but was absent thereafter. Black-crowned Night Heron *Nycticorax nycticorax* also declined from 28 nests (2012–13) to three nests (2017–18) and did not nest thereafter (Image 5).

Breeding waterbird community composition

The steep rank–abundance slope indicates reduced evenness, indicating strong dominance by a few species. Asian Openbill was the most abundant species, followed by Black-headed Ibis and Little Cormorant (Image

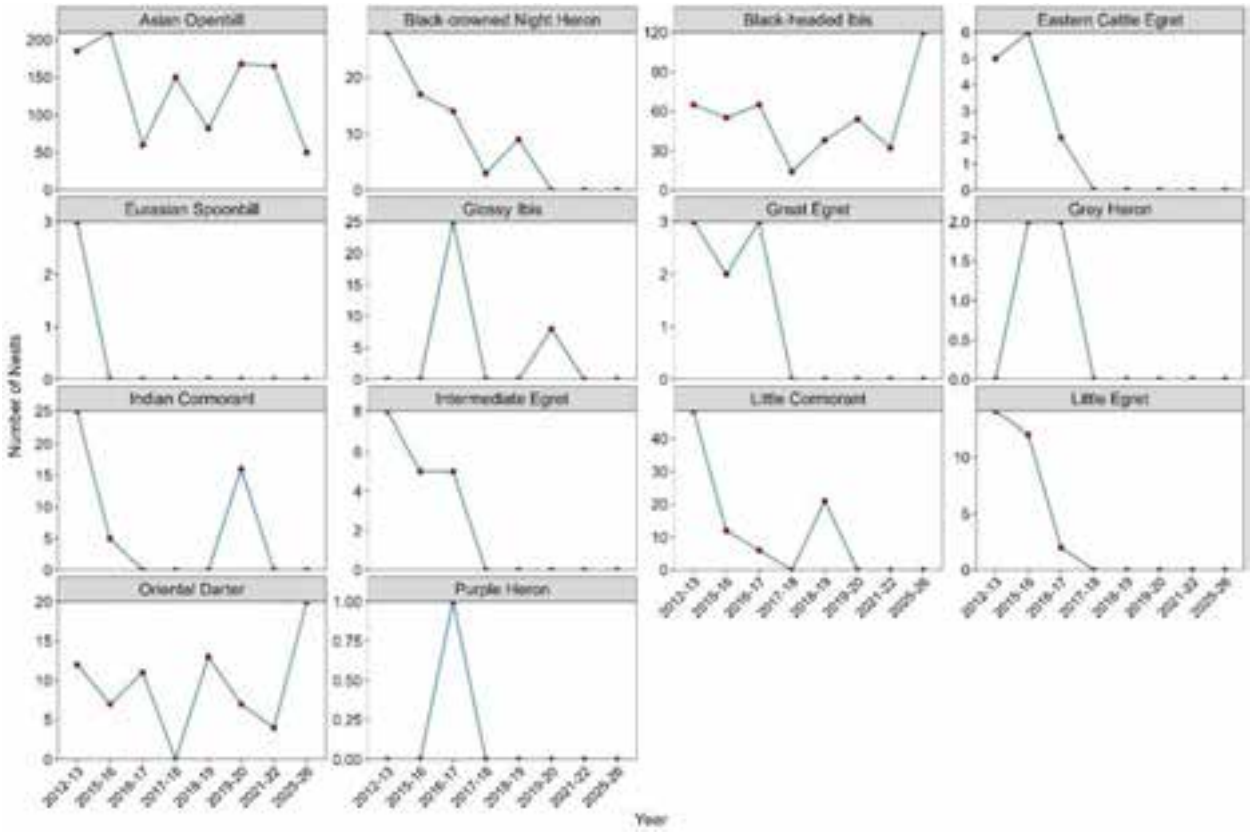

Image 5. Nest abundance of waterbird species recorded across years in Vettangudi Bird Sanctuary.

6). Bray–Curtis similarity values varied substantially among years, ranging 0.00–0.64. The highest similarity was recorded between 2017–18 and 2025–26 (0.64), followed by 2015–16 and 2025–26 (0.58). Hierarchical clustering further supported this pattern, grouping 2015–16, 2018–19, and 2021–22 together, while 2017–18 and 2025–26 formed a distinct cluster (Image 7).

Temporal trends

No significant overall temporal trend was detected in total waterbird abundance (τ = −0.071, p = 0.902), although Sen's slope indicated a marginal decline. At the species level, significant declining trends were detected for Black-crowned Night Heron (τ = −0.764, p = 0.013), Little Egret (τ = −0.618, p = 0.046), and Red-naped Ibis *Pseudibis papillosa* (τ = −0.701, p = 0.032).

Non-significant increasing trends were observed in Asian Openbill (τ = 0.109, p = 0.803), Black-headed Ibis (τ = 0.182, p = 0.618) and Oriental Darter *Anhinga melanogaster* (τ = 0.255, p = 0.454) (Image 8).

Seasonal habitat characteristics and the breeding waterbirds

LULC and breeding waterbird diversity

Shannon diversity was the highest in 2016–17 (H' = 1.772) and lowest in 2017–18 (H' = 0.376) (Table 1). In the entire study period, water extent exhibited a significant negative correlation in August (ρ = −0.74, p = 0.035), and significant relationships were observed between Shannon diversity and moderate vegetation (ρ = 0.38, p = 0.36) or dense vegetation (ρ = −0.24, p = 0.58). In December, none of the LULC variables showed significant associations with diversity, including water extent (ρ = −0.25, p = 0.56), moderate vegetation (ρ = 0.17, p = 0.70), and dense vegetation (ρ = 0.02, p = 0.98), even though water extent showed a slightly negative correlation (Table 2).

LULC and nesting abundance

In the entire period of study, no significant relationship was observed between water extent and waterbird nesting abundance in either August (ρ = −0.06, p = 0.88) or December (ρ = −0.28, p = 0.50). Similarly, moderate vegetation exhibited no association with nesting abundance in August (ρ = 0, p = 1.00), although a

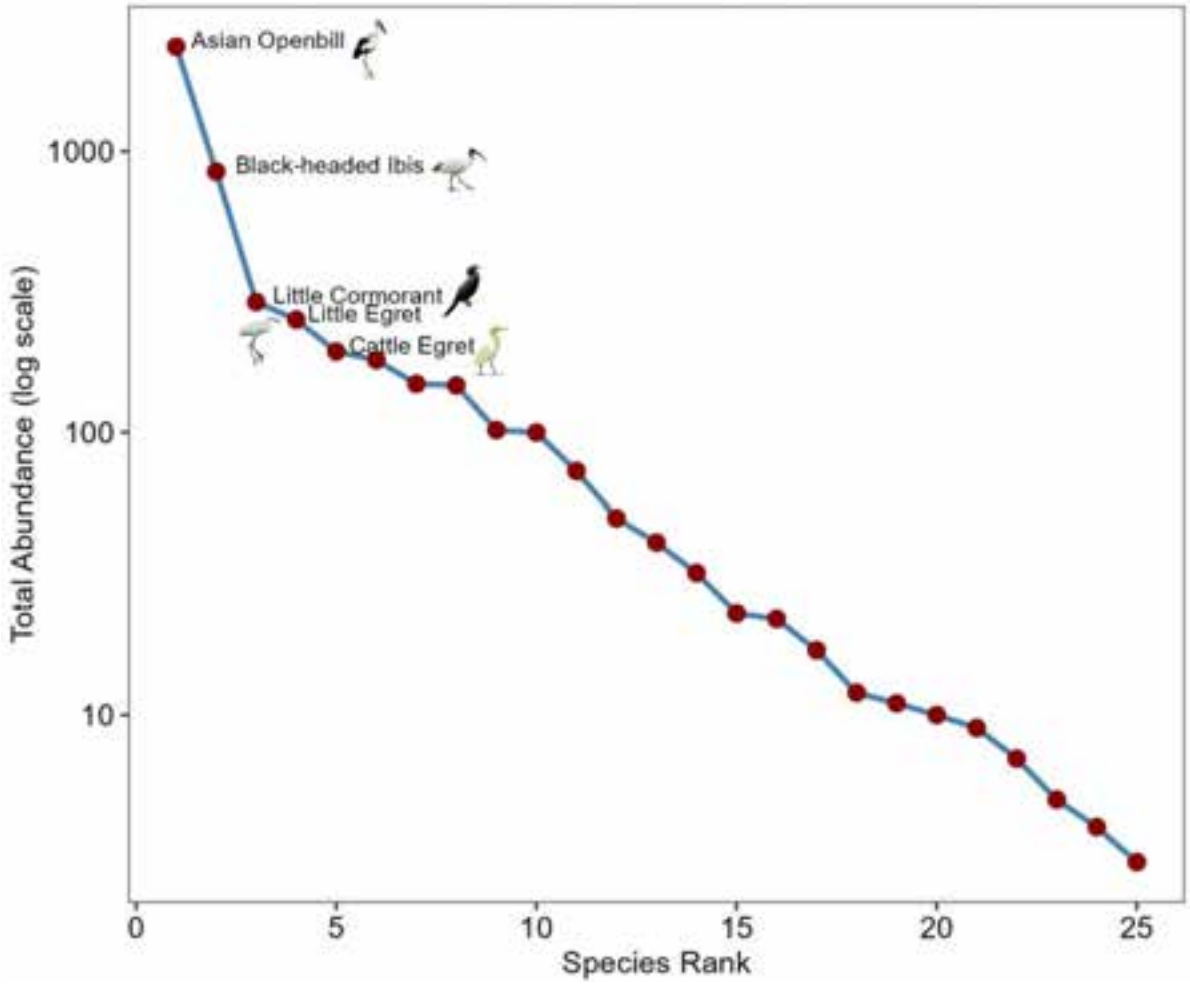

Image 6. Rank abundance curve showing the five most abundant waterbirds recorded across all years.

negative trend was observed in December (ρ = −0.60, p = 0.13). Dense vegetation showed a positive relationship with nesting abundance, with a stronger association in December (ρ = 0.52, p = 0.20) than August (ρ = 0.43, p = 0.30), with no statistical significance (Table 2).

DISCUSSION

Temporal patterns in abundance and species composition

In Vettangudi, all waterbirds showed a declining trend, except four species. Although total waterbird abundance showed considerable interannual fluctuations and no significant overall temporal trend, nesting abundance decreased from 2012–13 to 2025–26. The decline in nesting activity was accompanied by a reduction in breeding species richness, indicating that population size alone may not reflect habitat suitability for breeding waterbirds. Similar patterns have been reported from other tropical wetlands, where wetlands continue to support large numbers of foraging individuals despite experiencing reductions in nesting opportunities and breeding success (Mott et al. 2023; Wang et al. 2023).

The pronounced decline observed after 2016–17 suggests that the sanctuary underwent ecological changes affecting breeding suitability. Waterbird breeding colonies are highly sensitive to alterations in hydrological conditions, prey availability, and nesting habitat stability; hence, even relatively small changes can lead to reduced nesting effort or colony abandonment (Frank et al. 2021). The reduction in 11 nesting waterbird species during earlier years to only three species in 2025–26 indicates a possible loss of ecological resilience (Byju et al. 2025a).

Changes in assemblage composition were further reflected in the Bray-Curtis similarity analysis, which showed substantial turnover among years. The low similarity values between some breeding seasons indicate that species composition was highly dynamic

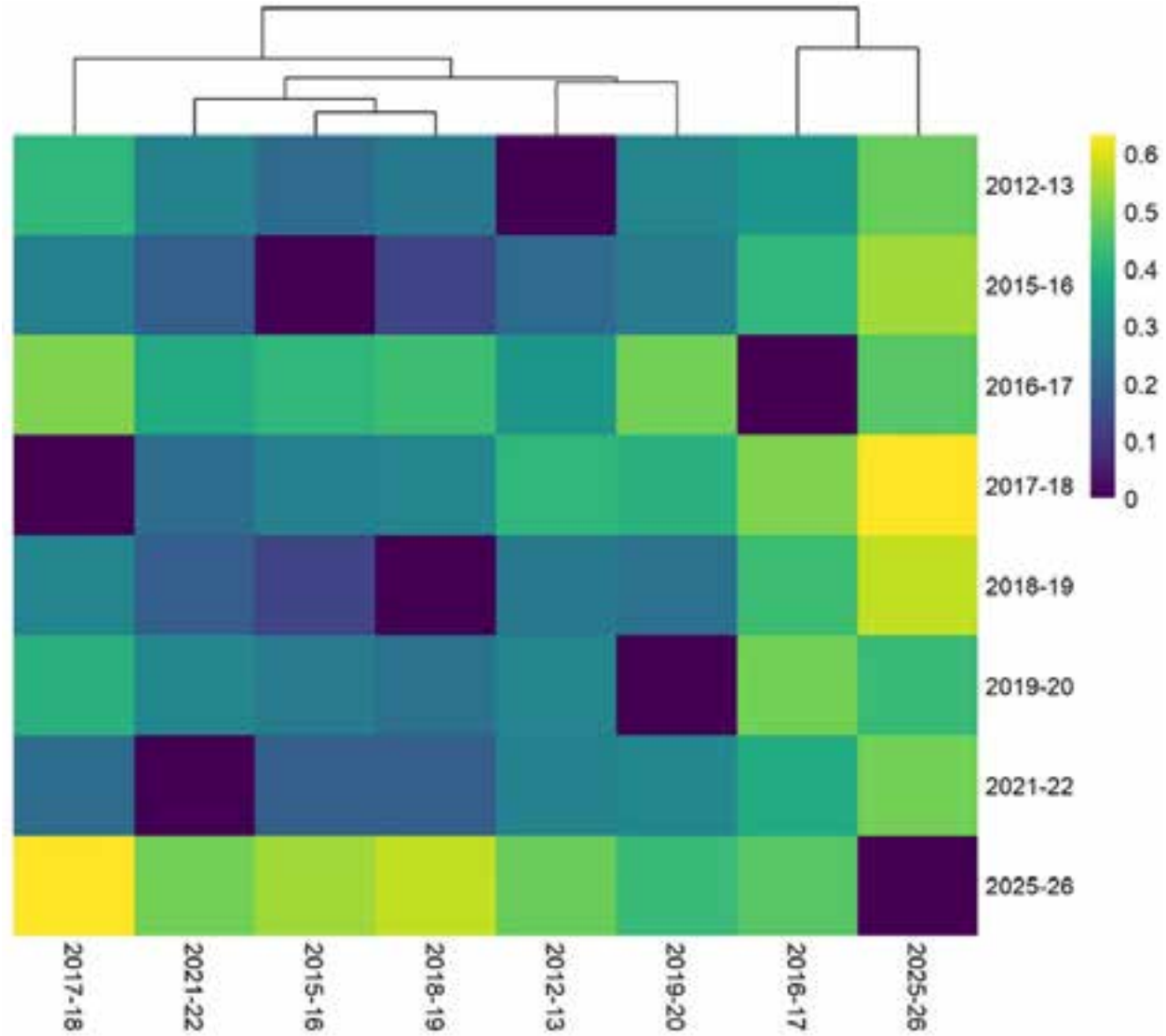

Image 7. Hierarchical cluster diagram showing the similarities in waterbird species composition among study years with Bray-Curtis values.

rather than stable through time. Such temporal turnover is often associated with fluctuations in hydrological conditions, changes in habitat structure, and shifts in resource availability that differentially affect species according to their ecological requirements (Magurran & Henderson 2010; Byju et al. 2024). The observed dominance of a few species in later years, as reflected in the steep rank–abundance curves, suggests that habitat conditions increasingly favoured a limited subset of adaptable species while becoming less suitable for others (Narwade & Ukarande 2021; Byju et al. 2023b).

Climate variability may have further contributed to these patterns. In tropical wetlands, breeding initiation is strongly influenced by rainfall, water availability, and seasonal productivity (Ramamohan & Rao 2024). Irregular rainfall and hydrological instability have been identified as major drivers of declining breeding performance in wetland birds across the Central Asian Flyway and South Asia (Mundkur et al. 2023). Consequently, the long-term changes observed in Vettangudi are likely the result of multiple interacting factors, including habitat alteration, hydrological fluctuations, and anthropogenic disturbance.

Changes in nesting tree composition/ diversity and habitat characteristics

The observed changes in colonial nesting waterbird breeding patterns appear closely linked to alterations in nesting habitat structure, reducing interspecific competition (Venkataraman et al. 2012). In Vettangudi Sanctuary, Oriental Darter, Asian Openbill and Black-headed Ibis nested on medium-sized *Acacia nilotica* and

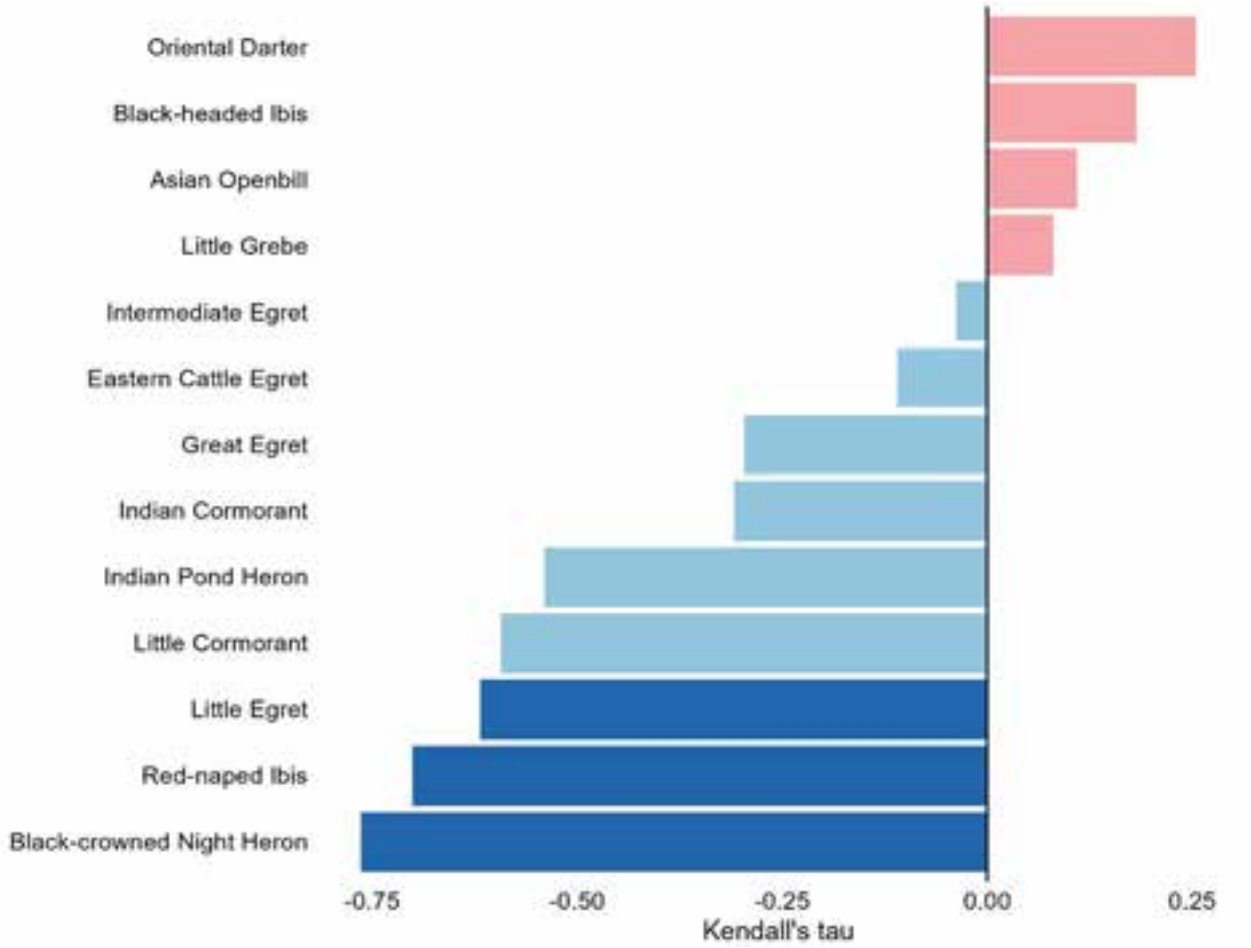

Image 8. Mann-Kendall trend analysis showing the species with positive and negative Tau values: dark blue—those with statistically significant trends | light blue and light red—no significant trend.

Neltuma juliflora trees, corroborating the findings by Frank et al. (2021), for both protection and proximity to feeding areas (Subramanya 2005). In the initial years of the study, the front layer of trees facing the waterfront had mature *Parkinsonia aculeata* trees where egrets and herons nested. In the middle years of the study period, these trees were removed for widening and deepening of the water-holding area, leading to fewer or no nesting trees for the species. Towards the later years of the study, since the newly growing young *Parkinsonia aculeata* plants are not yet suitable for nesting, the egrets and herons might have abandoned nesting in the tank for now.

The LULC analysis provides additional evidence that habitat quality may be more important than habitat extent in determining breeding responses, as clear seasonal differences were observed between August (nest initiation) and December (peak nesting) across years. Dense vegetation exhibited substantial interannual variability in August, whereas it remained comparatively more stable during December. This is reflected in relatively stronger associations between dense vegetation structure and breeding responses during December, while species diversity patterns appear more responsive to variation in water extent during the nest initiation phase. These patterns suggest that habitat conditions during the peak breeding period may exert a greater influence on nesting abundance (Ion et al. 2026).

The findings of LULC indicated that an increase in total water area alone did not correspond to improved nesting conditions, as the suitability of foraging habitats may still depend on factors such as water depth. Increased water may reduce prey availability for species that require shallow waters for foraging (Kalam & Urfi 2008). Similarly, dense vegetation did not transform into higher nesting, suggesting that the quality, structure, or vegetation heterogeneity may be more critical than their overall extent, especially with the homogenized, less diverse tree species with dominance of *Neltuma*

juliflora (Hafner 2000; Mott et al. 2023), reducing habitat suitability for several breeding species despite maintaining overall vegetation cover.

Waterbird species-specific responses

Asian Openbill and Black-headed Ibis were the only species that showed increasing abundance and maintained substantial nesting populations in recent years. Asian Openbill, in particular, remained the dominant breeding species throughout the study and reached its highest abundance during the final breeding season. The species is known for its ecological flexibility and its ability to exploit a variety of wetland habitats and agricultural landscapes, particularly where freshwater molluscs are abundant (Choi et al. 2007). Similarly, Black-headed Ibis exhibited a marked increase in both abundance and nesting activity, suggesting that the sanctuary continues to provide suitable nesting and foraging conditions for large-bodied generalist species (Narwade & Ukarande 2021).

In contrast, several species exhibited severe declines or complete cessation of breeding. Little Egret, once among the most abundant breeding species, disappeared entirely from the nesting assemblage after 2016–17, despite continued occurrence in the surrounding landscape. Likewise, Black-crowned Night Heron declined steadily and failed to nest during the later years of the study. Red-naped Ibis also showed a significant negative trend. These declines suggest that habitat changes may have affected species differently according to their nesting preferences, foraging ecology, and tolerance to disturbance. The disappearance of several egret and heron species indicates that the sanctuary may no longer provide the structural characteristics required for nesting, even if suitable foraging habitats of agricultural fields and wetlands nearby suggest a shift in breeding site selection rather than complete local population loss (Xie et al. 2019; Byju et al. 2025b). Species-specific responses have been documented where environmental changes may selectively favour adaptable species while causing declines in habitat specialists similar to other colonial waterbird assemblages (Weseloh & Green 2018).

The increasing dominance of Asian Openbill and Black-headed Ibis therefore represents a partial recovery of waterbird populations rather than a recovery of the breeding community as a whole. This shows that only a few resilient species can adapt to changing environmental conditions, increasing their dominance (Byju et al. 2025c). Increasing dominance by a few species may indicate declining habitat heterogeneity within the wetland ecosystem (Magurran & Henderson 2010).

Management Implications

The results highlight the importance of maintaining habitat quality and structural heterogeneity rather than focusing solely on increasing water availability or vegetation cover. Conservation efforts in Vettangudi should prioritize the protection and afforestation of suitable nesting trees, particularly species historically used by egrets, herons, and ibises. Habitat restoration programmes should promote a diverse assemblage of native nesting tree species rather than reliance on a single dominant species.

Hydrological changes may represent a major concern, particularly the withdrawal of water for irrigation coinciding with the breeding period. Although measures such as strengthening bunds and desilting might have improved water availability in recent years, their timing of implementation might have disrupted the breeding season in waterbirds. Breeding waterbirds in the sanctuary are affected by a combination of hydrological changes, habitat alteration, and human disturbance due to its proximity to settlements, all of which can influence nesting success and colony stability (Byju et al. 2025d).

Asian Openbill was the first among all species to start nesting in the sanctuary in all years, particularly in the 2025–26 breeding season, despite the construction work, sand mining to increase the depth of the water column, and the related disturbances by humans and machines for a few months inside the tank.

Activities such as fuelwood collection, livestock grazing, large gatherings with noise, and sometimes firecrackers by the villagers also contribute to disturbance to birds. Establishing seasonal buffer zones around active nesting colonies and increasing community participation in sanctuary management could reduce disturbance pressures while strengthening local conservation support

CONCLUSION

This study provides one of the few long-term assessments of breeding waterbird assemblages in a tropical irrigation-tank wetland of southern India. Nesting abundance and breeding species richness declined substantially over the study period, indicating a progressive reduction in the suitability of Vettangudi Bird Sanctuary as a breeding habitat for several waterbird species.

Breeding responses appear to be influenced by a combination of habitat quality attributes, including nesting substrate availability, vegetation heterogeneity,

hydrological stability, and levels of disturbance. The removal of mature nesting trees, coupled with increasing vegetation homogenization and habitat modification, likely contributed to the observed changes in species composition and nesting patterns. These results support the hypothesis that habitat quality is a more important determinant of breeding assemblage structure and nesting abundance than habitat extent alone.

The study highlights the conservation value of long-term ecological monitoring in identifying gradual changes that may not be evident from short-term surveys in Vettangudi Sanctuary. As climate variability and anthropogenic pressures continue to reshape tropical wetlands, sustaining breeding waterbird populations will require management strategies that focus not only on preserving wetland area, but also on maintaining the ecological processes and habitat complexity that underpin successful reproduction.

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ARTICLE

Avifaunal diversity with reference to their feeding guilds of Mahadare Conservation Reserve, Maharashtra, India

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Abstract: The study aims to provide baseline data on avian diversity and their feeding guilds in the Mahadare Conservation Reserve. Surveys were conducted over a period of two years, from April 2021 to May 2023, with point count methods. A total of 126 species of birds were recorded, with the order Passeriformes being dominant, followed by Accipitriformes. The findings also showed that the Insectivore guild had the highest number of species, followed by Carnivore and Omnivore guilds, respectively. Furthermore, the study also recorded high feeding guild diversity (H'_{FD} = 2.247), which provides a basis for diversity and feeding behavior. The records include seven endemic, three 'Vulnerable', and two 'Near Threatened' species, along with seven winter migrants and 23 local migrant species, highlighting the avifaunal significance of the area. The study area is surrounded by human settlements and still holds a diversity of birds, and attention is required to understand more about the guilds, along with their distribution and preferences. This first-time study documents avifaunal diversity, evaluates feeding guilds, and assesses the conservation significance of Mahadare Conservation Reserve.

Keywords: Baseline data, bird conservation, ecotone, feeding behavior, functional diversity, guild distribution, scheduled species, Western Ghats.

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Author contributions: Riya Patil contributed to conceptualisation, field surveys, data collection, and manuscript writing. Gayatri Pawar contributed to manuscript writing and editing. Sunil Bhoite contributed to conceptualisation and manuscript editing. Neha Bendre contributed to manuscript writing and editing. Aruna Shelar contributed to field surveys and data collection.

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INTRODUCTION

Birds are recognized as excellent biodiversity indicators due to their diverse range of habitats and distribution (Fraixedas et al. 2020). Since they belong to higher trophic levels in a food web, they are easily affected by the variations or effects caused on the lower levels. They are also effective bio-controllers, thus reducing their harmful effects on the environment as well as human health (Gregory et al. 2003; Manigandan et al. 2024). Food and feeding habits of birds influence their reproductive success and also provide more details about the constitution of a habitat (Molokwu-Odozi et al. 2007; Archana et al. 2024). Livestock grazing, human encroachment, extraction of resources, an increase in agricultural land, and non-native monoculture plantations lead to degradation of the habitat. These major threats are the genesis of habitat fragmentation, forming discontinuous systems and producing the edge effect in birds (Kale et al. 2010). Logging has caused significant ecosystem damage to the region, exposing the avian population to edge effects, human activities, predators, and brood parasites. The resulting loss of forest cover and leaf litter also affects the forest interior-dependent birds, which rely on closed canopy forest conditions away from habitat edge (Zakaria et al. 2014; Shafie et al. 2023).

Bird feeding guilds provide valuable insights into functional diversity and ecosystem functioning by reflecting resource use, trophic interactions, and habitat quality, making them effective indicators of ecological integrity (Naveen et al. 2026). In the biodiversity-rich Western Ghats, conservation reserves play a crucial role in safeguarding heterogeneous habitats and their avifauna, yet information on the functional structure of bird communities in many reserves remains limited. Mahadare forest lies in the northwestern part of Satara District, Maharashtra (Mohite et al. 2020). It comprises evergreen, semi-evergreen, and deciduous forest types, forming a unique ecotone region, and was declared a conservation reserve in 2022 (WLP.06.22/CR-170/F-1). The forest also consists of paddy cultivation, adding to the lepidopteran and arachnid diversity. Mahadare is a fragmented patch situated within the city and is surrounded by settlements, making it susceptible to anthropogenic activities such as logging, light pollution, and constant disturbance. It is also a part of the Western Ghats and is therefore home to a diversity of organisms. However, there exists a gap in the study of avian diversity in the region, making this the first methodical avifaunal survey of the area with an aim to document avifaunal diversity, evaluate functional composition through feeding guilds, and assess the conservation significance of Mahadare Conservation Reserve.

MATERIALS AND METHODS

Study area

Mahadare Conservation Reserve (MCR) (17.247° N, 73.963° E) situated at an average elevation of 800 m, lies in the northern Western Ghats, with temperatures ranging from 19–31 °C. Its topography includes paddy fields, human settlements, teakwood plantations, grassland, and wetlands with a total area of 105 ha. The reserve consists of two major water bodies, one being a reservoir and the second an irrigation tank (Sutar et al. 2025)

Data collection

Field surveys were carried out for a period of two years, from April 2021 to May 2023, twice a week in four-hour time blocks (600–1,000 h; 1,000–1,400 h; 1,400–1,800 h), which were covered on alternate days using the point count method and opportunistic sightings. The points were allotted empirically in the form of concentric zones (Image 1) around the point (approximately 100 m), and birds were identified with their audio and visual cues (Roy et al. 2013). A total of eight points (human settlement, teak plantations, forest area, paddy field, grassland 1, grassland 2, Mahadare Lake, Elephant Lake) were identified in the area with a minimum distance of 100 m between them. Bird observations and documentation were done with the help of a camera (Nikon D5300) and Nikon Action EX 7 x 50 binoculars. The standard field guides were referred to for species identification (Grimmett et al. 1998; Ali 2002). Feeding guilds were assigned based on field observations (Aggarwal et al. 2015; Mukhopadhyay & Mazumdar 2019; Bernard et al. 2023). The migratory status of birds was followed (Bhuyan et al. 2024). Species present year-round were classified as Resident (R), those observed only in winter were marked as Winter Migratory (WM), and those migrating locally as Local Migratory (LM). IUCN Red List categories: Vulnerable (VU), Near Threatened (NT), and Least Concern (LC) have been mentioned for the respective species (Derebe et al. 2023). The Wildlife Protection Act status: Schedule I and II were followed (Gaur et al. 2021).

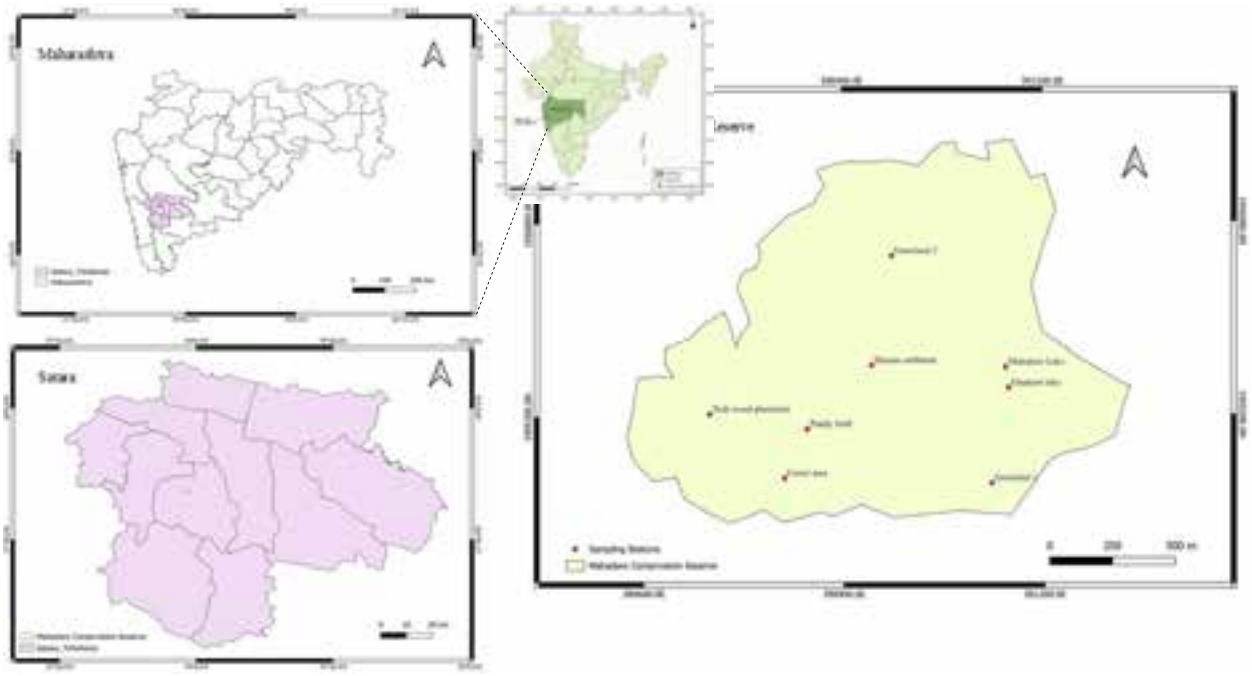

Image 1. Location map of Mahadare Conservation Reserve, Satara, Maharashtra, India.

Data analysis

The Shannon–Wiener index (Shannon & Weaver 1963) was used to understand the feeding guild richness (Gamito & Furtado 2009).

It is calculated as: $H'_{FD} = -\sum^{n}_{i=1} (p_i \log_2 p_i)$

Where p_i is the relative abundance of the i^{th} feeding group, obtained as $p_i = fg_i / \sum^{n}_{i=1} fg_i$ with fg_i representing the number of individuals belonging to the i^{th} feeding group, and n being the total number of feeding groups. This index varied between 0 and H'_{FD} maximum ($H'_{FD}max = \log_2 n$); that is, for six feeding guilds, it would range between 0–2.584. The evenness index (Pielou 1969) would help in understanding the feeding guild distribution in species with the equation: $J_{FD} = H'_{FD} / H'_{FD}max$, which varies between 0–1. All graphs (Pie charts and bar plots) were prepared in Microsoft Excel 365.

RESULTS AND DISCUSSION

In the present study, a total of 126 species of birds, belonging to 19 different orders and 55 families, were recorded (Table 1). Among these, order Passeriformes (58) represented the highest number of species, followed by order Accipitriformes (10). The fewest species were found in order Sulliformes (1), Podicipediformes (1), and Ciconiiformes (1) (Image 2). The families that recorded the highest number of species are Accipitridae (10), Muscicapidae (8) and Cuculidae (6). In addition, 124 (98%) of the recorded bird species were listed under the Wildlife Protection Act of 1972. Of these, a total of 17 (13%) birds were categorised under Schedule I and 107 (84%) under Schedule II. According to the IUCN Red List criteria, two 'Near Threatened' species, Asian Woolly-necked Stork *Ciconia episcopus*, and Indian Courser *Cursorius coromandelicus*, and three 'Vulnerable' species, Tawny Eagle *Aquila rapax*, River Tern *Sterna aurantia*, and Great Hornbill *Buceros bicornis*, were observed. The remaining 121 species were listed under 'Least Concern'.

Additionally, the study also reports seven species in the region that are endemic to India, namely Indian Scimitar-Babbler *Pomatorhinus horsfieldii*, Indian Yellow Tit *Machlolophus aplonotus*, Spot-breasted Fantail *Rhipidura albogularis*, White-cheeked Barbet *Psilopogon viridis*, Grey Junglefowl *Gallus sonneratii*, Malabar Lark *Galerida malabarica*, and Malabar Whistling-Thrush *Myophonus horsfieldii* (Table 1). The studies of Sayyed (2016) recorded 208 avian species across 10,48,000 ha of Satara District, whereas our study, conducted within just 105 ha, recorded 126 avian species, which accounts for approximately 61% of the total species reported in the district. This underscores the ecological importance of the present habitat. The nearest Important Bird and Biodiversity Area (IBA) site, Koyna Wildlife Sanctuary

Table 1. Checklist of birds from Mahadare Conservation Reserve, Satara, Maharashtra, India.

Order	Family	Scientific name	Common name	IUCN Red List status	Migratory status (for India)	Feeding guild
Podicipediformes	Podicipedidae	*Tachybaptus ruficollis* (Pallas, 1764) [II]	Little Grebe	LC	LM	Car
Sulliformes	Phalacrocoracidae	*Microcarbo niger* (Vieillot, 1817) [II]	Little Cormorant	LC	R	Car
Pelicaniformes	Ardeidae	*Ardea cinerea* (Linnaeus, 1758) [II]	Grey Heron	LC	LM	Car
		Nycticorax nycticorax (Linnaeus, 1758) [II]	Black-crowned Night Heron	LC	LM	Car
		Ardeola grayii (Sykes, 1832) [II]	Indian Pond Heron	LC	R	Car
		Ardea coromanda (Linnaeus, 1758) [II]	Eastern Cattle Egret	LC	R	Car
		Egretta garzetta (Linnaeus, 1766) [II]	Little Egret	LC	R	Car
	Threskiornithidae	*Threskiornis melanocephalus* (Latham, 1790) [II]	Black-headed Ibis	LC	LM	Car
		Pseudibis papillosa (Temminck, 1824) [II]	Red-naped Ibis	LC	LM	Car
Ciconiiformes	Ciconiidae	*Ciconia episcopus* (Boddaert, 1783) [II]	Asian Woolly-necked Stork	NT	LM	Car
Anseriformes	Anatidae	*Anas poecilorhyncha* (Forster, 1781) [II]	Indian Spot-billed duck	LC	R	Omn
		Tadorna ferruginea (Pallas, 1764) [II]	Ruddy Shelduck	LC	LM	Omn
		Anas crecca (Linnaeus, 1758) [II]	Green-winged Teal	LC	WM	Omn
Accipitriformes	Accipitridae	*Elanus caeruleus* (Desfontaines, 1789) [II]	Black-winged kite	LC	R	Car
		Pernis ptilorhynchus (Temminck, 1821) [II]	Crested Honey Buzzard	LC	R	Car
		Milvus migrans (Boddaert, 1783) [II]	Black Kite	LC	R	Car
		Haliastur indus (Boddaert, 1783) [I]	Brahminy Kite	LC	R	Car
		Tachyspiza badia (Gmelin, JF, 1788) [I]	Shikra	LC	R	Car
		Aquila rapax (Temminck, 1828) [I]	Tawny Eagle	VU	LM	Car
		Nisaetus cirrhatus (Gmelin, JF, 1788) [I]	Changeable Hawk- Eagle	LC	R	Car
		Aquila fasciata (Vieillot, 1822) [I]	Bonelli's Eagle	LC	LM	Car
		Ictinaetus malaiensis (Temminck, 1822) [I]	Black Eagle	LC	LM	Car
		Spilornis cheela (Latham, 1790) [I]	Crested Serpent Eagle	LC	R	Car
Falconiformes	Falconidae	*Falco tinnunculus* (Linnaeus, 1758) [II]	Common Kestrel	LC	R	Car
		Falco peregrinus (Tunstall, 1771) [I]	Peregrine Falcon	LC	WM	Car
Galliformes	Phasianidae	*Perdicula asiatica* (Latham, 1790) [II]	Jungle Bush Quail	LC	R	Gran
		Gallus sonneratii (Temminck, 1813) [I*]	Grey Junglefowl	LC	R	Gran
		Pavo cristatus Linnaeus, 1758 [I]	Indian Peafowl	LC	R	Gran
Gruiformes	Rallidae	*Amaurornis phoenicurus* (Pennant, 1769) [II]	White-breasted waterhen	LC	R	Omn
		Porphyrio poliocephalus (Latham, 1801) [II]	Grey-headed swamphen	LC	R	Omn
Charadriiformes	Recurvirostridae	*Himantopus himantopus* (Latham, 1801) [II]	Black-winged Stilt	LC	LM	Car
	Glareolidae	*Cursorius coromandelicus* (Gmelin, JF, 1789) [I]	Indian Courser	NT	LM	Car
	Charadriidae	*Vanellus indicus* (Boddaert, 1783) [II]	Red-wattled Lapwing	LC	R	Car
	Laridae	*Sterna aurantia* (Gray, JE), 1831 [I]	River Tern	VU	LM	Car
Columbiformes	Columbidae	*Treron phoenicopterus* (Latham, 1790) [II]	Yellow-footed Green Pigeon	LC	R	Gran
		Columba livia (Gmelin JF, 1789)	Rock Pigeon	LC	R	Gran
		Spilopelia chinensis (Scopoli, 1786) [II]	Spotted Dove	LC	R	Gran
		Spilopelia senegalensis (Linnaeus, 1766) [II]	Laughing Dove	LC	R	Gran
		Chalcophaps indica (Linnaeus, 1758) [II]	Asian Emerald Dove	LC	LM	Gran
Psittaciformes	Psittaculidae	*Psittacula krameri* (Scopoli, 1769) [II]	Rose-ringed Parakeet	LC	R	Frug
		Psittacula eupatria (Linnaeus, 1766) [II]	Alexandrine Parakeet	LC	R	Frug
		Psittacula cyanocephala (Linnaeus, 1766) [II]	Plum-headed Parakeet	LC	R	Frug
		Loriculus vernalis (Sparrman, 1787) [II]	Vernal Hanging Parrot	LC	LM	Frug

Order	Family	Scientific name	Common name	IUCN Red List status	Migratory status (for India)	Feeding guild
Cuculiformes	Cuculidae	*Cuculus micropterus* (Gould, 1838) [II]	Indian Cuckoo	LC	R	Omn
		Hierococcyx varius (Vahl, 1797) [II]	Common Hawk Cuckoo	LC	R	Ins
		Cacomantis passerinus (Vahl, 1797) [II]	Grey-bellied Cuckoo	LC	LM	Ins
		Clamator coromandus (Linnaeus, 1766) [II]	Chestnut-winged Cuckoo	LC	LM	Omn
		Eudynamys scolopaceus (Linnaeus, 1758) [II]	Asian Koel	LC	R	Omn
		Centropus sinensis (Stephens, 1815) [II]	Greater Coucal	LC	R	Omn
Strigiformes	Tytonidae	*Tyto javanica* (Scopoli, 1769) [I]	Eastern Barn Owl	LC	R	Car
	Strigidae	*Bubo bengalensis* (Franklin, 1831) [I]	Rock Eagle- Owl	LC	R	Car
		Athene brama (Temminck, 1821) [II]	Spotted Owlet	LC	R	Car
Caprimulgiformes	Apodidae	*Apus affinis* (Hodgson, 1837) [II]	Little Swift	LC	R	Ins
	Caprimulgidae	*Caprimulgus indicus* (Latham, 1790) [II]	Jungle Nightjar	LC	LM	Ins
Coraciiformes	Alcedinidae	*Ceryle rudis* (Linnaeus, 1758) [II]	Pied Kingfisher	LC	R	Car
		Alcedo atthis (Linnaeus, 1758) [II]	Common Kingfisher	LC	R	Car
		Halcyon smyrnensis (Linnaeus, 1758) [II]	White-throated Kingfisher	LC	R	Car
	Meropidae	*Merops orientalis* (Latham, 1801) [II]	Asian Green Bee-eater	LC	R	Ins
	Coraciidae	*Coracias benghalensis* (Linnaeus, 1758) [II]	Indian Roller	LC	LM	Omn
Bucerotiformes	Upupidae	*Upupa epops* (Linnaeus, 1758) [II]	Common Hoopoe	LC	LM	Omn
	Bucerotidae	*Buceros bicornis* (Linnaeus, 1758) [I]	Great Hornbill	VU	LM	Frug
		Ocyceros birostris (Scopoli, 1786) [II]	Indian Grey Hornbill	LC	R	Frug
Piciformes	Megalaimidae	*Psilopogon hemacephalus* (S. Müller, 1776) [II]	Coppersmith Barbet	LC	R	Frug
		Psilopogon zeylanicus (Gmelin JF, 1788) [II]	Brown-headed Barbet	LC	R	Frug
		Psilopogon viridis (Boddaert, 1783) [II]*	White-cheeked Barbet	LC	R	Frug
	Picidae	*Leiopicus mahrattensis* (Latham, 1801) [I]	Yellow-crowned Woodpecker	LC	R	Ins
		Dinopium benghalense (Linnaeus, 1758) [II]	Black-rumped Flameback	LC	R	Ins
		Dryocopus javensis (Horsfield, 1821) [II]	White-bellied Woodpecker	LC	R	Ins
Passeriformes	Alaudidae	*Galerida malabarica* (Scopoli, 1786) [II]*	Malabar Lark	LC	LM	Omn
	Hirundinidae	*Hirundo rustica* Linnaeus, 1758 [II]	Barn Swallow	LC	R	Ins
		Petrochelidon fluvicola (Blyth, 1855) [II]	Streak-throated Swallow	LC	R	Ins
		Hirundo smithii (Leach, 1818) [II]	Wire-tailed Swallow	LC	R	Ins
	Laniidae	*Lanius schach* (Linnaeus, 1758) [II]	Long-tailed Shrike	LC	R	Ins
	Oriolidae	*Oriolus kundoo* (Sykes, 1832) [II]	Indian Golden Oriole	LC	R	Omn
	Dicruridae	*Dicrurus macrocercus* (Vieillot, 1817) [II]	Black Drongo	LC	R	Omn
		Dicrurus leucophaeus (Vieillot, 1817) [II]	Ashy Drongo	LC	WM	Omn
		Dicrurus caerulescens (Linnaeus, 1758) [II]	White-Bellied Drongo	LC	R	Omn
	Sturnidae	*Sturnia pagodarum* (Gmelin, JF, 1789) [II]	Brahminy Starling	LC	R	Omn
		Acridotheres tristis (Linnaeus, 1766) [II]	Common Myna	LC	R	Omn
		Acridotheres fuscus (Wagler, 1827) [II]	Jungle Myna	LC	R	Omn
	Corvidae	*Dendrocitta vagabunda* (Latham, 1790) [II]	Rufous Treepie	LC	R	Ins
		Corvus splendens (Vieillot, 1817)	House Crow	LC	R	Omn
		Corvus macrorhynchos Wagler, 1827 [II]	Large-billed Crow	LC	R	Omn
	Vangidae	*Tephrodornis pondicerianus* (Gmelin JF, 1789) [II]	Common Woodshrike	LC	R	Omn
	Campephagidae	*Lalage melanoptera* (Rüppell, 1839) [II]	Black-headed Cuckooshrike	LC	LM	Omn
		Pericrocotus speciosus (Latham, 1790) [II]	Scarlet Minivet	LC	R	Ins
		Pericrocotus cinnamomeus (Linnaeus, 1766) [I]	Small Minivet	LC	R	Ins

Order	Family	Scientific name	Common name	IUCN Red List status	Migratory status (for India)	Feeding guild
Passeriformes	Aegithinidae	*Aegithina tiphia* (Linnaeus, 1758) II	Common Iora	LC	R	Ins
	Pycnonotidae	*Pycnonotus cafer* (Linnaeus, 1766) II	Red-vented Bulbul	LC	R	Omn
		Pycnonotus jocosus (Linnaeus, 1758) II	Red-whiskered Bulbul	LC	R	Omn
	Pellorneidae	*Pellorneum ruficeps* (Swainson, 1832) II	Puff-throated Babbler	LC	R	Ins
	Timaliidae	*Dumetia hyperythra* (Franklin, 1831) II	Tawny-bellied Babbler	LC	R	Omn
		Pomatorhinus horsfieldii (Sykes, 1832) II*	Indian Scimitar- Babbler	LC	R	Omn
	Leiothrichidae	*Alcippe poioicephala* (Jerdon, 1841) II	Brown-cheeked Fulvetta	LC	R	Ins
		Argya striata (Dumont, 1823) II	Jungle Babbler	LC	R	Omn
	Muscicapidae	*Muscicapa muttui* (Layard, 1854) II	Brown-breasted Flycatcher	LC	R	Ins
		Ficedula parva (Bechstein, 1792) II	Red-breasted Flycatcher	LC	WM	Ins
		Ficedula superciliaris (Jerdon, 1840) II	Ultramarine Flycatcher	LC	WM	Ins
		Cyornis tickelliae (Blyth, 1843) II	Tickell's Blue Flycatcher	LC	R	Ins
		Luscinia svecica (Linnaeus, 1758) II	Bluethroat	LC	WM	Ins
		Copsychus fulicatus (Linnaeus, 1766) II	Indian Robin	LC	R	Ins
		Myophonus horsfieldii (Vigors, 1831) II*	Malabar Whistling Thrush	LC	R	Ins
		Copsychus saularis (Linnaeus, 1758) II	Oriental Magpie Robin	LC	R	Ins
	Monarchidae	*Terpsiphone paradisi* (Linnaeus, 1758) II	Indian Paradise-flycatcher	LC	R	Ins
		Hypothymis azurea (Boddaert, 1783) II	Black-naped Monarch	LC	R	Ins
	Rhipiduridae	*Rhipidura albogularis* (Lesson, 1831) II*	Spot-breasted Fantail	LC	R	Ins
	Cisticolidae	*Prinia buchanani* (Blyth, 1844) I	Rufous-fronted Prinia	LC	R	Ins
		Prinia inornata (Sykes, 1832) II	Plain Prinia	LC	R	Ins
		Prinia socialis (Sykes, 1832) II	Ashy Prinia	LC	R	Ins
		Orthotomus sutorius (Pennant, 1769) II	Common Tailorbird	LC	R	Ins
	Turdidae	*Turdus simillimus* (Jerdon, 1839) II	Indian Blackbird	LC	R	Ins
		Geokichla citrina (Latham, 1790) II	Orange-headed Thrush	LC	R	Ins
	Paridae	*Parus cinereus* (Vieillot, 1818) II	Cinereous Tit	LC	R	Ins
		Machlolophus aplonotus (Blyth, 1847) II*	Indian Yellow Tit	LC	R	Ins
		Dicaeum erythrorhynchos (Latham, 1790) [2] II	Pale-billed Flowerpecker	LC	R	Nect
	Motacillidae	*Motacilla cinerea* (Tunstall, 1771) II	Grey Wagtail	LC	WM	Car
		Motacilla maderaspatensis (Gmelin, JF, 1789) II	White-browed Wagtail	LC	R	Car
	Nectariniidae	*Leptocoma zeylonica* (Linnaeus, 1766) II	Purple-rumped Sunbird	LC	R	Nect
		Cinnyris asiaticus (Linnaeus, 1766) II	Purple Sunbird	LC	R	Nect
	Zosteropidae	*Zosterops palpebrosus* (Temminck, 1824) II	Indian White-eye	LC	R	Ins
	Passeridae	*Gymnoris xanthocollis* (Burton, 1838) II	Yellow-throated Sparrow	LC	R	Omn
		Passer domesticus (Linnaeus, 1758) II	House Sparrow	LC	R	Omn
	Ploceidae	*Ploceus philippinus* (Linnaeus, 1766) II	Baya Weaver	LC	R	Gran
	Emberizidae	*Emberiza lathami* (Gray JE, 1831) II	Crested Bunting	LC	R	Gran
	Estrildidae	*Amandava amandava* (Linnaeus, 1758) II	Red Avadavat	LC	R	Gran
		Lonchura punctulata (Linnaeus, 1758) II	Scaly-breasted Munia	LC	R	Gran

IUCN—International Union for Conservation of Nature | LC—Least Concern | NT—Near Threatened | VU—Vulnerable | R—Resident | Local Migratory—LM | Winter Migratory—WM | Car—Carnivore | Omn—Omnivore | Ins—Insectivore | Frug—Frugivore | Gran—Granivore | Nect—Nectivore | *—Endemic to India | Wildlife Protection (Amendment) Act, 2022: I—Schedule I | II—Schedule II.

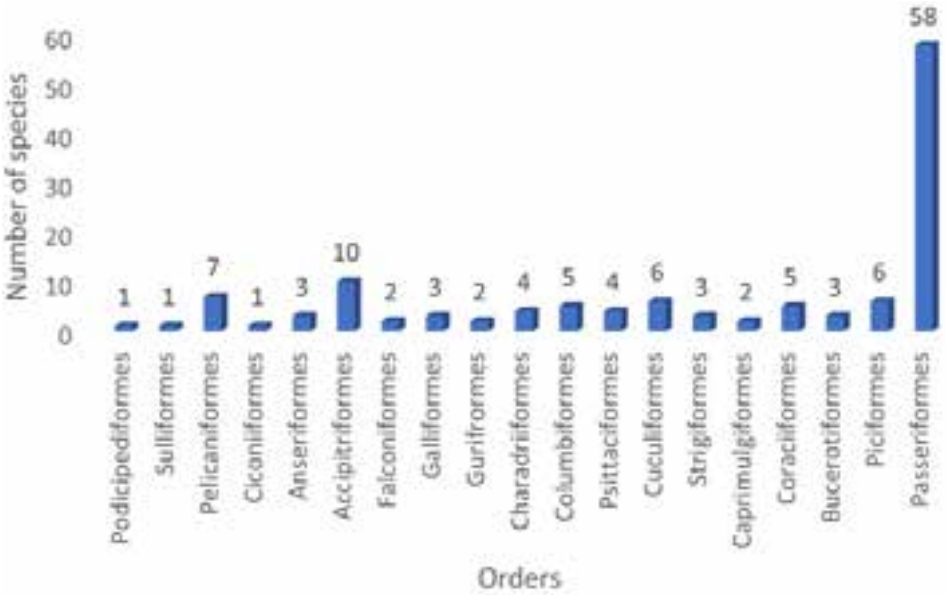

Image 2. Order-wise composition of avian species at Mahadare Conservation Reserve.

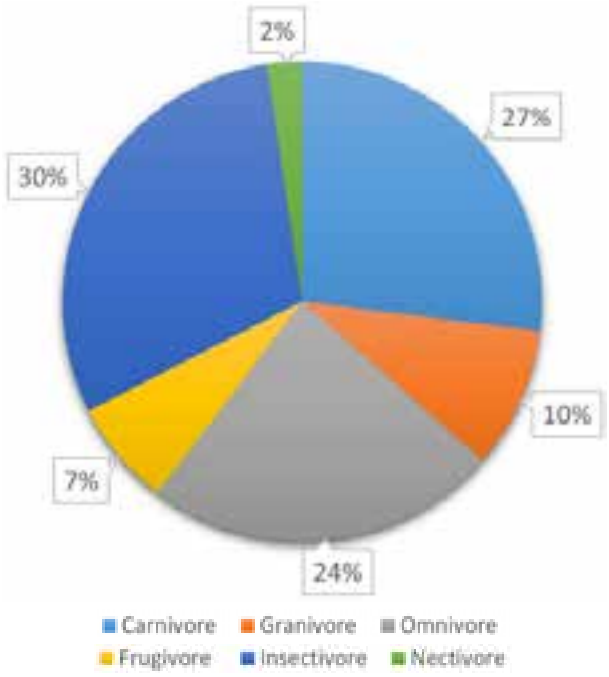

Image 3. Percentage of avian species based on feeding guilds at Mahadare Conservation Reserve.

(Mehta 2012), recorded 269 species of birds (Sreekumar & Bhatnagar 2021). The present study documented 96 (76%) birds resident to the Indian subcontinent, 23 (18%) Local Migratory, and seven (5%) Winter Migratory species.

Birds observed during the study are placed under six different categories according to their dietary preferences as Insectivore, Carnivore, Nectivore, Omnivore, Granivore, and Frugivore. MCR consists of a mosaic of different habitats (Image 3). These include two freshwater bodies and small seasonal streams. Surrounding these water bodies are patches of dry deciduous forest characterized by an open canopy and seasonal leaf shedding. The landscape also features patches of semi-evergreen and evergreen forest. In addition, grasslands and cultivated paddy fields add to the habitat heterogeneity. The diverse habitat structures within the study area influence the coexistence of avian species (Panda et al. 2021; Byju et al. 2025; Kumar et al. 2025). It was seen that the Insectivore guild (38) comprised the highest number of bird species, followed by Carnivores (34), Omnivores (30), Granivores (12), Frugivores (9), whereas the Nectivore Guild (3) made up the least number of species (Image 4). The feeding guild diversity index (H'_{FD} = 2.25) and the evenness index (J_{FD}= 0.87) show high feeding diversity with a slightly uneven distribution, as Insectivorous and Carnivorous guilds dominate (Ghosh et al. 2022).

The feeding behaviour in birds varies in accordance with resource availability and niche partitioning, eventually providing insights into the habitat. Mahadare, with its diverse habitats, comprises 51 reptile and nine amphibian species (Dhale et al. 2024). These species serve as an important food source for carnivorous avian species, especially for migratory raptors such as the Peregrine Falcon *Falco peregrinus* (R. Patil per. obs.

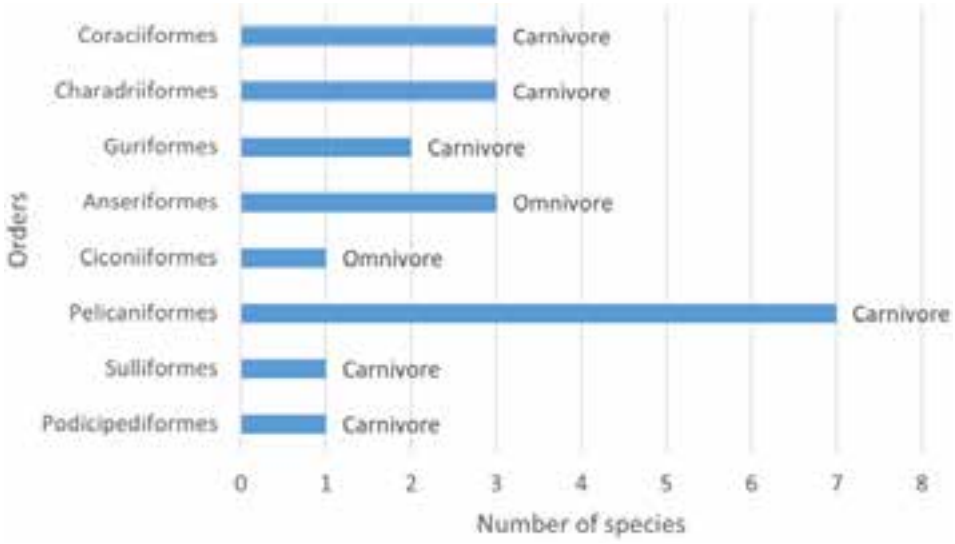

Image 4. Guild separation in aquatic feeders at Mahadare Conservation Reserve.

2022). Takahashi & Ohkawara (2007) and Wood et al. (2010) stated that paddy fields are suitable habitats for breeding and foraging of aquatic and terrestrial birds. We have observed that the ploughed soil of paddy fields attracts birds such as Blue-cheeked Bee-eater *Merops orientalis*, Tickell's Blue Flycatcher *Cyornis tickelliae*, Red-vented Bulbul *Pycnonotus cafer*, Indian Paradise Flycatcher *Terpsiphone paradisi*, and Black-naped Monarch *Hypothymis azurea* that feed on the insect diversity of paddy fields. MCR consists of multiple small streams, a natural reservoir, and an irrigation tank. These waterbodies support rich aquatic biodiversity with 22 species of fish, which serve as a food source for the fish-eating birds (Mohite et al. 2020). The waterbodies host 21 species of aquatic birds from two feeding guilds: Carnivore (16) and Omnivore (5). Species from the Carnivorous guild are mainly dependent on fishes and amphibians as their primary source of food, along with invertebrates such as snails, worms, and crustaceans. Aquatic birds such as Indian Spot-billed Duck *Anas poecilorhyncha*, Ruddy Shelduck *Tadorna ferruginea*, and Green-winged Teal *Anas crecca* of the Omnivorous guild feed on young shoots and seeds of grasses of the aquatic vegetation, along with molluscs and other invertebrates (Image 4).

Butterflies act as a prey base for many avifaunal species . Resendiz-Infante & Gauthier (2020) mentioned observations referring to the seasonal diversity of birds, which often reflects the timing of breeding in accordance with the abundance of caterpillars. Sutar et al. (2025) recorded 184 butterfly species from MCR, which supports the observation of rich insect availability. Similarly, the present study showed bird count at its peak during winter months (Oct-Jan), coinciding with high butterfly activity (Seress et al. 2018). Several insectivorous winter migrants, such as the Bluethroat *Luscinia svecica*, Ultramarine Flycatcher *Ficedula superciliaris*, and Red-breasted Flycatcher *Ficedula parva*, were also recorded during this period. Colour, seed size, and fruiting arrangement influence fruit selection in frugivorous birds (Azman et al. 2011), and Mahadare comprises 392 plant species, which include a diversity of fruiting and flowering trees such as Black Clutch *Senegalia catechu*, Golden Shower *Cassia fistula*, and Indian Beech *Pongamia pinnata*. The region also reported 72 flowering plants, which serve as host plants for butterflies (Bhoite et al. 2025). This indirectly supports avian diversity by hosting their prey base. The floral diversity of the area supports the avian population in numerous ways, including nesting and feeding on those trees or shrubs. During summer, it was observed that birds such as Small Minivet *Pericrocotus cinnamomeus*, Coppersmith Barbet *Psilopogon haemacephalus*, Brown-headed Barbet *Psilopogon zeylanicus*, and Pale-Billed Flowerpecker *Dicaeum erythrorhynchos* were mostly seen feeding on Cluster Fig *Ficus racemosa*. Coppersmith Barbet was also seen nesting in the crevices of this tree. Trees such as Red Silk Cotton *Bombax ceiba* and Indian Mango *Mangifera indica* are a few important species that are directly beneficial to the avian populations of the region, fulfilling the guild structure. Species such as the Puff-throated Babbler *Pellorneum ruficeps* were mainly observed foraging in the leaf litter of Teak *Tectona grandis* by turning over leaves.

CONCLUSION

MCR is an ecotone region that acts as a transition zone between diverse habitats. The presence of multiple feeding guilds highlights the functional diversity of the region, not just taxonomic richness. Studying the feeding guild distribution in a region can also help in understanding the various nuances of community assemblages, along with the structural complexity of a given area. Since feeding guilds provide insights into ecosystem functioning, the loss of specific guilds can potentially disrupt activities such as pest regulation, pollination, and seed dispersal, which could severely alter ecosystems. In order to gain in-depth knowledge about the effects of change in feeding guild diversity, it is important to assess the long-term impacts of climate change and land-use change, along with their functional redundancy and resilience.

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ARTICLE

Nesting colonies and breeding ecology of the Cattle Egret *Bubulcus ibis* (Linnaeus, 1758) in northern and northeastern Bangladesh

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Abstract: A study on the Cattle Egret *Bubulcus ibis* was conducted between March 2017 and August 2023 in northern and northeastern Bangladesh to document the nesting sites and breeding biology of this species. A total of 218 colony sites were identified, of which 56.42% were active breeding ones, 17.43% night roosting, and 26.15% abandoned ones. The active breeding colony sites occupied 107.06 ha, with 1.10 ha of government land and 105.96 ha of private land. Active nesting sites ranged from 2–150 years old. The most active breeding colonies were found in Rajshahi (41) and Sylhet (41), followed by Rangpur (21) and Mymensingh (20). A total of 29,412 nests were counted, with Rajshahi at 38.29% (n = 11,262), Sylhet at 29.47% (n = 8,669), Rangpur at 19.49% (n = 5,731), and Mymensingh at 12.75% (n = 3,750). Paddy fields were the preferred habitat (77.50%), followed by wetlands (10.94%), mixed agriculture (5.51%), tea gardens (3.74%), mango orchards (1.95%), and homesteads (0.36%). Breeding occurred from April to July, with colony sizes ranging from 2–2,260 nests. A total of 29,412 active nests were counted from 1,963 plants of 42 species, with a preference for Bamboo (76.32%), followed by Mango (7.77%), Jackfruit (3.14%), and Tamarind (2.51%). They usually laid 3–4 eggs in 4–8 days, with an incubation period of 25–29 days. Chicks fledged after 35–45 days, and breeding success was 63.50%.

Keywords: Ardeidae, active breeding colony, breeding success, habitat, heronry, nest, nesting site, spatial distribution, waterbirds, wetland.

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Author contributions: Allama Shibli Sadik: Conceptualization (lead); funding acquisition (lead); investigation (lead); project administration (lead); data curation (lead); formal analysis (lead); methodology (lead); visualization (lead); writing – original draft (lead); writing – review and editing (equal). M. Monirul H. Khan: Conceptualization (equal); investigation (equal); methodology (supporting); visualization (supporting); writing – original draft (supporting). M. Kamrul Hasan: Conceptualization (equal); investigation (equal); methodology (supporting); visualization (supporting); writing – original draft (supporting). Fahad Hossain Haider: Investigation (supporting); visualization (supporting); writing – review and editing (supporting). Md. Sher-E-Afgan: Investigation (supporting), including field surveys, trap-camera installation and monitoring, and documentation of breeding colonies; writing – review and editing (supporting).

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INTRODUCTION

Cattle Egret *Bubulcus ibis* is classified as a species of 'Least Concern' globally and nationally in the tropics, with a distribution that spans North & South America, Europe, Africa, Australia, and Asia and is widely distributed in Bangladesh (Begum 2008; Naher 2015; BirdLife International 2024). A majority of the population of this species is migratory, moving long distances for food, especially with seasonal rainfall, and some populations, like those in northeastern Asia and North America, are fully migratory (BirdLife International 2024). The population trend indicates an overall increase, though some populations are stable or declining, with others having unknown trends (BirdLife International 2024). The species thrives in various open grassy habitats, including meadows, pastures, floodplains, irrigated grasslands, as well as in small water bodies and artificial environments like lawns and parks that experience seasonal flooding (Hancock & Kushlan 1984; del Hoyo et al. 1992; Kushlan & Hancock 2005). This species rarely inhabits marine or forested areas (del Hoyo et al. 1992), although it can occasionally be found in brackish or saline environments (Kushlan & Hancock 2005; Byju et al. 2023). Its range spans from sea level to altitudes of up to 1,500 m (Kushlan & Hancock 2005), and in certain regions, it may even reach around 4,000 m (del Hoyo et al. 1992). In tropical regions, the species breeds year-round, with varying peaks in breeding activity depending on the availability of food resources and rainfall patterns, leading to annual fluctuations in productivity (del Hoyo et al. 1992; Kushlan & Hancock 2005; BirdLife International 2024; Byju et al. 2025a). This species breeds in colonies with group sizes from dozens to thousands of pairs (del Hoyo et al. 1992). These patterns illustrate the species' resilience and the importance of understanding environmental conditions that affect breeding success (Ballerini et al. 2009; Byju et al. 2024). During the non-breeding season, these birds remain social (Brown et al. 1982; del Hoyo et al. 1992; Birdlife International 2024). del Hoyo et al. (1992) observed feeding behaviour in loose flocks including 10–20 individuals; as well as the regularity with which bigger groups of hundreds or even thousands meet when food is plentiful.

The Cattle Egret *Bubulcus ibis* plays a significant ecological role in both agricultural and wetland ecosystems by controlling insect populations, particularly pests associated with livestock and crop fields (Kushlan & Hancock 2005). The species serves as an important bioindicator of wetland health and environmental change (Burger et al. 1992; Begum 2008) in Bangladesh, where agro-ecosystems and wetlands are vital for livelihoods. Hence, the conservation of Cattle Egret colonies reflects broader ecosystem integrity and supports biodiversity management within human-dominated landscapes. There is no comprehensive study yet conducted on the breeding ecology of Cattle Egrets in Bangladesh. The primary goal is to investigate their breeding ecology, including colony distribution, population abundance, nesting plant requirements, and conservation status. Although the Cattle Egret is widely distributed, it exhibits the distinctive behaviour of nesting in dense assemblages, resulting in breeding concentrated within a limited number of sites. Consequently, the loss of even a few breeding areas could have significant implications at the population level. Regional studies on its breeding ecology are therefore essential to evaluate local responses to habitat alteration, anthropogenic disturbance, and climatic variability. Such investigations provide critical baseline data and fill knowledge gaps for the long-term monitoring and conservation of the species within Bangladesh's rapidly changing wetland and agro-ecosystem landscapes.

MATERIAL AND METHODS

The study was conducted in the northern and northeastern regions of Bangladesh across 24 districts of Rajshahi, Rangpur, Mymensingh, and Sylhet (Image 1). Nesting site data collection was done from March 2017–August 2023. During the COVID-19 lockdown (2020–2021), the core survey team was unable to conduct direct field visits. Nevertheless, local field assistants, activists, community members, and other stakeholders played a crucial role in providing locational information on colony sites. Detailed investigations on population size, breeding ecology, and reproductive success were subsequently conducted in the post-pandemic period (2022–2023) to ensure consistency in environmental conditions and to minimize potential data bias arising from altered human activities during the lockdown. A total of 345 field days (approximately 13–15 days per district) were spent on population estimation and breeding ecology, covering at least two breeding seasons. Multi-stakeholder focus group discussions (FGDs) were held at the sub-district (upazila) and union levels following Krueger & Casey (2014). Direct field visits and use of citizen science (newspapers, eBird, social media), local conservation activists, youth conservation group members, and union parishad chairmen helped to locate

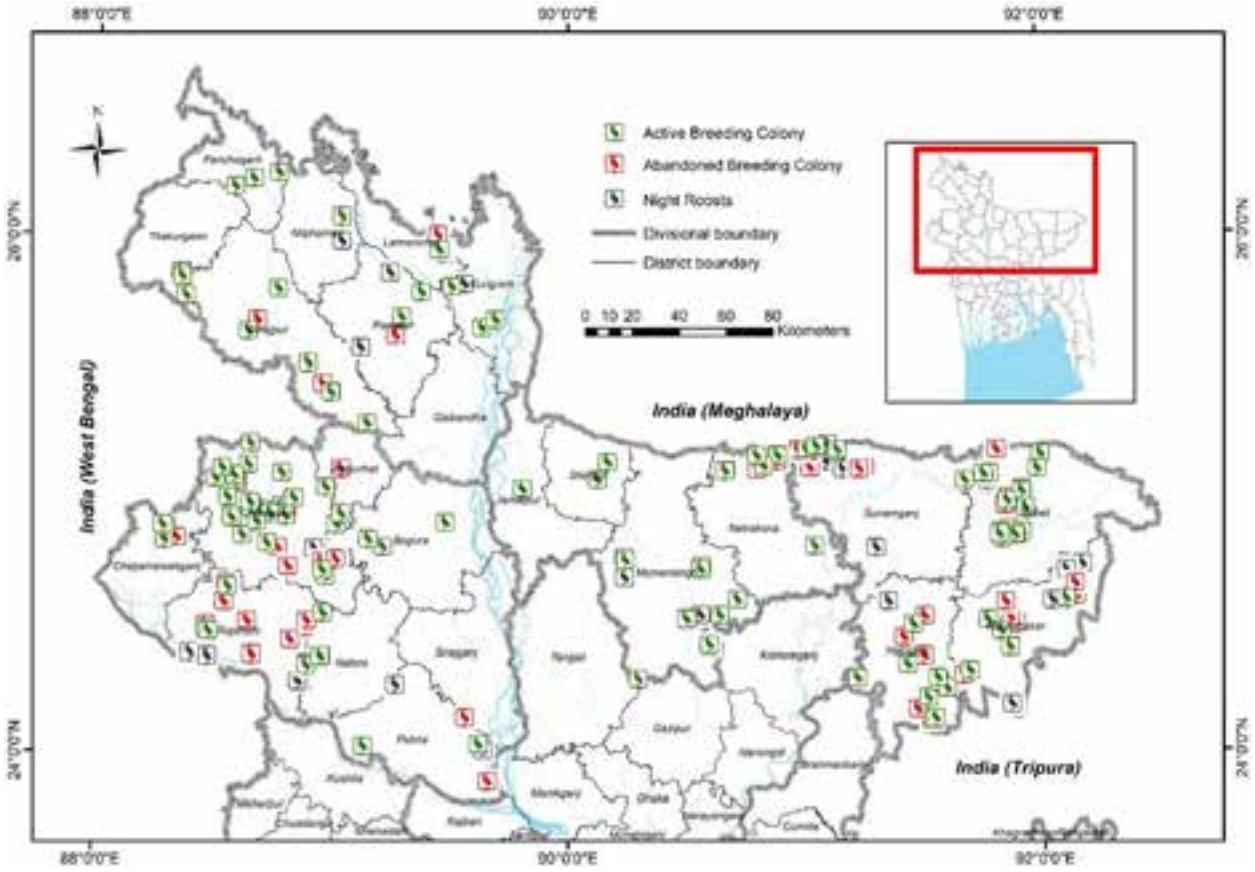

Image 1. GIS-based distribution map of the nesting sites and key habitats of Cattle Egret in all 24 districts of Rajshahi, Rangpur, Mymensingh, and Sylhet division.

the nesting sites. Identification of birds was done using field guides (Grimmett et al. 1999). Breeding pairs were considered independent colonies if they were at least 400 m apart from neighbouring groups or separated by a significant habitat discontinuity (Watts & Watts 2018). Field observations utilized binoculars (10 x 42), a spotting scope, GPS, measuring tape, laser rangefinder (Trupulse 200x), camera traps (GardePro & Scout Guard), a drone, and a digital camera. If there were young chicks or at least one adult in the nest, the nest is clearly categorized as active or occupied (Bibby et al. 2000). Population estimates were based on the count of active nests during the breeding season. The census was conducted at the peak nesting period to assess the number and distribution of nests (pairs). Observers systematically recorded the tree number, species, nest height, and total number of nests. Each tree with a nest was tagged with a unique number and marked with paint to indicate it had been counted. The six main habitat groups are paddy fields (rice farming), mixed agriculture (varied crops in dry lands), homesteads (urban settlements), orchards (areas with mango trees), tea gardens, and wetlands (ponds, rivers, marshes, and lakes). Land-cover data were derived from satellite imagery and reclassified to match the analytical requirements of the study. The reclassified land-cover layer was then clipped to a 5-km radius buffer surrounding each colony to assess the types of land cover associated with colony establishment. Each land-cover class within the buffer was assigned to the corresponding colony using a unique colony identifier. For every colony, the area (ha) and proportional (%) representation of each land-cover category were calculated. All spatial analyses were conducted using the Spatial Analyst tools in ArcGIS Pro 3.3, and tabular computations and summaries were performed in Microsoft Excel 365.

The age of the colony, defined as the duration of nesting site use by Cattle Egrets, was primarily determined from historical records (e.g., government reports, social media, and print and electronic media) and corroborated with community-based knowledge. Scientific literature, government reports, and historical accounts can provide information on the duration of colony site use (Ogden 1994). Interviews with local

communities and indigenous peoples can also offer valuable insights into the history of colony sites (Gawlik 2006). We marked 36 nests on five plant species: Jackfruit *Artocarpus heterophyllus*, Bamboo *Bambusa* spp., Mango *Mangifera indica*, Velvet Apple *Diospyros discolor*, and Sandpaper Tree *Streblus asper*. Eleven nests were monitored using camera traps at four colony sites: Chanpukur Mission and Alidewna in Naogaon, Teligaon in Tahirpur, and Lilapara in Khadimnagar, Sylhet. Each nest had a GardePro or Scout camera installed for about 55 days, capturing motion and photos every four minutes. Nesting success was recorded when at least one egg hatched per nest, while fledgling success was the proportion of chicks that fledged. Breeding success is calculated as the ratio of surviving chicks to the total number of eggs laid. Hatching success is the proportion of eggs that hatch successfully, while total breeding success measures the number of chicks that survive compared to the number of eggs laid (Katuwal et al. 2022). Data were analyzed using computer-based statistical models, including linear regression and GIS, to identify colony locations, habitat preferences, and distribution patterns of Cattle Egrets.

RESULTS AND DISCUSSION

Status and distribution of nesting colonies

A total of 218 colony sites were identified, of which 56.42% (n = 123) were active breeding colonies, 17.43% (n = 38) were night roosting, and 26.15% (n = 57) were breeding abandoned. The total area of active breeding colony sites was 107.06 ha, including 1.10 ha of government land and 105.96 ha of private land. The age of nesting sites ranged from 2 to 150 years (mean 20.78 ± 29.14 SD, n = 123), with one site in Domar, Nilphamari, estimated to be 200 years old. Nesting sites were reused annually (n = 123) as long as the habitat remained suitable and undisturbed. The highest number of active breeding colonies was found in the Rajshahi (n = 41) and Sylhet divisions (n = 41), followed by Rangpur (n = 21) and Mymensingh (n = 20). Naogaon District had the most nesting sites (n = 25) (Image 2), while Pabna, Lalmonirhat, and Jamalpur had the least (n = 1), with no nesting sites in Sirajganj and Gaibandha (Image 1). The highest percentage of nests was found in the Rajshahi division (38.29%, n = 11,262), followed by Sylhet (29.47%, n = 8,669), Rangpur (19.49%, n = 5,731), and Mymensingh (12.75%, n = 3,750) (Image 3). The number of active nests varied notably across the four divisions. Rajshahi recorded the highest number of colonies and nests, with an average of about 275 nests per colony, indicating highly productive nesting activity. Rangpur showed a similarly high average of 273 nests per colony, reflecting strong colony performance relative to its size. Sylhet had an average of 211 nests per colony, while Mymensingh showed the lowest productivity, with 188 nests per colony. Overall, Rajshahi and Rangpur exhibited higher nesting densities per colony, whereas Sylhet and Mymensingh showed comparatively lower nesting intensity, suggesting potential differences in habitat quality, resource availability, or colony maturity among the divisions.

The linear regression analysis revealed a positive relationship between the number of colonies and the number of nests, with each additional colony associated with approximately 257 more nests. The model explained a substantial proportion of the variation in nest numbers (R^2 = 0.85) (Image 5A). However, the relationship was not statistically significant at the 0.05 level (p = 0.077). Nevertheless, the trend indicates that an increase in the number of colonies generally corresponds to a higher number of nests. The study results indicate that habitat suitability for Cattle Egret colonies varies considerably across northern and northeastern Bangladesh. The highest number of active breeding colonies and nests was recorded in the Rajshahi and Sylhet divisions, suggesting these areas provide optimal conditions for nesting. Factors contributing to this suitability likely include the presence of abundant suitable trees for nesting, low human disturbance, and proximity to productive foraging habitats such as wetlands and agricultural fields. In contrast, Mymensingh had fewer colonies and nests, while districts such as Pabna, Lalmonirhat, and Jamalpur hosted limited nesting sites. Nesting was completely absent in Sirajganj and Gaibandha, clearly indicating that these areas likely lack suitable nesting trees, experience higher levels of human disturbance, or have limited access to nearby foraging grounds, thereby reducing their suitability for Cattle Egret colonies. Moreover, hunting pressure was higher in Mymensingh than in other regions, which could have limited the breeding of the Cattle Egret.

Breeding season, habitat and nesting site selection

Nest construction occurs from April to June, with breeding occurring between April and July. Breeding season varied in the study area: nest construction started early April in the Sylhet division, and the nest construction started in mid to late May in Rajshahi, Rangpur, and Mymensingh divisions. The core breeding time in the Sylhet division was April to early June, while

Image 2. Incubation of eggs (A & B) and hatchlings with unhatched eggs (C & D) at Chanpukur Catholic Church Bird Colony, Patnitala, Naogaon. © Allama Shibli Sadik.

in Rajshahi, Rangpur, and Mymensingh, it was mid-May to July. The most nesting sites and nests were found in paddy field habitats (89 sites, 22,795 nests), followed by wetlands (16 sites, 3,217 nests), agricultural mixed habitats (7 sites, 1,620 nests), tea gardens (seven sites, 1,099 nests), mango orchards (2 sites, 575 nests), and homesteads (1 site, 106 nests). A total of 123 colonies were identified, with six as single colonies and the others as mixed-species colonies alongside egrets, herons, cormorants, darters, storks, and ibises. All the nesting sites were associated with human settlements (Issa et al. 2023), including rural villages and urban areas, where feeding grounds were within easy reach. This observation strongly supports the findings of the present study. The number of active nests and nesting sites varied notably across habitats. Paddy fields supported the highest total number of nests with a high density of about 256 nests per site, indicating favourable nesting conditions. Mango orchards, though limited to two sites, showed the highest density (288 nests per site), suggesting strong site productivity. Homesteads had the fewest nests, while agriculture-mixed areas and wetlands provided moderate nesting opportunities, and tea gardens supported relatively fewer nests per site. The linear model revealed a strong positive relationship between the number of nesting sites and the number of nests. Each additional nesting site was associated with approximately 260 more nests on average. The model explained nearly all the variation in nest numbers (R^2 = 0.998) (Image 5B), and the relationship was highly significant ($p < 0.001$). These results indicate that the number of nesting sites serve as a strong predictor of nest abundance across habitats.

Colony sizes varied, ranging 2–2,260 nests (mean 116.25 ± 225.52 SD, n = 123). The largest colony, in Akandapara, Bogura, had 2,260 nests. Colony size depends on the number of nesting plants and the area's safety for establishing nests . Cattle Egrets are colonial nesters, often found with other species like herons and storks (Snow & Perrins 1998; Bharti 2024). Cattle Egrets nest in various tree types, with height preferences influenced by environment and human activity (Si-Bachir et al. 2008; Sbiki et al. 2015). A total of 29,412 active nests was observed among 1,963 plants of 42

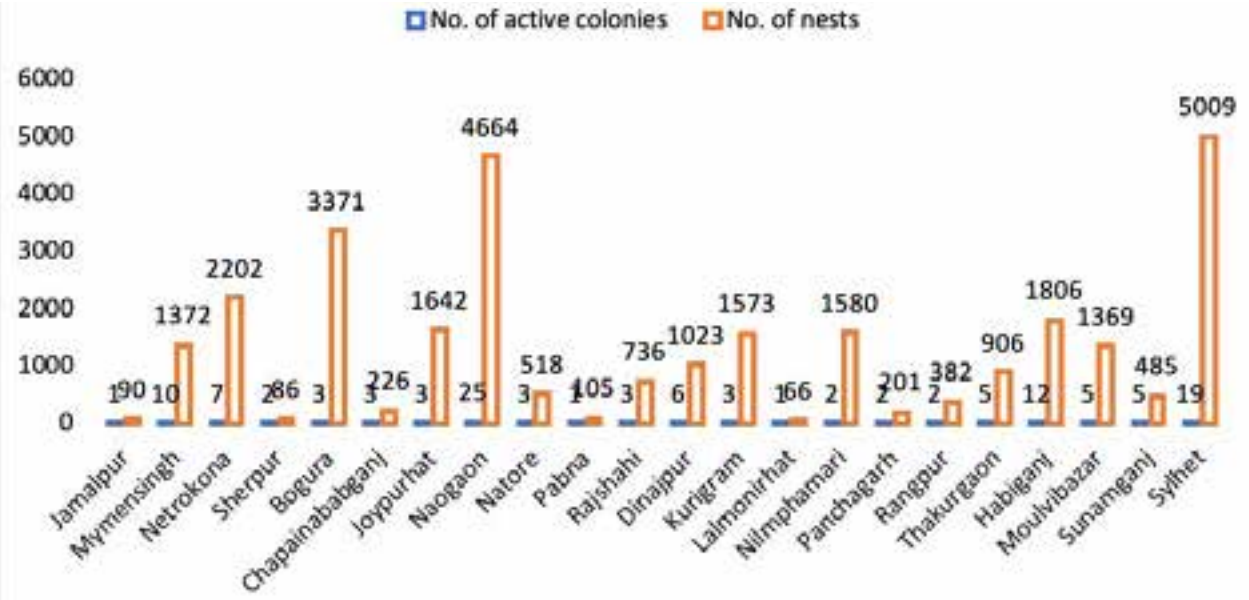

Image 3. Average nesting height of the tress/plants preferred by Cattle Egret.

species. They primarily favoured Bamboo *Bambusa* spp. (76.32%), followed by Mango *Mangifera indica* (7.77%), Jackfruit *Artocarpus heterophyllus* (3.14%), Tamarind *Tamarindus indica* (2.51%), and least often Scholar Tree *Alstonia scholaris* with one nest. Cattle Egrets often nest in trees at heights of 4–17 m; the mean average nesting height was 4.3–15 m (mean 10.30 ± 2.81 SD, n = 1963); the mean lowest height was 4.2–15 m (mean 9.22 ± 2.50 SD, n = 1963); and the mean highest height was 5.8–17 m (mean 11.06 ± 2.71 SD, n = 1963). The lowest height was 3 m nesting at the Bamboo *Bambusa* spp. cluster, and the highest nesting height was 17 m at African Mahogany (Image 4). In Gujarat, Patankar et al. (2007) reported that the average nesting height on *Mimusops* trees was 8.6 m, whereas on *Lagerstroemia* trees it averaged only 3.7 m. In Faisalabad, Pakistan, nests were primarily built in Kikar *Acacia nilotica* trees, followed by Jamun *Syzygium cuminii* trees, at average heights ranging 7.19 ± 1.45–8.01 ± 1.31 m above the ground (Abdullah et al. 2017). These findings are consistent with the results of the present study, indicating that Cattle Egrets preferentially select tall trees for nesting and subsequently use other available suitable trees within heronries. Wayne et al. (1998) reported relatively low nesting heights on Montserrat, West Indies, averaging 2.1–5.7 m above the tree canopy, suggesting potential variability in nesting preferences across different regions. Cattle Egret breeding seasons vary by region: in temperate areas, it happens from spring to late summer, while in tropical regions, it can occur year-round, often during the rainy season (Hancock & Kushlan 1984). The breeding period starts from March to July in Jammu, India (Novel & Sahi 2013), and the breeding season in Bangladesh is from June to August (Begum 2008), but our study found that they regularly breed from April to July. The breeding season varies by region: in Sylhet, it runs from early April to late June, while in Rajshahi and Rangpur, it lasts from mid-May to late July due to food availability, as they nest in paddy fields and agricultural dominated habitats. Flash floods upstream of Meghalaya have caused waterlogging in the Sylhet division, benefiting early-harvesting rice crops. In contrast, delayed rains in Rajshahi and Rangpur divisions have left rice fields dry, resulting in insufficient food supply in April. The rainy season in Rajshahi and Rangpur divisions starts in mid-to-late May, nourishing the auricular rice fields and providing ample food, determining the breeding season. Local regional rainfall positively correlated with nest numbers (Novel & Sahi 2013). Cattle Egrets are adaptable and thrive in various environments, but their breeding season timing varies by location and climate. Insufficient rainfall can interrupt breeding (Geering 1993; Kushlan & Hancock 2005; Ballerini et al. 2009; Kelly & Condeso 2014).

Cattle Egret colony sizes vary considerably across regions. Reports include 107 nests in France and Morocco (Hafner 1978; Franchimont 1985); 1,222 in Brazil (Petry & Fonseca 2005); 550–7,953 in India (Hilaluddin et al. 2003; Novel & Sahi 2013); 1,416 in South Africa (Siegfried 1972); and 4,500 in the USA (Dusi & Dusi 1970). More localized studies further highlight

Table 1. Nesting tree/plant species preferences.

Plant species	No. of plants	No. of nests
African Mahagoni *Khaya anthotheca*	12	63
Agar *Aquilaria malaccensis*	53	90
Acacia *Acacia auriculiformis*	41	143
Hog Plum *Spondias pinnaata*	1	7
Arjan *Terminalia arjuna*	18	103
Babul Tree *Vachellia nilotica*	2	51
Stone Apple *Aegle marmelos*	1	3
Spanish Cherry *Mimusops elengi*	3	22
Bamboos *Bambusa* spp.	912	22450
Indian Plum *Ziziphus mauritiana*	4	101
Banyan Tree *Ficus benghalensis*	2	32
Scholar Tree *Alstonia scholaris*	1	1
Coconut *Cocos nucifera*	15	15
False Ashoka *Monoon longifolium*	14	96
Eucalyptus *Corymbia citriodora*	2	13
Velvet Apple *Diospyros discolor*	3	34
Indian Oak *Barringtonia acutangula*	3	15
Jackfruit *Artocarpus heterophyllus*	105	925
Black Plum *Syzygium cumini*	19	113
Betel-nut Palm *Areca catechu*	108	128
Tala Palm *Borassus flabellifer*	7	20
Tamarind *Tamarindus indica*	47	740
Queen Flower *Lagerstroemia speciosa*	19	132
Kadam *Neolamarckia cadamba*	10	50
Carambola *Averrhoa carambola*	3	21
Indian Date Palm *Phoenix sylvestris*	10	27
Wood Apple *Limonia acidissima*	2	15
Koroch *Dalbergia reniformis*	8	92
White Siris *Albizia procera*	6	86
Lichi *Litchi chinensis*	2	21
Mahagoni *Swietenia mahagoni*	92	440
Mango *Mangifera indica*	299	2286
Neem *Azadirachta indica*	68	269
Sacred Fig *Ficus religiosa*	9	153
Fishtail Palm *Caryota urens*	3	16
Royal Siris *Albizia richardiana*	1	16
Indian Laurel *Litsea glutinosa*	1	6
False White Teak *Trewia nudiflora*	20	145
Pithraj *Aphanamixis polystachya*	1	21
Rain Tree *Albizia saman*	13	235
Indian Rosewood/Shisham *Dalbergia sisu*	9	72
Sandpaper Tree *Streblus asper*	14	144

this variation: 550 nests were documented in a mixed colony in Amroha, Uttar Pradesh, India (Hilaluddin et al. 2003); Issa et al. (2023) reported 135 nests in Sharkia Governorate, Egypt; and Patankar et al. (2007) counted 159 nests in an industrial area of Vadodara, Gujarat. Nesting substrates also vary widely, including trees, bamboo, palms, and occasionally the ground or reed beds, depending on local availability (Hancock & Kushlan 1984). In contrast, our study found that Cattle Egrets in Bangladesh bred exclusively in trees and shrubs, such as bamboo clusters and palms, with no nests observed on the ground or in reed beds. Similar regional variability in nesting plant selection has been reported in Jammu, India, where *Acacia nilotica* is the preferred nesting tree, followed by *Mangifera indica* (Novel & Sahi 2013), *Neltuma juliflora* and *Acacia nilotica* in Tamil Nadu (Byju et al. 2025b), underscoring the influence of local habitat conditions and anthropogenic pressure on nesting ecology.

Courtship, nest building, egg-laying, and incubation

During courtship displays, various behaviours such as mutual grooming, bill-touching, and an array of postures, body colours, and vocalizations were observed. The birds built simple, oval nests atop trees or tall shrubs using sticks and various plant materials. After pairing, they copulated. Cattle Egrets typically lay 3–4 eggs (mean 3.80 ± 0.40 SD, n = 36), and clutch size was completed in 4–8 days. They built new nests each year, but do not reuse them the following year. Incubation begins with the first egg laid, with both parents sharing the duty for around 25–29 days (mean 26.5 ± 1.5 SD, n = 6). This allows one to guard the nest while the other forages. Nesting success was 100%, with hatching success 81.02%.

The nests were constructed from twigs, sticks, and other plant materials, with males primarily responsible for collecting the materials and females arranging them into a stable structure. Nesting materials were mostly gathered from nearby areas, and in some cases, individuals were observed stealing materials from neighbouring nests within the same colony; such type of behaviour was reported by Iyer (2004) and Patankar et al. (2007). Although previous studies noted that Cattle Egrets often reuse their nests across multiple breeding seasons when conditions remain favourable (Kushlan & Hancock 2005), the observations differed, as the birds in the present study built new nests each year.

Females typically lay 2–5 eggs per clutch (Kushlan & Hancock 2005; Begum 2008; Issaa et al. 2023). Patankar et al. (2007) reported a relatively smaller clutch size of 2–3 eggs in Gujarat, suggesting that clutch

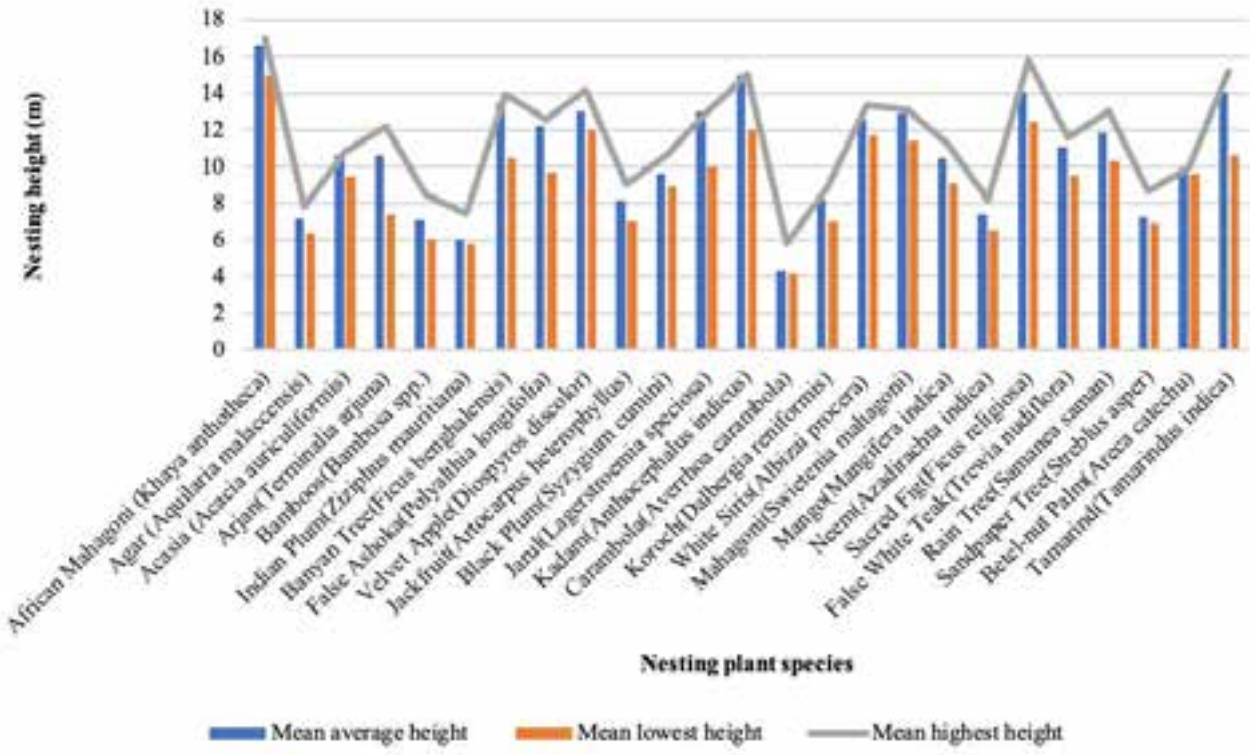

Image 4.. Average nesting height of the tress/plants preferred by Cattle Egret.

size may vary geographically, possibly influenced by environmental conditions and resource availability. Both parents share incubation duties. Reported incubation periods for *Bubulcus ibis* vary widely, ranging 19–27 days: about 3–4 weeks (Kushlan & Hancock 2005); 21–23 days (Novel & Sahi 2013); 21–24 days (Joshi & Shrivastava 2012); 22–23 days (Patankar et al. 2007); 22–25 days (Abdullah 2017; Issaa et al. 2023); 19–22 days (Omar & Hassan 2019). Begum (2008) reported 24 days, while Fujioka (1984) recorded 22–27 days in central Japan—both closely matching our observations. Overall, incubation duration in *B. ibis* shows notable regional variation, likely influenced by environmental conditions and food availability. Overall, variation in incubation duration appears to reflect the combined effects of environmental conditions, food availability, and parental behavioural traits (Higgott et al. 2020). Telfair & Bister (2004) reported that hatching success of Cattle Egrets in northeastern Texas ranged from 71% to 96%. Similarly, Issaa et al. (2023) recorded success rates of approximately 90.21%, while Metallaoui et al. (2020) observed 80%, 90%, and 100% hatching success in different colonies across Algeria. These earlier studies broadly support the findings of the present research. In contrast, relatively lower nesting success has been reported by Kour & Sahi (2013) in Jammu, India, indicating that regional environmental factors and habitat conditions can influence reproductive outcomes.

Parental care

After hatching, the altricial chicks were undeveloped and relied on their parents for food and warmth. The chicks needed warmth for 10–13 days after hatching. They remained in the nests until 18–22 days and started venturing out over the next 5–7 days. By around 30–35 days, they were rarely seen at the nest, but would return for parental feeding. Both parents feed the chicks by regurgitating partially digested food into their mouths. Fledgling survival was 78.37%. Cattle Egrets provide a well-documented example of intensive parental care, with both male and female actively involved in rearing and weaning their chicks (Patankar et al. 2007; Abdullah et al. 2017). Altricial chicks require close parental care and provisioning in the early weeks. Soon after hatching, adults feed them with regurgitated food, teaching chicks to take it from the partially opened beak (Abdullah et al. 2017).

Observations revealed that the diet of *Bubulcus ibis* included a diverse range of prey such as insects, small fish, and amphibians, including frogs and tadpoles, reflecting the species' opportunistic, generalist feeding strategy (Kushlan & Hancock 2005). The weaning period

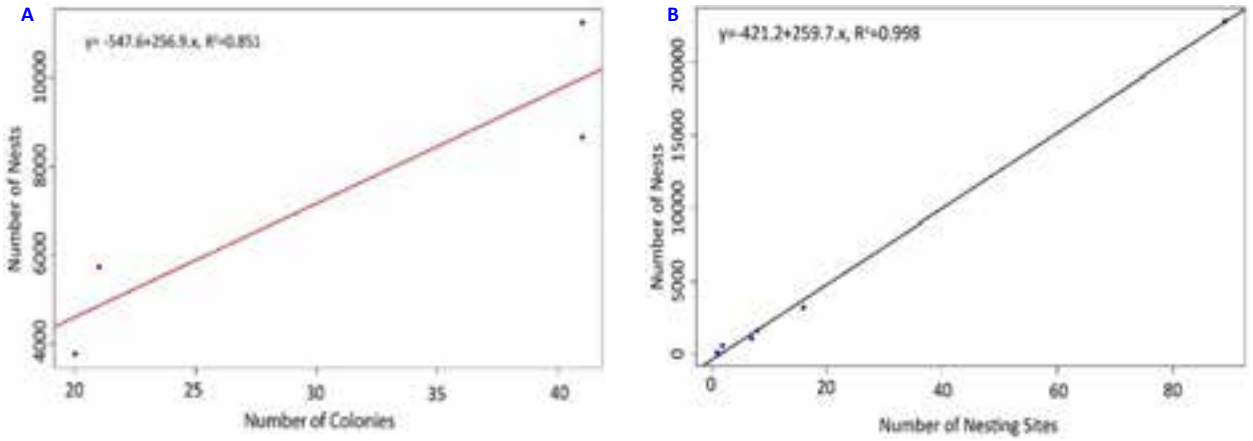

Image 5. A—Relationship between the number of colonies and the number of nests across divisions | B—habitats.

ranged from 25–35 days, supporting Abdullah et al. (2017), while slightly shorter durations of 21–28 days and 21–23 days were reported by Patankar et al. (2007) and Kour & Sahi (2013), respectively. These findings highlight the species' consistent parental investment and suggest that variation in weaning period may be influenced by environmental conditions, food availability, and colony dynamics. Overall, biparental care and structured feeding behaviours appear crucial for chick survival and successful fledging in Cattle Egrets.

Predator defense and post-breeding dispersal

Cattle Egret nesting colonies benefited from protection by cattle and humans but remained vulnerable to predators like crows, snakes, and raptors. Cattle Egrets exhibited collective defense behaviours like mobbing intruders and distracting predators. After breeding, they dispersed to various habitats, such as wetlands, rice fields, and grasslands, based on food availability. The final breeding success was 63.50%. Chicks fledged (left the nest) after about 35–45 days. Both parents actively cared for and fed the nestlings with dedication. At 45 days, they are self-sufficient; by 50 days, they take short flights; and at about 60 days, they fly to foraging sites (Telfair 1994). In Jammu, India, hatching success is 58.65%, whereas chick survival or breeding success is 39.99% (Novel & Sahi 2013). In Australia, annual breeding success is between 1.8 and 2.9 fledglings per pair (McKilligan 2000). About 28-year research in Texas revealed a mean annual breeding success of 86% (Telfair & Bister 2004). According to our findings, chicks fledged after about 35–45 days; the hatching success rate was 81.02%, the fledging survival was 78.37%, and fledgling success per pair/nest was 41.37%, or 2.41 per nest. Bangladesh had higher hatching and chick survival rates than Jammu. The breeding success is roughly comparable to that of Texas, and it is also extremely close to Australia. Cattle Egret nesting colonies benefited from protection by cattle and humans but remained vulnerable to predators like crows, snakes, and raptors. Cattle Egrets exhibited collective defense behaviours like mobbing intruders and distracting predators. Both parents actively cared for and fed the nestlings with dedication. After breeding, they dispersed to various habitats, such as wetlands, rice fields, and grasslands, based on food availability. In this study, hatching success was 81.02%, fledgling production averaged 2.41 per nest (41.37%), and overall breeding success was 63.50%. Chicks fledged after 35–45 days, becoming self-sufficient by about 45 days, taking short flights by 50 days, and flying to foraging sites by 60 days, consistent with Telfair (1994). In Australia, annual breeding success is between 1.8–2.9 fledglings per pair (McKilligan 2000), and in Texas, breeding success 86% (Telfair & Bister 2004), which supports our study. But a previous study in Jammu, India show the relatively low hatching success 58.65% and also the breeding success 39.99% (Novel & Sahi 2013). Overall, breeding performance in Bangladesh was higher than in Jammu and generally aligned with findings from Australia and Texas.

CONCLUSION

The Cattle Egret has received little attention in Bangladesh, so the species has faced significant threats in the study area, resulting in the abandonment of 57 nesting sites over the past five (2019–2023) years. This is primarily due to habitat loss caused by cutting

down the nesting trees, chick poaching, hunting, and poisoning of adult birds. Specifically, 66% of colonies were abandoned because of habitat loss, while 44% were lost to various human activities. Effective conservation should ensure the protection of the crucial breeding sites and raise awareness among the local communities about the importance of birds. This study suggests several conservation measures, including habitat protection, compensation for resource damages, installing signboards at colony sites, enforcing laws against bird hunting and poaching, hiring wildlife watchers, and constructing sheds beneath nesting trees during breeding seasons. The study findings can aid in developing targeted conservation plans.

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ARTICLE

An annotated checklist of the avifauna of Pichavaram Mangrove Forest, southern India: a Ramsar wetland with conservation significance

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Abstract: An assessment of avian diversity was conducted in the Pichavaram Mangrove Forest (PMF), Tamil Nadu, from October 2022 to December 2025. A consolidated inventory combining historical and present records documented 221 bird species for PMF, of which 196 species belonging to 58 families and 20 orders were recorded during the present survey. Comparison with previous studies revealed a marked decline in recorded species richness during 2004–2007 relative to 1984–1988, followed by a substantial increase in species richness during the present study. Of the 196 species documented, 98 were waterbirds and 98 terrestrial species, reflecting a balanced community structure. The dominance of Charadriiformes, Passeriformes, and Pelecaniformes reflects the availability of diverse aquatic and terrestrial habitats within PMF. Frequency of occurrence status showed a skewed distribution with more frequent than infrequent species, suggesting the presence of a relatively stable core assemblage of regularly occurring species within this wetland system. Migratory status comprised 55.6% Residents, 38.8% Winter Migrants, 3.6% Local Migrants, 1.0% Passage Migrants, and 1.0% Summer Migrants. Fifteen species generally regarded as winter migrants were recorded throughout the year during the present study, and were therefore classified as over-summering winter migrants, highlighting the availability of resources within PMF. The occurrence of 13 'Near Threatened', six 'Vulnerable', and two 'Endangered' species underscores the conservation importance of the site. Seven shorebird species and 37 other species were newly-recorded, reflecting either range extensions or improved detection. Twenty-five historically-reported species were not detected in core habitats, suggesting potential shifts in habitat suitability. Overall, the findings reinforce the ecological significance of PMF within the Central Asian Flyway, and highlight its critical role in sustaining both migratory and resident communities.

Keywords: Avian diversity, bird conservation, Central Asian Flyway, coastal wetlands, mangrove ecosystem, over-summering winter migrants, shorebirds, wetland birds.

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Author contributions: IJH—conducted field surveys, collected and analyzed the data, and prepared the original manuscript draft. KJH conceptualized and supervised the study, provided methodological guidance, and critically revised the manuscript.

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INTRODUCTION

Mangrove ecosystems are among the most productive and ecologically significant wetland habitats worldwide, providing vital ecological services including coastal protection, biodiversity support, and biogeochemical cycling. The Pichavaram Mangrove Forest (PMF) comprises a network of tidal creeks, mudflats, mangrove islands, and rich mangrove vegetation, which dynamically interact with riverine habitats, supporting diverse avian assemblages throughout the year (Sampath & Krishnamurthy 1993; Kathiresan 2000). The PMF was designated as a Ramsar Site (Site no. 2482) on 8 April 2022, in recognition of its international ecological importance (Ramsar Convention Secretariat 2022). The avifauna of PMF includes resident as well as long- and short-distance migratory species, as documented in earlier studies (Sampath & Krishnamurthy 1993; Nagarajan & Thiyagesan 1996). A total of 75 waterbird species have been recorded in this area (Nagarajan & Thiyagesan 2014). The migratory season extends from September to April, with peak abundance observed between November and January (Sampath & Krishnamurthy 1993; Nagarajan & Thiyagesan 1996). The high availability of benthic invertebrates and aquatic prey within mangrove mudflats attracts large congregations of wetland birds, especially from the end of the northeast monsoon to the post-monsoon season (Jagadheesan & Pandiyan 2021). PMF functions as a critical stopover and wintering ground for migratory birds along the Central Asian Flyway (CAF) (Rashiba et al. 2022).

Despite their ecological richness, Indian mangroves face escalating threats from anthropogenic activities such as land reclamation, aquaculture, and pollution, which have led to documented declines in bird populations across various coastal regions (Kathiresan et al. 2015). Earlier avifaunal assessments at Pichavaram indicated a peak in bird diversity during the 1980s (Sampath & Krishnamurthy 1993), followed by a lower number of recorded species during the 2000s, coinciding with habitat degradation and wetland conversion for shrimp aquaculture (Sandilyan 2017). No comprehensive long-term updates have been published in the past decade. This study sought to provide a thorough reassessment of avifaunal diversity in the PMF, to evaluate the current status and temporal patterns in species richness, composition and taxonomic dominance. This study integrated historical species lists with new field observations conducted between 2022 and 2025. In addition to compiling an updated avifaunal checklist, this study assessed patterns of species persistence, local disappearance, re-detection, and new species records by comparing historical records with contemporary field observations, highlighting their ecological and conservation significance.

MATERIAL AND METHODS

The PMF (11.442° N, 79.789° E), located in the Cauvery Delta region near the Bay of Bengal in Tamil Nadu, is one of the largest mangrove ecosystems in India, covering 1,474 ha (Image 1). Of the total area, 1,358 ha (92.13%) is designated as protected forest. The mangrove-estuarine ecosystem connects to the sea between the Vellar (north), Coleroon (south), and Uppanar (west) rivers, with water depths ranging 0.3–3.0 m. It comprises marshes, swamps, open water, sandbanks, dense mangroves (Image 4), mudflats (Image 5), agricultural lands, and abandoned fields (Kathiresan 2000). The PMF supports ecotourism through boating activities managed by the Tamil Nadu Tourism and Forest Department, while local fishing communities rely on its rich fish and shellfish resources for their livelihoods.

Field surveys were conducted once per month in different habitats at the PMF and adjacent areas from October 2022 to December 2025. Surveys were carried out during peak avian activity periods (0600–1130 h and 1500–1730 h) and avoided during adverse weather conditions. All surveys were conducted by the same observer to minimise observer-related variation in species detection and identification. To compile a comprehensive avifaunal checklist and facilitate comparison with previous inventories, surveys were conducted using the area search method (Ralph et al. 1993; Bibby et al. 2000), which involved systematic visual scans across predefined habitat areas, with all birds seen and heard being recorded during each survey. A total of 39 monthly surveys were undertaken across six major habitat types: mature mangrove forests, intertidal mudflats, sandbanks, shallow-water areas, restored mangrove areas, and adjacent agricultural lands, comprising a total of 234 surveys (39 months x 6 habitats). Each survey lasted approximately 45 min and covered about 2 km. Surveys were conducted using a combination of boat-based (33.3%) and foot-based (66.7%) observations, depending on habitat accessibility. This approach enabled systematic coverage of the study area and improved the detection of rare, cryptic, mobile, and habitat-specialist species. Observations were made using 10 × 50 binoculars and a spotting scope.

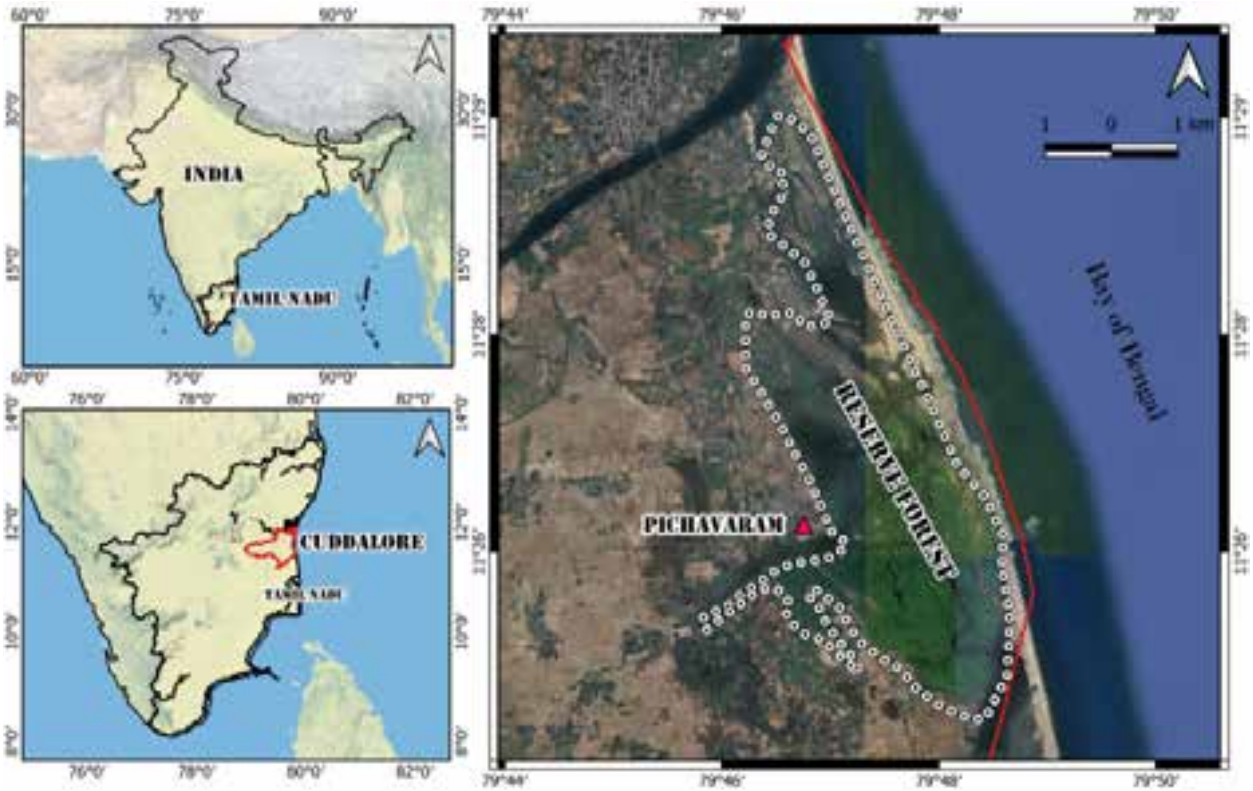

Image 1. Map of the study area showing Pichavaram Mangrove Forest.

Species identification was based on direct field observations and standard ornithological field guides (Ali 2002; Grimmett et al. 2016). Merlin Bird ID was used solely as an auxiliary identification tool and not as a standalone source for species confirmation (Cornell Lab of Ornithology 2023). Uncertain records were verified using photographic evidence obtained with a Nikon Coolpix P1000 camera and cross-referenced with field guides before inclusion in the final checklist.

Species were categorized as Resident (R), Winter Migrant (WM), Local Migrant (LM), Passage Migrant (PM), and Summer Migrant (SM) following Grimmett et al. (2016). Species with documented breeding records in Tamil Nadu were denoted as winter migrants with breeding records (WM#) or summer migrants with breeding records (SM#), as appropriate, based on published literature (Subramanya 2005; Byju et al. 2023b, 2025; Hussain & Hussain 2026). Species recorded throughout the year despite being recognized as winter migrants were denoted as over-summering winter migrants (WM*) following Byju et al. (2024a). Occurrence status was classified based on the frequency of sightings across 39 pooled monthly visits following MacKinnon & Phillipps (1993). Species recorded during > 60 % of visits (24–39 visits) were categorised as Common (C), those recorded during 20–59 % of visits (8–23 visits) as Uncommon (UC), those recorded during 5–19 % of visits (2–7 visits) as Rare (Ra), and species recorded only once as Very Rare (VR). These categories represent frequency of occurrence rather than quantitative abundance. Nomenclature and taxonomic sequence followed the updated online Checklist of the Birds of India maintained by Praveen & Jayapal (2026, Version 10.0; accessed January 2026), while conservation status followed the IUCN Red List of Threatened Species (IUCN 2025).

RESULTS AND DISCUSSION

An annotated checklist of the avifauna recorded from PMF, including common and scientific names, frequency of occurrence, migratory status and IUCN conservation status, is provided in Table 1. During this survey, 196 species belonging to 58 families and 20 orders were documented. Of these, 152 species were reported in previous surveys, whereas 44 species constitute new records for PMF (Table 1). In contrast, 25 species documented in earlier studies were not detected during the current survey (Table 2). Consequently, the cumulative avifaunal inventory of PMF, integrating both historical

Table 1. Checklist and status of avifauna in Pichavaram Mangrove Forest, southern India.

Common name	Scientific name	Migratory status	Frequency of occurrence	IUCN Red List status
Order: Anseriformes				
Family: Anatidae				
Northern Pintail	*Anas acuta*	WM	Ra	LC
Common Teal	*Anas crecca*	WM	Ra	LC
Indian Spot-billed Duck	*Anas poecilorhyncha*	R	UC	LC
Fulvous Whistling-Duck+	*Dendrocygna bicolor*	R	Ra	LC
Lesser Whistling-Duck+	*Dendrocygna javanica*	R	Ra	LC
Eurasian Wigeon	*Mareca penelope*	WM	Ra	LC
Gadwall	*Mareca strepera*	WM	Ra	LC
Cotton Pygmy-Goose	*Nettapus coromandelianus*	R	VR	LC
Northern Shoveler	*Spatula clypeata*	WM	VR	LC
Garganey	*Spatula querquedula*	WM	Ra	LC
Order: Phoenicopteriformes				
Family: Phoenicopteridae				
Greater Flamingo	*Phoenicopterus roseus*	R	VR	LC
Order: Galliformes				
Family: Phasianidae				
Grey Francolin	*Ortygornis pondicerianus*	R	C	LC
Indian Peafowl	*Pavo cristatus*	R	C	LC
Jungle Bush-Quail	*Perdicula asiatica*	R	VR	LC
Order: Podicipediformes				
Family: Podicipedidae				
Little Grebe	*Tachybaptus ruficollis*	R	Ra	LC
Order: Columbiformes				
Family: Columbidae				
Rock Pigeon	*Columba livia*	R	C	LC
Eurasian Collared-Dove	*Streptopelia decaocto*	R	C	LC
Spotted Dove	*Spilopelia chinensis*	R	C	LC
Laughing Dove	*Spilopelia senegalensis*	R	Ra	LC
Order: Apodiformes				
Family: Apodidae				
Little Swift	*Apus affinis*	R	Ra	LC
Asian Palm Swift	*Cypsiurus balasiensis*	R	C	LC
Order: Cuculiformes				
Family: Cuculidae				
Grey-bellied Cuckoo+	*Cacomantis passerinus*	PM	Ra	LC
Greater Coucal	*Centropus sinensis*	R	C	LC
Pied Cuckoo	*Clamator jacobinus*	R	UC	LC
Asian Koel	*Eudynamys scolopaceus*	R	C	LC
Common Hawk-Cuckoo	*Hierococcyx varius*	R	C	LC
Blue-faced Malkoha+	*Phaenicophaeus viridirostris*	R	UC	LC
Order: Gruiformes				
Family: Rallidae				
White-breasted Waterhen	*Amaurornis phoenicurus*	R	C	LC
Eurasian Coot+	*Fulica atra*	R	Ra	LC
Watercock	*Gallicrex cinerea*	SM	VR	LC
Common Moorhen+	*Gallinula chloropus*	R	UC	LC
Grey-headed Swamphen+	*Porphyrio poliocephalus*	R	Ra	LC
Order: Charadriiformes				
Family: Burhinidae				
Great Thick-knee	*Esacus recurvirostris*	R	Ra	NT
Indian Thick-knee	*Burhinus indicus*	R	UC	LC
Family: Haematopodidae				
Eurasian Oystercatcher	*Haematopus ostralegus*	WM	UC	NT
Family: Recurvirostridae				
Black-winged Stilt	*Himantopus himantopus*	R	C	LC
Family: Charadriidae				
Kentish Plover	*Anarhynchus alexandrinus*	WM*	C	LC
Tibetan Sand-Plover	*Anarhynchus atrifrons*	WM*	C	LC
Greater Sand-Plover	*Anarhynchus leschenaultii*	WM*	C	LC
Common Ringed Plover	*Charadrius hiaticula*	WM	Ra	LC
Pacific Golden-Plover	*Pluvialis fulva*	WM*	C	LC
Grey Plover	*Pluvialis squatarola*	WM*	C	VU
Little Ringed Plover	*Thinornis dubius*	WM#	C	LC
Grey-headed Lapwing+	*Vanellus cinereus*	WM	Ra	LC
Red-wattled Lapwing	*Vanellus indicus*	R	C	LC
Yellow-wattled Lapwing	*Vanellus malabaricus*	R	Ra	LC
Family: Jacanidae				
Pheasant-tailed Jacana+	*Hydrophasianus chirurgus*	R	VR	LC
Family: Scolopacidae				
Common Sandpiper	*Actitis hypoleucos*	WM*	C	LC
Ruddy Turnstone	*Arenaria interpres*	WM	UC	NT

Common name	Scientific name	Migratory status	Frequency of occurrence	IUCN Red List status
Great Knot+	*Calidris tenuirostris*	WM	VR	EN
Sanderling+	*Calidris alba*	WM	UC	LC
Dunlin	*Calidris alpina*	WM	Ra	NT
Broad-billed Sandpiper	*Calidris falcinellus*	WM	VR	VU
Curlew Sandpiper	*Calidris ferruginea*	WM	Ra	VU
Little Stint	*Calidris minuta*	WM	UC	LC
Ruff	*Calidris pugnax*	WM	Ra	LC
Red-necked Stint+	*Calidris ruficollis*	WM	Ra	NT
Temminck's Stint	*Calidris temminckii*	WM	UC	LC
Common Snipe	*Gallinago gallinago*	WM	UC	LC
Pin-tailed Snipe+	*Gallinago stenura*	WM	Ra	LC
Bar-tailed Godwit	*Limosa lapponica*	WM	Ra	NT
Black-tailed Godwit	*Limosa limosa*	WM	Ra	NT
Eurasian Curlew	*Numenius arquata*	WM	UC	NT
Whimbrel	*Numenius phaeopus*	WM*	C	LC
Spotted Redshank	*Tringa erythropus*	WM	Ra	LC
Wood Sandpiper	*Tringa glareola*	WM*	C	LC
Common Greenshank	*Tringa nebularia*	WM*	C	LC
Green Sandpiper	*Tringa ochropus*	WM	UC	LC
Marsh Sandpiper	*Tringa stagnatilis*	WM*	C	LC
Common Redshank	*Tringa totanus*	WM*	C	LC
Terek Sandpiper	*Xenus cinereus*	WM	Ra	LC
Family: Glareolidae				
Small Pratincole	*Glareola lactea*	R	UC	LC
Oriental Pratincole+	*Glareola maldivarum*	SM#	Ra	LC
Family: Laridae				
Whiskered Tern	*Chlidonias hybrida*	WM	UC	LC
Brown-headed Gull	*Chroicocephalus brunnicephalus*	WM	UC	LC
Slender-billed Gull+	*Chroicocephalus genei*	WM	Ra	LC
Black-headed Gull	*Chroicocephalus ridibundus*	WM	UC	LC
Gull-billed Tern	*Gelochelidon nilotica*	WM*	C	LC
Caspian Tern	*Hydroprogne caspia*	WM*	C	LC
Pallas's Gull	*Ichthyaetus ichthyaetus*	WM	UC	LC
Lesser Black-backed Gull	*Larus fuscus*	WM	UC	LC
Bridled Tern+	*Onychoprion anaethetus*	WM#	VR	LC
River Tern	*Sterna aurantia*	LM	Ra	VU
Common Tern	*Sterna hirundo*	WM	UC	LC
Little Tern	*Sternula albifrons*	WM#	C	LC
Lesser Crested Tern+	*Thalasseus bengalensis*	WM*	C	LC
Great Crested Tern	*Thalasseus bergii*	WM#	C	LC
Sandwich Tern+	*Thalasseus sandvicensis*	WM	Ra	LC
Order: Ciconiiformes				
Family: Ciconiidae				
Asian Openbill	*Anastomus oscitans*	R	C	LC
Painted Stork	*Mycteria leucocephala*	R	C	LC
Order: Suliformes				
Family: Anhingidae				
Oriental Darter	*Anhinga melanogaster*	R	UC	LC
Family: Phalacrocoracidae				
Little Cormorant	*Microcarbo niger*	R	C	LC
Great Cormorant	*Phalacrocorax carbo*	WM#	Ra	LC
Indian Cormorant	*Phalacrocorax fuscicollis*	R	Ra	LC
Order: Pelecaniformes				
Family: Pelecanidae				
Spot-billed Pelican+	*Pelecanus philippensis*	R	Ra	NT
Family: Ardeidae				
Great Egret	*Ardea alba*	R	C	LC
Eastern Cattle Egret	*Ardea coromanda*	R	C	LC
Intermediate Egret	*Ardea intermedia*	R	C	LC
Grey Heron	*Ardea cinerea*	R	C	LC
Purple Heron	*Ardea purpurea*	R	C	LC
Indian Pond Heron	*Ardeola grayii*	R	C	LC
Little Heron	*Butorides atricapilla*	R	C	LC
Black Bittern	*Botaurus flavicollis*	LM	Ra	LC
Little Egret	*Egretta garzetta*	R	C	LC
Western Reef Egret	*Egretta gularis*	LM	Ra	LC
Cinnamon Bittern	*Botaurus cinnamomeus*	LM	Ra	LC
Yellow Bittern+	*Botaurus sinensis*	LM	UC	LC
Black-crowned Night Heron	*Nycticorax nycticorax*	R	UC	LC
Family: Threskiornithidae				
Eurasian Spoonbill	*Platalea leucorodia*	R	UC	LC
Glossy Ibis	*Plegadis falcinellus*	R	UC	LC
Black-headed Ibis	*Threskiornis melanocephalus*	R	C	LC
Order: Accipitriformes				
Family: Pandionidae				
Osprey	*Pandion haliaetus*	WM	UC	LC

Common name	Scientific name	Migratory status	Frequency of occurrence	IUCN Red List status
Family: Accipitridae				
White-eyed Buzzard+	*Butastur teesa*	LM	VR	LC
Short-toed Snake-Eagle+	*Circaetus gallicus*	R	VR	LC
Greater Spotted Eagle+	*Clanga clanga*	WM	VR	VU
Western Marsh Harrier	*Circus aeruginosus*	WM	VR	LC
Pallid Harrier	*Circus macrourus*	WM	VR	NT
Black-winged Kite	*Elanus caeruleus*	R	UC	LC
Brahminy Kite	*Haliastur indus*	R	C	LC
Booted Eagle+	*Hieraaetus pennatus*	WM	Ra	LC
White-bellied Sea-Eagle	*Icthyophaga leucogaster*	R	VR	LC
Black Kite	*Milvus migrans*	R	C	LC
Oriental Honey-Buzzard+	*Pernis ptilorhynchus*	LM	VR	LC
Shikra	*Tachyspiza badia*	R	C	LC
Order: Strigiformes				
Family: Tytonidae				
Eastern Barn Owl	*Tyto javanica*	R	Ra	LC
Family: Strigidae				
Spotted Owlet	*Athene brama*	R	UC	LC
Indian Scops-Owl+	*Otus bakkamoena*	R	VR	LC
Mottled Wood-Owl+	*Strix ocellata*	R	VR	LC
Order: Bucerotiformes				
Family: Upupidae				
Eurasian Hoopoe	*Upupa epops*	R	C	LC
Order: Piciformes				
Family: Megalaimidae				
Coppersmith Barbet	*Psilopogon haemacephalus*	R	UC	LC
Family: Picidae				
Black-rumped Flameback	*Dinopium benghalense*	R	UC	LC
Order: Coraciiformes				
Family: Meropidae				
Asian Green Bee-eater	*Merops orientalis*	R	C	LC
Blue-tailed Bee-eater	*Merops philippinus*	R	C	LC
Family: Coraciidae				
Indian Roller	*Coracias benghalensis*	R	C	NT
Family: Alcedinidae				
Common Kingfisher	*Alcedo atthis*	R	C	LC
Pied Kingfisher	*Ceryle rudis*	R	C	LC
Black-capped Kingfisher	*Halcyon pileata*	R	Ra	VU
White-throated Kingfisher	*Halcyon smyrnensis*	R	C	LC
Order: Falconiformes				
Family: Falconidae				
Common Kestrel	*Falco tinnunculus*	WM	Ra	LC
Peregrine Falcon	*Falco peregrinus*	WM	VR	LC
Order: Psittaciformes				
Family: Psittaculidae				
Rose-ringed Parakeet	*Psittacula krameri*	R	C	LC
Order: Passeriformes				
Family: Pittidae				
Indian Pitta	*Pitta brachyura*	WM	Ra	LC
Family: Campephagidae				
Black-headed Cuckooshrike+	*Lalage melanoptera*	PM	VR	LC
Family: Oriolidae				
Indian Golden Oriole	*Oriolus kundoo*	WM	UC	LC
Family: Artamidae				
Ashy Woodswallow	*Artamus fuscus*	R	UC	LC
Family: Vangidae				
Common Woodshrike	*Tephrodornis pondicerianus*	R	Ra	LC
Family: Aegithinidae				
Common Iora	*Aegithina tiphia*	R	Ra	LC
Family: Dicruridae				
Black Drongo	*Dicrurus macrocercus*	R	C	LC
Family: Laniidae				
Brown Shrike	*Lanius cristatus*	WM	Ra	LC
Family: Corvidae				
House Crow	*Corvus splendens*	R	C	LC
Large-billed Crow	*Corvus macrorhynchos*	R	C	LC
Rufous Treepie	*Dendrocitta vagabunda*	R	C	LC
Family: Monarchidae				
Indian Paradise-Flycatcher	*Terpsiphone paradisi*	R	Ra	LC
Family: Dicaeidae				
Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	R	UC	LC
Family: Nectariniidae				
Loten's Sunbird+	*Cinnyris lotenius*	R	UC	LC
Purple Sunbird	*Cinnyris asiaticus*	R	C	LC
Purple-rumped Sunbird	*Leptocoma zeylonica*	R	C	LC
Family: Ploceidae				
Baya Weaver+	*Ploceus philippinus*	R	Ra	LC

Common name	Scientific name	Migratory status	Frequency of occurrence	IUCN Red List status
Family: Estrildidae				
Indian Silverbill+	*Euodice malabarica*	R	Ra	LC
Scaly-breasted Munia	*Lonchura punctulata*	R	Ra	LC
Tricoloured Munia+	*Lonchura malacca*	R	Ra	LC
White-rumped Munia+	*Lonchura striata*	R	Ra	LC
Family: Passeridae				
House Sparrow	*Passer domesticus*	R	UC	LC
Yellow-throated Sparrow	*Gymnoris xanthocollis*	R	UC	LC
Family: Motacillidae				
Blyth's Pipit+	*Anthus godlewskii*	WM	Ra	LC
Richard's Pipit+	*Anthus richardi*	WM	Ra	LC
Paddyfield Pipit	*Anthus rufulus*	R	C	LC
Forest Wagtail	*Dendronanthus indicus*	WM	VR	LC
White Wagtail	*Motacilla alba*	WM	VR	LC
Grey Wagtail	*Motacilla cinerea*	WM	VR	LC
Citrine Wagtail+	*Motacilla citreola*	WM	Ra	LC
Western Yellow Wagtail	*Motacilla flava*	WM	UC	LC
White-browed Wagtail	*Motacilla maderaspatensis*	R	C	LC
Eastern Yellow Wagtail+	*Motacilla tschutschensis*	WM	Ra	LC
Family: Alaudidae				
Oriental Skylark	*Alauda gulgula*	R	UC	LC
Ashy-crowned Sparrow-Lark	*Eremopterix griseus*	R	UC	LC
Singing Bushlark+	*Mirafra javanica*	R	UC	LC
Jerdon's Bushlark+	*Plocealauda affinis*	R	C	LC
Indian Bushlark	*Plocealauda erythroptera*	R	Ra	LC
Family: Cisticolidae				
Zitting Cisticola+	*Cisticola juncidis*	R	UC	LC
Common Tailorbird	*Orthotomus sutorius*	R	C	LC
Plain Prinia	*Prinia inornata*	R	UC	LC
Ashy Prinia+	*Prinia socialis*	R	C	LC
Family: Acrocephalidae				
Blyth's Reed Warbler	*Acrocephalus dumetorum*	WM	Ra	LC
Family: Hirundinidae				
Eastern Red-rumped Swallow	*Cecropis daurica*	WM	Ra	LC
Barn Swallow	*Hirundo rustica*	WM*	C	LC
Wire-tailed Swallow+	*Hirundo smithii*	R	C	LC
Family: Pycnonotidae				
White-browed Bulbul	*Pycnonotus luteolus*	R	UC	LC
Red-vented Bulbul	*Pycnonotus cafer*	R	C	LC
Family: Leiothrichidae				
Yellow-billed Babbler+	*Argya affinis*	R	C	LC
Family: Sturnidae				
Common Myna	*Acridotheres tristis*	R	C	LC
Rosy Starling	*Pastor roseus*	WM	Ra	LC
Brahminy Starling	*Sturnia pagodarum*	R	C	LC
Family: Muscicapidae				
Indian Robin	*Copsychus fulicatus*	R	UC	LC
Oriental Magpie-Robin	*Copsychus saularis*	R	C	LC
Pied Bushchat +	*Saxicola caprata*	R	Ra	LC

Migratory status: R—Resident | WM—Winter Migrant | LM—Local Migrant | PM—Passage Migrant | SM—Summer Migrant | WM*—Over-summering winter migrant | WM#—Winter migrant with breeding records in Tamil Nadu | SM#—Summer migrant with breeding records in Tamil Nadu.
Frequency of occurrence: C— Common | UC—Uncommon | Ra—Rare | VR—Very Rare.
IUCN Red List status: LC—Least Concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered.
+—New records added in the present study.

and contemporary records, comprises 221 species. The avifaunal assemblage was taxonomically dominated by Charadriiformes (56 species) and Passeriformes (55 species), followed by Pelecaniformes (17 species) and Accipitriformes (13 species). All remaining orders showed moderate to low representation, with several taxa represented by few or single species, reflecting variation in species richness among orders (Image 2).

The predominance of Charadriiformes and Pelecaniformes reflects the importance of aquatic habitats, particularly mudflats, sandbanks and shallow wetlands, within the study area. The comparable representation of Passeriformes reflects the presence of dense mangrove vegetation and surrounding terrestrial habitats, highlighting the heterogeneous nature of the ecosystem. Similar taxonomic patterns have been reported from comparable coastal wetland ecosystems (Balachandran & Thirunavukarasu 2022; Byju et al. 2023a; Alam et al. 2023; Shree & Malathi 2024). Regional inventories have reported 160 species from Muthupet (Deiva 1999), 178 species from Kalpakkam (Hussain et al. 2011), 294 species from Point Calimere (Balachandran

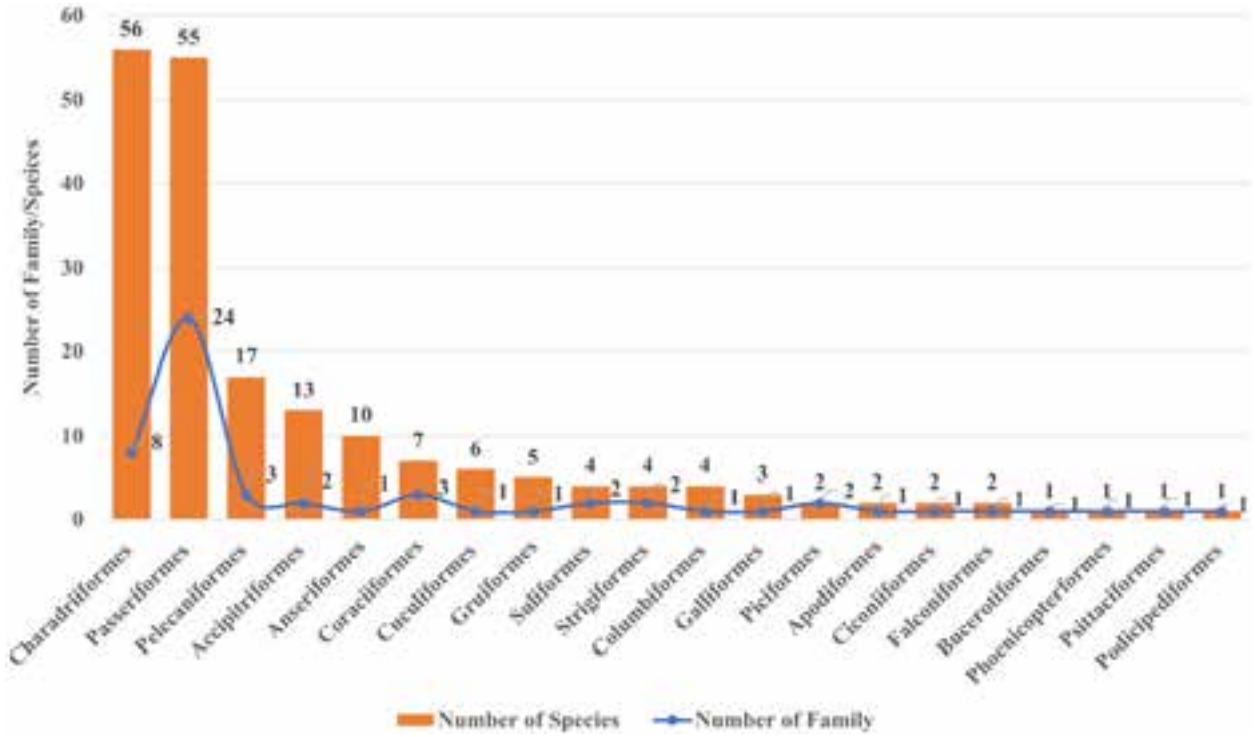

Image 2. Community richness of avian orders and families in Pichavaram Mangrove Forest.

& Thirunavukarasu 2022), 107 species from Karangadu (Byju et al. 2023a), 124 species from Muttukadu (Shree & Malathi 2024), and 161 species from Pulicat Lake (Alam et al. 2023). While these comparisons provide useful regional context, differences in survey duration, sampling effort, seasonal coverage, habitat extent, and survey methodologies among studies may influence recorded species richness and should be considered when interpreting direct comparisons across sites.

Based on the cumulative inventory of 221 species, PMF represents one of the more species-rich mangrove-associated bird habitats documented along the east coast of India and within Tamil Nadu; its avifaunal diversity ranks second only to that of Point Calimere. Such comparisons should be interpreted cautiously due to differences in sampling effort and habitat extent. The earliest comprehensive inventory conducted in PMF between 1984 and 1988 recorded 177 species (Sampath & Krishnamurthy 1993), whereas a subsequent survey during 2004–2007 documented only 100 species (Sandilyan 2012). Across the three survey periods mentioned (including the present study), 94 species were consistently recorded, indicating a core assemblage that has persisted over time. In addition to these shared species, 58 species recorded during the 1984–1988 study were also detected in the present investigation but were not documented during the 2004–2007 survey. In contrast, 19 species reported by Sampath & Krishnamurthy (1993) and six species reported by Sandilyan (2012), a total of 25 species, were not detected during the current survey. The present study additionally documented 44 species that had not been reported in previous inventories, thereby substantially expanding the known avifaunal diversity of PMF (Table 1).

Of the 196 species recorded during this survey, 98 were waterbirds, and 98 were terrestrial birds. Compared with the historical baseline of 177 species reported by Sampath & Krishnamurthy (1993), 152 species (85.8%) were recorded again in the present study. Among the major taxonomic groups, Pelecaniformes showed the highest proportion of species recorded (100%; 15 of 15 species), followed by Charadriiformes (93.8%; 45 of 48 species), Anseriformes (88.9%; 8 of 9 species), and Passeriformes (75.6%; 38 of 49 species). Families represented by a single species in the historical baseline and absent from the present survey included Turnicidae (Small Buttonquail *Turnix sylvaticus*), Sylviidae (Lesser Whitethroat *Curruca curruca*), and Phylloscopidae (Large-billed Leaf Warbler *Phylloscopus magnirostris*). This observed loss aligns with previous research attributing such declines to a combination of habitat degradation, aquaculture expansion, tourism-induced disturbances, and cyclonic impacts (Sandilyan 2017; Byju et al. 2026).

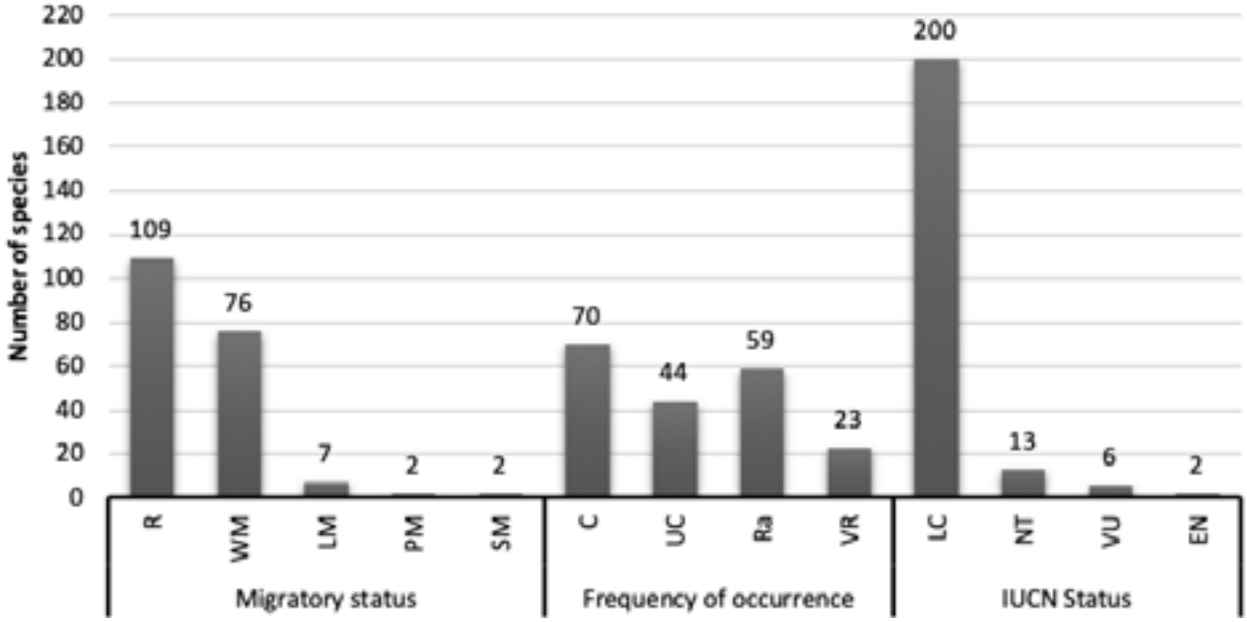

Image 3. Avifauna of Pichavaram Mangrove Forest based on migratory status, occurrence and IUCN Red List status.

Table 2. Species reported in previous surveys of Pichavaram Mangrove Forest by Sampath & Krishnamurthy (1993) and Sandilyan (2012) that were not recorded during the present study (n = 25).

Common name	Scientific name	IUCN Red List status
Egyptian Vulture	*Neophron percnopterus*	EN
Asian Dowitcher	*Limnodromus semipalmatus*	NT
Red-necked Falcon	*Falco chicquera*	NT
Asian Brown Flycatcher	*Muscicapa dauurica*	LC
Bay-backed Shrike	*Lanius vittatus*	LC
Bengal Bushlark	*Plocealauda assamica*	LC
Besra	*Tachyspiza virgata*	LC
Brown-breasted Flycatcher	*Muscicapa muttui*	LC
Common Babbler	*Argya caudata*	LC
Chestnut-headed Bee-eater	*Merops leschenaulti*	LC
Crested Lark	*Galerida cristata*	LC
Eurasian Sparrowhawk	*Accipiter nisus*	LC
Large-billed Leaf Warbler	*Phylloscopus magnirostris*	LC
Lesser Whitethroat	*Curruca curruca*	LC
Long-tailed Shrike	*Lanius schach*	LC
Mallard	*Anas platyrhynchos*	LC
Montagu's Harrier	*Circus pygargus*	LC
Pied Avocet	*Recurvirostra avosetta*	LC
Pied Harrier	*Circus melanoleucos*	LC
Slaty-breasted Rail	*Lewinia striata*	LC
Slaty-legged Crake	*Rallina eurizonoides*	LC
Small Buttonquail	*Turnix sylvaticus*	LC
Streak-throated Swallow	*Petrochelidon fluvicola*	LC
Thick-billed Warbler	*Arundinax aedon*	LC
White Stork	*Ciconia ciconia*	LC

The migratory composition revealed the dominance of resident species (109 species; 55.6%), followed by winter migrants (76 species; 38.8%), local migrants (7 species; 3.6%), passage migrants (2 species; 1%), and summer migrants (2 species; 1%). Notably, 15 typically migratory species, including Grey Plover *Pluvialis squatarola* (Image 6), Greater Sand Plover *Anarhynchus leschenaultii*, Pacific Golden-Plover *Pluvialis fulva* (Image 7), Whimbrel *Numenius phaeopus*, Common Greenshank *Tringa nebularia*, Common Redshank *Tringa totanus,* Kentish Plover *Anarhynchus alexandrinus*, Tibetan Sand-Plover *Anarhynchus atrifrons*, and Barn Swallow *Hirundo rustica* were recorded throughout the year. These species are winter migrants in the region (Grimmett et al. 2016); however, their year-round occurrence in PMF suggests the presence of over-summering individuals, a phenomenon that has also been documented along the southeastern coast of India (Byju et al. 2024a). The year-round occurrence of these species suggests that PMF provides suitable feeding and roosting resources for over-summering individuals beyond the typical wintering period (van de Kam et al. 2004). In addition, five species are classified as winter migrants and one species is classified as a summer migrant with published breeding records from Tamil Nadu and are denoted in present checklist (Subramanya 2005; Byju et al. 2023b, 2025; Hussain & Hussain 2026). The proportion of winter migrants aligns with other eastern coast studies (25–42 %) (Abhisheka et al. 2013; Alam et al. 2023; Byju et al. 2024b; Shree & Malathi 2024) (Image 3). These findings

Image 4. An aerial view of the mangrove forest in Pichavaram Reserve Forest.

Image 5. An aerial view of the mudflat and sandy beach in Killai Reserve Forest.

highlight the continued importance of the PMF as a key coastal wetland supporting resident and migratory bird communities along the Coromandel Coast.

The frequency of occurrence was classified into four categories based on sighting frequency (Image 3). The Common category (35.7%) included 70 species, primarily from Scolopacidae, Ardeidae, Laridae, Columbidae, and Motacillidae. Frequently recorded shorebird and water-associated species included Great Crested Tern *Thalasseus bergii* (Image 8), Lesser Crested Tern *Thalasseus bengalensis*, Caspian Tern *Hydroprogne caspia*, Gull-billed Tern *Gelochelidon nilotica*, Wood Sandpiper *Tringa glareola*, Pacific Golden-Plover, and Whimbrel, consistent with previous studies (Sampath & Krishnamurthy 1993; Deiva 1999; Byju et al. 2024b; Shree & Malathi 2024). The Uncommon category (22.5%) included 44 species such as members of Sturnidae, Meropidae, Strigidae, and Accipitridae, likely to reflect habitat specificity or seasonal variation. Rare species (30.1%), including Black-capped Kingfisher *Halcyon pileata*, Laughing Dove *Spilopelia senegalensis*, Grey-bellied Cuckoo *Cacomantis passerinus*, Little Swift *Apus affinis*, Eurasian Coot *Fulica atra*, and Grey-headed Swamphen *Porphyrio poliocephalus* were recorded sporadically and were often associated with specific habitat features within PMF, including mangrove areas, shallow-water areas, and adjacent agricultural habitats. The Very Rare category (11.7%) comprised 23 species, including Watercock *Gallicrex cinerea*, Western Marsh Harrier *Circus aeruginosus*, Pallid Harrier *Circus macrourus*, Cotton Pygmy-Goose *Nettapus coromandelianus*, and Northern Shoveler *Spatula clypeata*, each recorded only once during this study. Similar patterns of infrequent occurrence of the above taxa have been reported from the Muthupet Mangrove Forest (Deiva 1999). The frequency of occurrence pattern exhibited unequal distribution, with many frequent species and comparatively few infrequent species. The observed pattern is consistent with findings from the southeast coastal mangrove ecosystems reported by Byju et al. (2023a).

Based on the IUCN Red List (IUCN 2025), of the 221 species, 200 were classified (Image 3) as 'Least Concern', 13 as 'Near Threatened', including Dunlin *Calidris alpina*, Ruddy Turnstone *Arenaria interpres* (Image 9), Eurasian Curlew *Numenius arquata* (Image 10), and Bar-tailed Godwit *Limosa lapponica* (Image 11). Six species were classified as 'Vulnerable', including Curlew Sandpiper *Calidris ferruginea* (Image 12), Broad-billed Sandpiper *Calidris falcinellus*, River Tern *Sterna aurantia*, Greater Spotted Eagle *Clanga clanga*, Grey Plover, and Black-

Image 6. Grey Plover.

Image 7. A flock of Pacific Golden-Plover in the Pichavaram Mangrove Forest.

Image 8. A flock of Great Crested Tern in the Pichavaram Mangrove Forest.

Image 9. Ruddy Turnstone.

Image 10. Eurasian Curlew.

Image 11. Bar-tailed Godwit.

Image 12. Curlew Sandpiper.

Image 13. Great Knot.

capped Kingfisher, while Great Knot *Calidris tenuirostris* (Image 13) and Egyptian Vulture *Neophron percnopterus* (historical record) were categorised as 'Endangered'. The occurrence of globally threatened species highlights the conservation importance of PMF (Table 1 & 2) and its role in regional and flyway-level biodiversity conservation. Comparable studies along the east coast report similar patterns of threatened species occurrence (Byju et al. 2023a; Alam et al. 2023; Shree & Malathi 2024). The intertidal mudflats and sandbanks function as critical feeding habitats for migratory shorebirds, while mangrove habitats provide important feeding, roosting, and refuge sites for several wetland-dependent species of conservation significance. Conservation efforts should prioritize the protection and restoration of mudflat and mangrove habitats, together with the maintenance of natural tidal connectivity, to sustain habitat quality and prey availability for migratory birds (van de Kam et al. 2004). Regulation of tourism, boat traffic, and intensive fishing activities in key feeding and roosting areas is also necessary, as anthropogenic disturbance represents an important pressure on coastal wetland ecosystems (Sandilyan 2017; Byju et al. 2024b). Furthermore, long-term monitoring of threatened and migratory species should be incorporated into management programmes to evaluate population trends and habitat use (Rashiba et al. 2022; Byju et al. 2026). The ongoing monitoring surveys established through the present study provide a valuable foundation for tracking temporal changes in avian diversity, habitat use, and population trends within PMF. Such measures would strengthen the role of PMF as an important stopover and wintering site for migratory birds along the Central Asian Flyway.

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ARTICLE

Snake diversity based on rescue records in urban Jaipur, Rajasthan, India

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Abstract: We documented the snakes of Jaipur City, Rajasthan, India, using rescue records generated through a structured volunteer network, comprising primary data collected between January 2024 and October 2025, supplemented by historical records. A total of 787 primary rescue events along with past records (before January 2024), yielded records of 21 snake species across six families, including three venomous and 18 non-venomous taxa. Rescue records were dominated by *Naja naja* (65.4% of all rescues), while other frequently recorded species included *Platyceps ventromaculatus* and *Spalerosophis atriceps*. In contrast, fossorial taxa such as *Indotyphlops braminus* and *Pseudoindotyphlops porrectus* were rarely encountered. In addition to confirmed records, the study identifies five species whose occurrence in Jaipur is considered plausible based on regional distribution patterns and habitat continuity. Findings are interpreted as occurrence records and baseline diversity data rather than estimates of abundance.

Keywords: Citizen-derived data, human-snake interaction, *Naja naja*, snakes checklist, urban biodiversity, urban herpetofauna, urban ecology, wildlife conservation.

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Author contribution: AK and JG facilitated the fieldwork, with AK also conducting fieldwork activities. AK designed the methodology and was responsible for data analysis and manuscript preparation. JG provided subject-matter expertise and guidance throughout the study. DS provided assistance with spatial mapping and proofreading. All authors contributed to the critical revision of the manuscript and approved the final version.

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INTRODUCTION

Urban environments host a wide variety of species, yet reptiles, especially snakes, remain underrepresented in biodiversity surveys. Herpetofaunal inventories in India have recently grown, but most urban-focused research remains limited to a small number of cities. Research from Delhi (Prasad 2018; Barhadiya & Ghosh 2021), Ujjain in Madhya Pradesh (Ingle et al. 2019), Ahmedabad in Gujarat (Urfi 2005; Shroff & Mehta 2024) and Guwahati in Assam (Purkayastha et al. 2011; Purkayastha 2018) shows that Indian cities can sustain a significant variety of reptiles despite rapid land-use changes. Documenting species richness, finding new locality records, learning more about their natural history and ecology, exposing temporal activity patterns, and determining local conservation priorities have all been made possible by these inventories.

Rescue-based data collection has also been successfully implemented in a few Indian cities, including Ahmedabad (Urfi 2005; Shroff 2016), Surat, Surendranagar, Valsad, Dahod, and Vadodara (Vyas 2013) in Gujarat; Kannur in Kerala (Roshnath 2017); Bengaluru in Karnataka (Kalki et al. 2021); Kolkata in West Bengal (Kuttalam et al. 2025) and Hyderabad in Telangana (Visvanathan et al. 2026). These datasets have produced reliable baseline inventories and insightful information on urban snake records when supported by photographs and cross-referenced with secondary sources.

As far as Jaipur is concerned, early research on the diversity of the local herpetofauna has been made possible by studies conducted in protected areas within and outside Jaipur city. Surveys of reptile assemblages from Jamwa Ramgarh and Nahargarh wildlife sanctuaries revealed the diversity associated with the Aravalli hill systems and dry deciduous forest habitats in the Jaipur District (Sharma 1998, 2000). These investigations show the existence of a diverse regional species pool, even though they were restricted to secured landscapes and did not address species occurrence within the urban matrix. Therefore, the goal of this study is to create a baseline dataset of the snakes of urban Jaipur.

Study Area

Jaipur City (26.91° N, 75.79° E) (Image 1), the capital city of Rajasthan, covers approximately 467 km² and supports a population exceeding four million. The city falls in the hot semi-arid (BSh) zone under the updated Köppen–Geiger classification (Kottek et al. 2006) characterised by extremely hot summers, monsoonal rainfall, and mild winters with sharp day-night temperature drops. Most of its ~650 mm annual rainfall occurs between July and September. Temperature fluctuations are substantial: while winter days remain warm and pleasant, night-time lows frequently plunge to around 5°C, in sharp contrast to summer peaks above 45°C.

The city exhibits distinct spatial and ecological heterogeneity: eastern Jaipur is shaped by the Aravali hill systems and fragmented forests, western sections are densely residential and industrial, and southern Jaipur transitions into peri-urban agricultural landscapes (Vaishnav et al. 2024; Dadhich & Dadhich 2026). Broadly categorised within an arid-to-semi-arid zone, the city's overall urban green cover spans only 24.75 km², resulting in a remarkably low per capita green space of 5.75 m² per resident (Oraon et al. 2025). Urban expansion has altered Jaipur's ecological character through increased built-up area, road networks, and drainage alterations (Jalan & Sharma 2014; Vaishnav et al. 2024; Dadhich & Dadhich 2026).

MATERIALS AND METHODS

To create a verified inventory of snakes in Jaipur City, primary and secondary data, in the form of rescue records, were used. The primary dataset used in this study was derived from rescue records attended by Hope & Beyond, Jaipur (a registered NGO active in wildlife conservation since 2015), between January 2024 and October 2025. During the study period, a 24 × 7 rescue helpline operated with 5–6 active rescuers, enabling coverage of all municipal zones in Jaipur City. All rescue and release activities followed Indian wildlife protection regulations and standard operating protocols of the Rajasthan Forest Department. Secondary data included historical rescue records from Hope & Beyond (2015–2023). Opportunistically derived biodiversity datasets, such as rescue records, are increasingly recognised as valuable sources of species occurrence information, particularly in urban and data-deficient landscapes, despite known limitations associated with uneven reporting effort and species detectability (Chandler et al. 2017; Johnston et al. 2022). To triangulate the data collected from primary and secondary sources, supplementary information on unusual rescue events and species occurrences was gathered through interview schedules with independent rescuers and members of other organisations operating in Jaipur city and its outskirts, including the Eco Rescuers Foundation and the Nature Care NGO. Wherever possible, records were cross-validated using photographic records and locality information.

A total of 939 rescue-calls were recorded. A total of

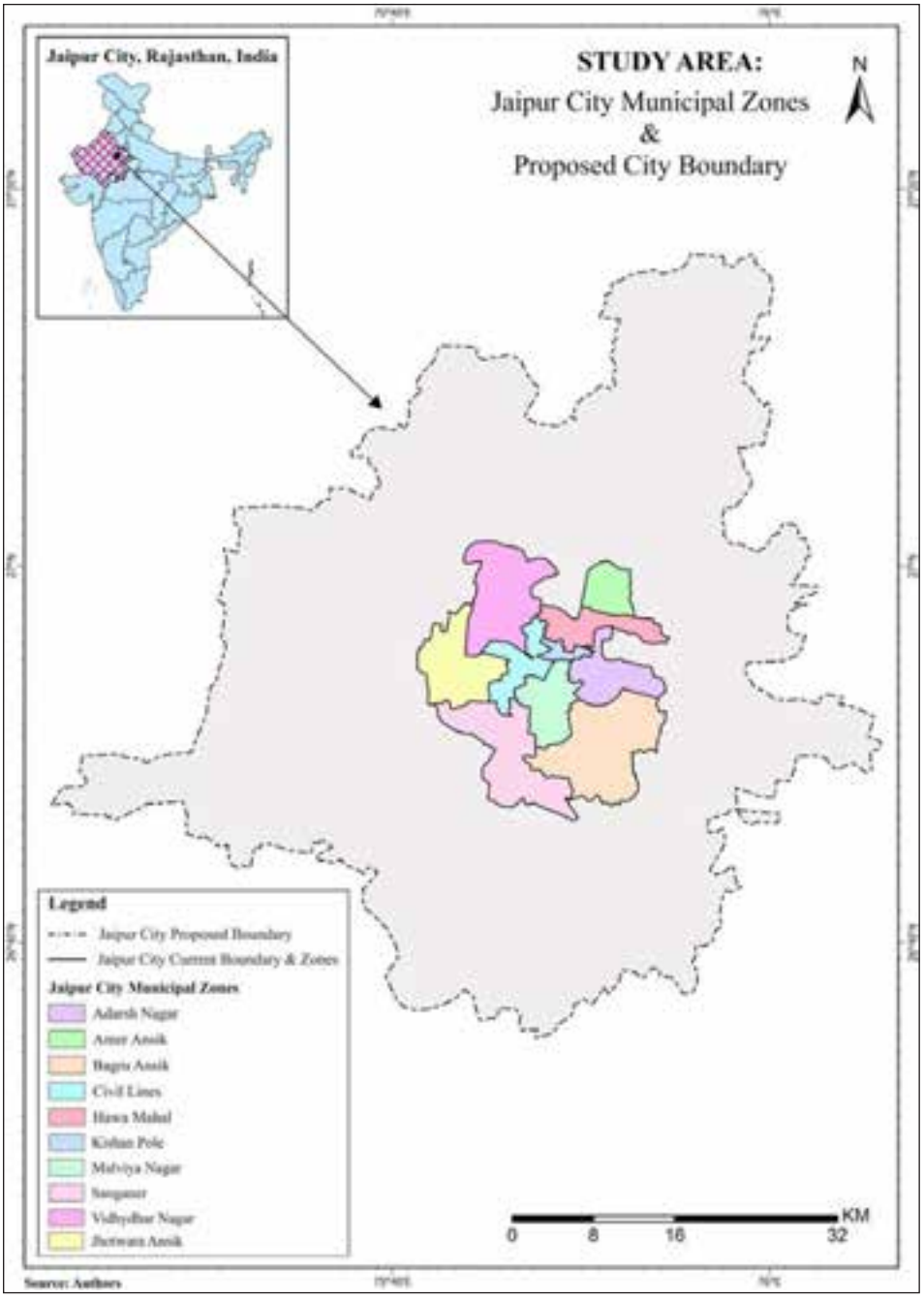

Image 1. Study area – Jaipur City, Rajasthan, India.

787 successful snake rescues were retained as primary data for analysis, after 'no rescue at location' and rescue of other wildlife incidents were eliminated. For each event, standardised forms were used to document date, time, GPS coordinates (WGS84), habitat notes, rescuer identity, and photographs (Dorcas & Willson 2009). These successful rescues occurred across 356 unique field days, representing the study's temporal sampling effort. All primary and secondary records were consolidated in a master spreadsheet in MS Excel (2013 version) for cleaning and preparation before computing rescue frequencies. Species encounter frequencies were evaluated using two independent parameters (2024–2025): (a) proportional representation in total rescues (n = 787) and (b) proportional representation in unique rescue days (n = 356). This dual-parametric system avoids biases associated with single-day clustering and effort variation while remaining appropriate for encounter-

based datasets.

Taxonomic identification and nomenclature of recorded species follow standard herpetological literature and recent taxonomic revisions, including Smith (1943), Whitaker & Captain (2004), Vogel & van Rooijen (2011), Pyron & Wallach (2014), Wallach et al. (2014), Boundy (2020), Bandara et al. (2022), Moradi et al. (2024), and Sidharthan et al. (2024). Previous studies on snakes from Jaipur were reviewed to identify gaps between pre-existing data and current findings; this was also done to anticipate potential species not yet reported from Jaipur City or the broader district.

We acknowledge certain limitations within which this study functions: (i) Rescue-based datasets are influenced by human reporting behaviour, rescuer accessibility, and species detectability, and therefore represent encounter-based occurrence records rather than direct measures of abundance; (ii) Hope & Beyond, Jaipur, follows a coexistence-oriented rescue approach; therefore, not all received calls resulted in rescue visits. Calls were often declined when snakes were identified as non-venomous and capable of dispersing naturally, when sightings were reported several hours later, when snakes entered inaccessible spaces, or when callers withdrew requests. Such filtering may have reduced records of non-venomous, fossorial, arboreal, nocturnal, and less conspicuous species; (iii) The present study is intended as an encounter-based indication of snake diversity, and not as a systematic assessment of snake abundance or occupancy.

RESULTS

Table 1 shows that primary rescue data documented 12 snake species from Jaipur City during the study period, with an additional record of *Python molurus* retained as a noteworthy out-of-study-period case. *Naja naja* (Linnaeus, 1758) was the most frequently rescued species with 515 rescue records, followed by *Platyceps ventromaculatus* (Gray, 1834) (109 rescues) and *Spalerosophis atriceps* (Fischer, 1885) (46 rescues). Moderate rescue frequencies were recorded for *Eryx conicus* (Schneider, 1801) (29 rescues), *Ptyas mucosa* (Linnaeus, 1758) (28 rescues), and *Coelognathus helena helena* (Daudin, 1803) (25 rescues). Less frequently encountered species included *Fowlea piscator* (Schneider, 1799) (13 rescues), *Eryx johnii* (Russell, 1801) (10 rescues), *Bungarus caeruleus* (Schneider, 1801) (5 rescues), and *Lycodon aulicus* (Linnaeus, 1758) (4 rescues). Rare rescue records included single observations of *Grypotyphlops acutus* (Duméril & Bibron, 1844) and *Pseudoindotyphlops porrectus* (Stoliczka, 1871). An additional rescue record of *Python molurus* (Linnaeus, 1758) was documented outside the defined primary study period; however, owing to the unusual occurrence of the species within the urban landscape of Jaipur City, the record was retained and discussed separately in the next section.

Table 1. Primary data (Jan 2024–Oct 2025) on snake rescues in Jaipur, Rajasthan, India.

	Species	Total rescues	% of total rescues	Rescue days	% of rescue days
1.	*Naja naja*	515	65.4%	246	69.1%
2.	*Platyceps ventromaculatus*	109	13.8%	95	26.6%
3.	*Spalerosophis atriceps*	46	5.8%	41	11.5%
4.	*Eryx conicus*	29	3.6%	29	8.0%
5.	*Ptyas mucosa*	28	3.5%	28	7.8%
6.	*Coelognathus helena helena*	25	3.1%	25	7.0%
7.	*Fowlea piscator*	13	1.6%	13	3.6%
8.	*Eryx johnii*	10	1.2%	10	2.7%
9.	*Bungarus caeruleus*	5	0.5%	5	1.3%
10	*Lycodon aulicus*	4	0.4%	4	1.0%
11.	*Grypotyphlops acutus*	1	0.12%	1	0.28%
12.	*Pseudoindotyphlops porrectus*	1	0.12%	1	0.28%
13.	*Python molurus* *	1	0.12%	1	0.28%

*Unique case study: Rescued outside of primary data collection duration, i.e., in December 2025.

Table 2 shows that secondary data compiled from Hope & Beyond records and interviews with other NGOs revealed eight additional snake species not recorded during primary data collection. These records included *Indotyphlops braminus* (Daudin, 1803), *Dendrelaphis proarchos* (Wall, 1909), *Dendrelaphis tristis* (Daudin, 1803), *Oligodon russelius* (Daudin, 1803), *Oligodon taeniolatus* (Jerdon, 1853), *Boiga trigonata* (Schneider, 1802), *Sibynophis subpunctatus* (Duméril, Bibron & Duméril, 1854), and *Echis carinatus sochureki* Stemmler, 1969. Integration of 12 species recorded during the defined primary study period, one additional out-of-period record of *Python molurus*, and eight species from historical and supplementary records resulted in a consolidated dataset of 21 snake species representing six families documented from Jaipur City (Table 3; Image 2).

DISCUSSION

The sampling bias associated with rescue-based datasets requires reiteration to avoid misinterpretation

Image 2. Photo records of snakes of Jaipur City: 1—*Grypotyphlops acutus* | 2—*Indotyphlops braminus* | 3—*Pseudoindotyphlops porrectus* | 4—*Eryx conicus* | 5—*Eryx johnii* | 6—*Python molurus* | 7—*Boiga trigonata* | 8—*Coelognathus helena helena* | 9—Dendrelaphis proarchos | 10—*Dendrelaphis tristis* | 11—*Fowlea piscator* | 12—*Lycodon aulicus* | 13—*Oligodon russelius* | 14—*Oligodon taeniolatus* | 15—*Platyceps ventromaculatus*. © Authors and volunteers of Hope & Beyond, Jaipur.

Image 2 continued. 16—*Ptyas mucosa* | 17—*Sibynophis subpunctatus* | 18—*Spalerosophis atriceps* | 19—*Bungarus caeruleus* | 20—*Naja naja* | 21—*Echis carinatus sochureki*. © Authors and Volunteers of Hope & Beyond, Jaipur.

Table 2. Secondary data from Hope & Beyond (2015–2023) and supplementary data from other organisations (2009–2026): additional species and unique rescue records.

	Snake species rescued	Total rescues	Rescue days	Year	Citation/ Organisation
1.	*Indotyphlops braminus*	19	1	2023	Hope & Beyond
2.	*Dendrelaphis proarchos*	4	4	1 in 2022 2 in 2023 1 in 2026	Sharma et al. 2023 Raksha Foundation and Hope & Beyond Hope & Beyond
3.	*Echis carinatus sochureki*	4	4	2 in 2017 1 in 2021 1 in 2023	Nature Care Eco Rescuers Hope & Beyond
4.	*Boiga trigonata*	3	3	2016	Hope & Beyond
5.	*Oligodon russelius*	2	2	2018	Hope & Beyond
6.	*Oligodon taeniolatus*	2	2	2017	Hope & Beyond
7.	*Pseudoindotyphlops porrectus*	2	2	2023	Hope & Beyond
8.	*Python molurus*	2	2	1 in 2017 1 in 2019	Raksha Foundation Hope & Beyond
9.	*Dendrelaphis tristis*	1	1	2021	Hope & Beyond
10.	*Sibynophis subpunctatus*	1	1	2009	Raksha Foundation

of the present study's scope. Consequently, the absence of particular species from rescue records should not be interpreted as definitive evidence of their absence from the urban environment (Kéry 2002). This limitation may be especially relevant for fossorial, arboreal, nocturnal, or cryptic species, which are less likely to be encountered or reported through rescue-based approaches (Henderson et al. 2016). Reptile detectability is often influenced by factors such as habitat use, activity patterns, and behavioural strategies that reduce visibility to observers (Boback et al. 2020). Arboreal species often occupy vertically complex microhabitats that restrict visibility and access to observers, while fossorial species may remain concealed underground or within substrate layers for extended periods (Henderson et al. 2016).

Indotyphlops braminus and *P. porrectus*, both small fossorial species, were poorly represented in rescue records, despite *I. braminus* being widely regarded as one of the most common snakes in India and frequently encountered as incidental bycatch during soil excavation or gardening activities (Whitaker & Captain 2004). The low detectability of both species is likely linked to their

Table 3. Snake diversity of Jaipur City (Rajasthan, India), compiled from primary and secondary/supplementary rescue records.

	Snake species	Common names
Family Typhlopidae		
1.	*Grypotyphlops acutus* (Duméril & Bibron, 1844)	Beaked Worm Snake
2.	*Indotyphlops braminus* (Daudin, 1803)	Brahminy Worm Snake
3.	*Pseudoindotyphlops porrectus* (Stoliczka, 1871)	Slender Worm Snake
Family Boidae		
4.	*Eryx conicus* (Schneider, 1801)	Common Sand Boa
5.	*Eryx johnii* (Russell, 1801)	Red Sand Boa
Family Pythonidae		
6.	*Python molurus* (Linnaeus, 1758)	Indian Rock Python
Family Colubridae		
7.	*Boiga trigonata* (Schneider, 1802)	Common Cat Snake
8.	*Coelognathus helena helena* (Daudin, 1803)	Common Trinket
9.	*Dendrelaphis proarchos* (Wall, 1909)	Eastern Bronzeback
10.	*Dendrelaphis tristis* (Daudin, 1803)	Common Bronzeback
11.	*Fowlea piscator* (Schneider, 1799)	Checkered Keelback
12.	*Lycodon aulicus* (Linnaeus, 1758)	Common Wolf Snake
13.	*Oligodon russelius* (Daudin, 1803)	Northern Kukri Snake
14.	*Oligodon taeniolatus* (Jerdon, 1853)	Streaked Kukri Snake
15.	*Platyceps ventromaculatus* (Gray, 1834)	Glossy-bellied Racer
16.	*Ptyas mucosa* (Linnaeus, 1758)	Indian Rat Snake
17.	*Sibynophis subpunctatus* (Duméril, Bibron & Duméril, 1854)	Dumeril's Black-headed Snake
18.	*Spalerosophis atriceps* (Fischer, 1885)	Black-headed Royal Snake
Family Elapidae		
19.	*Bungarus caeruleus* (Schneider, 1801)	Common Krait
20.	*Naja naja* (Linnaeus, 1758)	Indian Cobra
Family Viperidae		
21.	*Echis carinatus sochureki* Stemmler, 1969	Sochureki's Saw-scaled Viper

subterranean habits, small body size, and harmless appearance, which reduce the likelihood of rescue calls. In the case of *I. braminus*, rescue calls were generally made only when many individuals were observed together; for example, a 2023 secondary-data record from Jaipur city documented 19 individuals coiled at a single location. Conversely, the medically significant *N. naja* was disproportionately represented in the dataset, likely reflecting heightened public fear, rapid reporting, and greater willingness of rescuers to attend such calls. Rescue frequency of highly visible venomous species should therefore not be interpreted as a direct indicator of ecological dominance within the urban assemblage.

Records of *Python molurus* further highlight the importance of integrating secondary and primary datasets. Secondary records document the species from Vatika (in 2019) located within the Sanganer municipal zone. Vatika is a south-east peri-urban region of Jaipur City, characterised by mostly open or agricultural land and a sparsely built-up area, with the Dravyavati River running through it alongside other seasonally accumulated surface drainage sites. Additionally, a juvenile *P. molurus* (approximately 36 inches in length) with visible injuries near the head was rescued near Hawa Mahal, outside the defined primary study period, in December 2025. Its unusual presence in a heavily built-up, human-dominated area, with no resemblance to its known habitat, prompted enquiry. Local enquiries suggested that the animal had fallen from a vehicle, raising suspicions of accidental translocation or illegal transport.

The occurrence of *Dendrelaphis proarchos* in Jaipur is worth discussing. Because, so far, the species is understood to be primarily associated with the wet forests of northeastern India and the Indo-Burmese region (Biakzuala et al. 2022). Its documentation from Jaipur (Rajasthan) and Gwalior (Madhya Pradesh) has piqued researchers' curiosity about its presence in climatically dissimilar and geographically distant parts of north-western and central India (Sharma et al. 2023; Sharma & Verma 2023). Additional published reports from Surat (Gujarat), where the species has been interpreted as a stray introduction, and from Thane (Maharashtra), where its occurrence has been suggested as part of a possibly overlooked population, along with inconclusive bronzeback records from Mumbai, further indicate that comparable forms are being encountered across north-western India (Parmar et al. 2024; Mohandas & Dnyaneshwar 2025; Puranik et al. 2025). However, the biogeographic significance of these records requires a larger sample size from new ranges with dissimilar habitats. More recently, another study has reported a road-killed specimen of the species from Dudhwa Tiger Reserve, Uttar Pradesh, interpreting it in the context of range expansion and adding more complexity to the species' distributional status in the Indian subcontinent (Sainy et al. 2026). Informal communication within the snake rescue network has further indicated three additional unpublished records from Jaipur (bringing the total to four), as well as one each from multiple districts of Rajasthan (Alwar, Tonk, Udaipur, and Sirohi); Delhi and Dehradun (Uttarakhand), suggesting that its occurrence

may not be entirely isolated. Nevertheless, these records were not independently verified in the present study. With these new records coming to light, we believe they provide reasonable doubt that this population is more widespread in north, north-western and central India and warrant further scrutiny to understand its ecology.

Another noteworthy observation from the primary dataset was the record of *Grypotyphlops acutus*. Within Rajasthan, the species has previously been reported from Udaipur (Sharma 1999; Sharma et al. 2001; Bhatnagar & Mahur 2008, 2009) and Bikaner (Kumawat & Purohit 2021), while its northernmost known record in India is from Delhi (Barhadiya & Ghosh 2024). The present study further extends its documented occurrence to Jaipur City.

Acknowledging the previously mentioned limitations, the current data includes a subset of species likely to occur within Jaipur City, based on regional distribution and habitat continuity. The presence of *Ahaetulla laudankia* has been confirmed from Sariska Tiger Reserve in Rajasthan, representing a northern extension of its known range within the Aravalli system (Sengupta & Chandramouli 2020). Similarly, *Lycodon striatus* has been recorded from semi-arid rocky landscapes across northwestern India, including Rajasthan (Amarasinghe et al. 2023). Both *Myriopholis blanfordi* and *M. macrorhyncha* / *M. hamulirostris* complex (fide Wallach et al. 2014; Boundy 2020; Moradi et al. 2024) have historically been reported from arid and semi-arid regions of northwestern India, including records from Ambala (Haryana) and from Pilani and Jodhpur (Rajasthan). At the same time, the aforesaid taxa have also been confirmed from multiple localities in Gujarat (Patel et al. 2022). Their occurrence across the arid and semi-arid belt of the Aravalli-associated landscapes makes their presence in the peri-urban fringes of Jaipur ecologically plausible, even if undetected by rescue-based surveys that necessarily under-represent small burrowing snakes. *Psammophis leithii* is widely distributed across northwestern India and occupies habitat types comparable to those persisting in Jaipur's peri-urban landscape (Whitaker & Captain 2004). These species are associated with rocky outcrops, scrublands, open plains, and dry deciduous habitat mosaics that continue to persist in fragmented form within and around Jaipur City. Given their broad regional distribution and repeated records from areas immediately surrounding Jaipur, their complete absence from the intervening urban matrix appears unlikely. Their non-detection is therefore interpreted as a consequence of low encounter probability rather than ecological unsuitability.

In conclusion, urban ecology often exposes dissonance between how cities are envisioned and planned and the wildlife they inadvertently host. Among these, snakes remain particularly misunderstood and structurally excluded from urban decision-making, despite their continued persistence in densely modified landscapes. The present study, with its contribution to the existing literature and its exposed limitations, highlights the need for a more systematic, standardised, and collaborative framework for documenting urban snake diversity in Jaipur. Integration of rescue networks through coherent long-term data collection by volunteers trained in basic snake ecology, responsible data sharing, and supervision by relevant authorities seems to be the way forward.

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ARTICLE

Assessment of ichthyofaunal diversity of the suborder Cyprinoidei Fitzinger, 1832 (Actinopterygii: Cypriniformes) of western Indian Himalayan Region: present status and conservation - a systematic review

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Abstract: This review discusses the present status of freshwater fish families – Cyprinidae, Danionodae, and Xenocyprinidae of suborder Cyprinoidei and their conservation status, threats to the species diversity and the community-based conservation across the western Himalayan region. The family Cyprinidae, the largest among freshwater fish, consists of over 1,840 species; whereas Danionidae includes 375 species and Xenocyprinidae comprises around 173 species globally. A total of 35 genera and 76 species have been reported from various rivers and streams of four Indian Himalayan states. Of these, 67 species are classified as 'Least Concern', four as 'Vulnerable', two as 'Near Threatened', and one as 'Endangered' species as per the IUCN Red List. Uttarakhand exhibits the maximum species count (63) followed by Jammu & Kashmir (47), Ladakh (38), and Himachal Pradesh (36). The major threats faced by freshwater fish are damming, habitat fragmentation, pollution, invasive species, and climate change. Consequently, modern policies and community-led conservation initiatives play a vital role in preserving these freshwater ecosystems.

Keywords: Community conservation, Cyprinidae, fish diversity, freshwater conservation, freshwater ecology, habitat, IHR, India, IUCN status, rivers.

Abbreviations: IHR—Indian Himalayan Region | IUCN—International Union for Conservation of Nature.

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Author contribution: NC—conceptualization, literature survey, data collection, data organization and curation, data analysis, and manuscript writing and preparation of the final manuscript. DS—conceptualization, development of the study framework, editing, supervision and mentorship. SS—coordination and supervision of the study, and critical review of the manuscript.

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INTRODUCTION

The Indian Himalayan region extends approximately 2,500 km from northern Pakistan to northeastern India, covering an area of about 750,000 km^2 with elevations ranging 300–8,000$^+$ m (Rawal et al. 2013). The region is divided into three zones—Greater Himalaya (Himadri), Lesser Himalaya (Himachal), and Outer Himalaya (Shivalik)—that play a crucial role for ecological security, fertile land, water resources, biodiversity, and scenic landscapes (Dimri et al. 2021). The western Himalayan states of India includes Jammu & Kashmir, Ladakh, Uttarakhand, and Himachal Pradesh forming a mountainous region with rich and fragile freshwater ecosystems created by its snow-fed rivers, streams, and lakes (Choudhary et al. 2023). Major river systems such as Ganga River and Indus River sustain diverse fish communities, particularly carps and other Cypriniformes, as well as cold water hill- stream species including *Tor* (Mahseer) and *Schizothorax* (Snow trout) (Choudhary et al. 2023; Lata et al. 2026). Studies from various Himalayan rivers have documented species distribution across the altitude gradients, with species diversity increasing downstream due to deeper, broader and more environmentally diverse river channels (Ali et al. 2018; Das et al. 2020; Johnson et al. 2020).

The suborder Cyprinoidei Fitzinger, 1832, is a diverse group of freshwater fishes and divided into 12 families, including family Cyprinidae, Danionidae, and Xenocyprinidae, which comprise of freshwater fish species of carps, danionids and sharpbellies (or minnows) respectively (Van der Laan et al. 2026). According to 'The ETYFish Project' (Scharpf 2026) Cyprinidae family (carp or minnow), represents one of the largest and most diverse groups of freshwater fish with 172 genera and 1,840 species globally, particularly in Asia, Europe, and North America. The family Danionidae (danios) comprises 39 genera and 375 species, whereas the Xenocyprinidae (sharpbellies) includes 45 genera and 173 species/subspecies. They flourish in varied aquatic habitats, such as rivers, lakes and ponds, exhibiting remarkable adaptability and unique morphological traits like streamlined body, single dorsal fin, and small mouth suited for grazing algae and organic waste (Gidmark & Simons 2014). They play a crucial role in freshwater ecosystems by contributing to nutrient cycling and serving as prey for larger species (New World Encyclopedia 2008). Several cyprinids, danionids, and xenocyprinids are at risk due to habitat loss, hydropower, overfishing, pollution, invasive species, and climate change (Bhatt et al. 2023). To protect these ecologically significant fishes and their habitats, conservation efforts are essential that emphasizes the need to address environmental degradation and promote sustainable practices (Nelson et al. 2016; Froese & Pauly 2026).

Fish studies in the Indian Himalayan Region (IHR) from past to present: a brief account

The initial prominent research on fishes in the IHR (Image 1) can be traced back to the late 19th and early 20th centuries, particularly highlighting the introduction of non-native species and the documentation of the local fish fauna. According to Burrard & Hayden (1933), the Himalayan rivers can be grouped into four distinct groups. The first one consists of the rivers in the eastern region, located between the Brahmaputra and Tista, referred to as the rivers of the Assam Himalaya. The second group includes the rivers situated between the Tista and the Kali, known as the Nepal Himalaya. The third group encompasses those rivers found between the Kali and the Sutlej, termed the Kumaon Himalaya. Finally, the last group consists of the rivers located west of the Sutlej, identified as the Punjab Himalaya (Burrard & Hayden 1933).

The discovery and documentation of fish diversity in the Indian Himalayas have spanned nearly two centuries. In the year 1838, Heckel first described 10 schizothoracin fish species from Kashmir (Von Hugel & Heckel 1838). Subsequent contributions include Menon's work documenting 23 species from Kumaon, tabulating 92 torrential species across drainage systems, and compiling a list of 218 species from extensive surveys (Menon 1949, 1954). Das (1965) recognized 15 schizothoracin species from Kashmir, while Saxena (1968) reported 68 species from Jammu & Kashmir. Tilak (1967, 1990) detailed 38 species in the River Tawi, and Talwar (1977) discovered new *Gymnocypris* species during the Ladakh Expedition.

Current studies have expanded knowledge across Himalayan regions. Sivakumar (2008) studied the Indus River. Shrestha (2008) analyzed Nepal's Himalayan waters. The regional evaluation includes Central Himalaya (Agarwal et al. 2019), Uttarakhand's reservoirs (Tripathi 2020; Tomar et al. 2021; Uniyal & Uniyal 2021), and Kashmir's River systems (Hussain & Rashid 2021; Awes et al. 2023). Recent studies by Choudhary et al. (2023) highlights the decline of native species like *Schizothorax richardsonii* and the rise of exotic species like *Cyprinus carpio* while Chaudhary et al. (2024) reported 16 species in river Asan, Uttarakhand, with cyprinids being the dominant group in both cases. This comprehensive research highlights the rich but vulnerable fish diversity

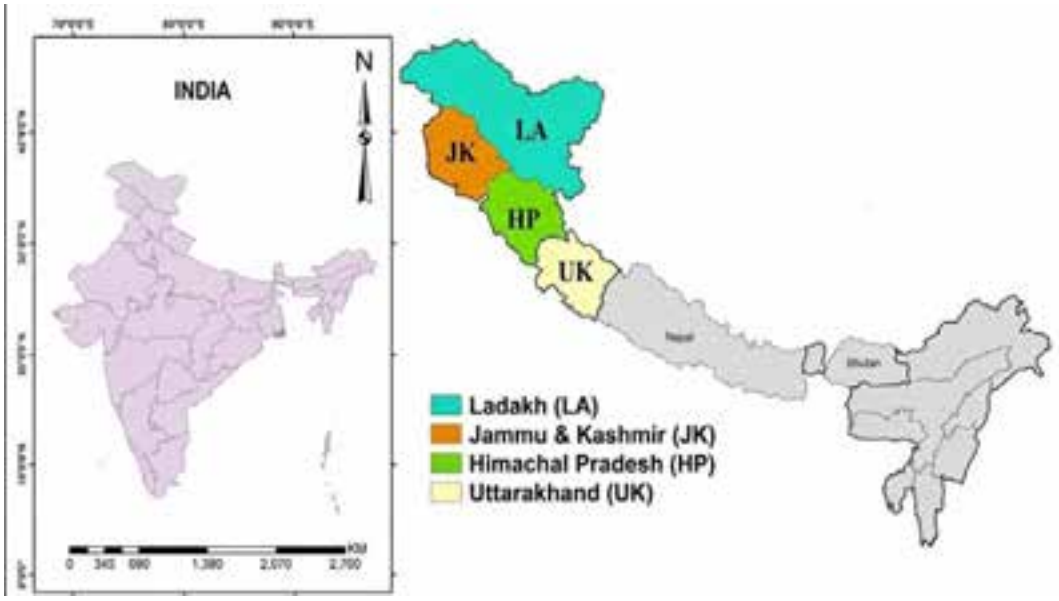

Image 1. The states of western Indian Himalayan Region.

of the Himalaya. Table 1 provides a record of suborder Cyprinoidei fish genera and species documented by various researchers from some major rivers and streams across states of western IHR, highlighting the diversity and distribution status of the fishes.

State-wise distribution of fishes species (family: Cyprinidae, Danionidae, and Xenocyprinidae) in western IHR

A state wise record detailing the distribution of various fish species belonging to the Cyprinidae, Danionidae, and Xenocyprinidae families has been presented here. The fauna of Jammu & Kashmir comprises of 47 species consisting of 30 cyprinids, 15 danionids, and two species of xenocyprinids with *Schizothorax richardsonii* (Gray, 1832) being the most abundant species (Table 2). Ladakh's fish fauna includes 38 species comprising 29 cyprinids, six danionids, and three xenocyprinids species (Table 3). In Uttarakhand, *Opsarius bendelisis* (Hamilton, 1807) is the most abundant among all 63 species recorded in the state's rivers comprising 40 cyprinids, 20 danionids, and three xenocyprinids (Table 4). Himachal Pradesh is the home to 36 species that includes 28 cyprinids and eight danionids but no xenocyprinid species (Table 5).

Present conservation status of fish species (family: Cyprinidae, Danionidae, and Xenocyprinidae) in western IHR

The IUCN Red List Categories and Criteria provide a widely recognized system for assessing species at risk of global extinction (Chandra et al. 2017). The current conservation status as per IUCN Red List for cyprinids, danionids, and xenocyprinids reported in the IHR is presented as Table 6. This table depicts a total of 76 species in the suborder – Cyprinoidei recorded from the four western Himalayan states of India comprising 50 species belonging to the family Cyprinidae, 23 species of the family Danionidae, and three species of the family Xenocyprinidae. Among these species, only one species, *Tor putitora*, falls under the 'Endangered' (EN) category. Four species, namely, *Naziritor chelynoides*, *Schizothorax richardsonii*, *S. plagiostomus*, and *S. esocinus*, are categorized as 'Vulnerable' (VU). Two species are listed as 'Near Threatened' (NT), four as 'Data Deficient' (DD), three as 'Not Evaluated' (NE), while the remaining 62 species belong to the 'Least Concern' (LC) category.

Conservation of fish diversity in western IHR

To conserve fish diversity in the Indian Himalayan region, several strategies have been proposed. Protecting and restoring habitats is critical, requiring measures to reduce pollution and manage water resources effectively (Singh 2016). Engaging local communities through community-based management can encourage sustainable practices, empowering them to monitor fish stocks and protect habitats. Constant research and monitoring are crucial for understanding ichthyofaunal diversity, identifying critical habitats, and tracking population changes to guide flexible management. Reinforcing legislation and policy frameworks is also crucial, including tougher guidelines on fishing practices, habitat destruction, and establishing protected areas.

Table 1. List of recorded fish species (suborder Cyprinoidei; family Cyprinidae, Danionidae, and Xenocyprinidae) in states of western Indian Himalayan Region.

	State	Name of river/ River system	Suborder Cyprinoidei recorded		References
			Genus	Species	
1	Jammu & Kashmir	Jhelum	3	5	Hussain & Rashid 2021
		Chenab	6	11	Bhutyal & Langer 2022; Chib et al. 2024
		Sewa	4	5	Gupta & Dutta 2021
		Ujh	14	23	Rathore & Dutta 2015
		Wajhoo Nullah	22	33	Dutta 2016
		Basantar	12	17	Sharma & Dutta 2012
		Neeru Nullah	1	1	Dutta et al. 1999; Zuber et al. 2010
		Anas nullah	7	9	Dutta 2015
		Marusudar	2	2	Magray et al. 2018
		Poonch	11	16	Awas et al. 2023
		Mendhar	10	12	Hussain & Dutta 2016
		Nowshera-Tawi	9	13	Nisa et al. 2020
		Tawi	10	12	Gandotra et al. 2017
		Lidder	2	4	Shafiya 2022; Gowhar et al. 2023
		Veshaw	2	5	Hamid & Singh 2019
		Kishanganga	1	1	Amin et al. 2022
		Sind	1	2	Gulzar et al. 2022
2	Ladakh	Indus	20	30	Sheikh et al. 2018; Choudhary et al. 2023
		Zanskar	6	8	Chandra et al. 2019; Kumar et al. 2020; Raghuvanshi et al. 2020
		Suru	3	3	Zakiya et al. 2023
		Shyok	4	4	Kumar et al. 2020
3	Uttarakhand	Song	17	25	Rauthan et al. 2023
		Dulhani	12	20	Rauthan et al. 2023
		Suswa	16	22	Rana et al. 2017; Rauthan et al. 2023
		Baldi	14	20	Rana et al. 2020; Rauthan et al. 2023
		Tons	17	25	Rauthan et al. 2023
		Asan	8	9	Chaudhary et al. 2024
		Yamuna	9	13	Rayal et al. 2021
		Ganga	13	16	Sarkar et al. 2012; Kamboj et al. 2023
		Alaknanda	7	13	Tomar et al. 2021; Malik et al. 2022
		Bhaghirathi	7	11	Agarwal et al. 2018; Rawat et al. 2020
		Bhilangna	7	13	Agarwal et al. 2011
		Nayar	6	7	Jeeva et al. 2011
		Ramganga	25	46	Das et al. 2020
		Kharmola	5	7	Singh et al. 2025
		Indrawati	3	6	Agarwal & Singh 2012
		Pinder	9	15	Agarwal et al. 2019
		Mal gad	4	6	Rayal et al. 2021
		Nandakini	5	6	Agarwal & Singh 2014
		Birahiganga	5	10	Singh & Agarwal 2017
		Laster Stream	7	12	Singh & Agarwal 2013
		Kyunja Stream	6	11	Bahuguna 2020
		Koshi	15	28	Badola et al. 2024
		Gaula	7	7	Mir et al. 2015

	State	Name of river/ River system	Suborder Cyprinoidei recorded		References
			Genus	Species	
	Uttarakhand	Mandal	15	21	Badola et al. 2024
		Palain	15	20	Badola et al. 2024
		Sona	14	21	Badola et al. 2024
		Goriganga	9	12	Ashok 2014
4	Himachal Pradesh	Beas	11	20	Kumar & Khanna 2014; Modeel et al. 2024
		Ravi	13	21	Moza 2014; Sharma & Dhanze 2018
		Maan Stream	8	10	Singh et al. 2023
		Kunah Stream	8	9	Sharma & Banyal 2024
		Son Stream	6	6	Pal et al. 2024
		Spiti	1	1	Sharma & Dhanze 2013
		Giri	6	7	Rumana et al. 2015
		Parbati	2	2	Kumar 2010
		Sutlej	11	16	Sharma & Dhanze 2018

Table 2. Fish fauna of Jammu & Kashmir (Suborder Cyprinoidei; family Cyprinidae, Danionidae, and Xenocyprididae).

TAXON **Phylum: Chordata** **Class: Actinopterygii** **Order: Cypriniformes**	**Jhelum**	**Chenab**	**Sewa**	**Ujh**	**Wajhoo Nullah**	**Basantar**	**Neeru Nullah**	**Anas nullah**	**Marusudar**	**Poonch**	**Mendhar**	**Nowshera tawi**	**Tawi**	**Lidder**	**Veshaw**	**Kishanganga**	**Sind**
Family: Cyprinidae																	
Bangana dero (Hamilton, 1822)	-	-	-	+	+	-	-	-	-	+	-	+	-	-	-	-	-
Cyprinus carpio Linnaeus, 1758	+	+	-	-	+	-	-	-	-	+	+	+	-	-	-	-	-
Tariqilabeo latius (Hamilton, 1822)	-	-	+	-	-	-	-	-	-	+	-	-	+	-	-	-	-
Tariqilabeo diplochilus (Heckel, 1838)	+	-	+	+	+	+	-	+	-	-	+	-	-	+	+	-	-
Cirrhinus reba (Hamilton, 1822)	-	-	+	+	+	+	-	+	-	-	-	-	-	-	-	-	-
Cirrhinus mrigala (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	+	-	-	-	-	-
Garra gotyla (Gray, 1930)	-	+	-	+	+	+	-	+	-	+	+	+	+	-	-	-	-
Garra lamta (Hamilton, 1822)	-	-	-	+	+	-	-	+	-	+	+	+	-	-	-	-	-
Labeo dyocheilus (McClelland, 1839)	-	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-	-
Labeo pangusia (Hamilton, 1822)	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Labeo calbasu (Hamilton, 1822)	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-
Labeo gonius (Hamilton, 1822)	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Labeo rohita (Hamilton, 1822)	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-
Labeo boggut (Sykes, 1839)	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Labeo bata (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	+	+	+	+	-	-	-	-
Labeo boga (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Labeo catla (Hamilton, 1822)	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Osteobrama cotio (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Puntius sophore (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	+	+	-	-	-	-
Puntius chola (Hamilton, 1822)	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Systomus sarana (Hamilton, 1822)	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Pethia conchonius (Hamilton, 1822)	-	-	-	+	+	-	-	-	-	+	+	-	+	-	-	-	-
Pethia ticto (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	+	+	-	-	-	-

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Jhelum	Chenab	Sewa	Ujh	Wajhoo Nullah	Basantar	Neeru Nullah	Anas nullah	Marusudar	Poonch	Mendhar	Nowshera tawi	Tawi	Lidder	Veshaw	Kishanganga	Sind
Schizothorax richardsonii (Gray, 1832)	-	+	-	-	-	-	+	+	+	+	+	+	+	-	+	-	-
Schizothorax plagiostomus Heckel, 1838	+	+	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+
Schizothorax curvifrons (Heckel, 1838)	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Schizothorax labiatus (McClelland, 1842)	+	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-
Schizothorax esocinus (Heckel, 1838)	+	+	-	-	-	-	-	-	-	-	-	-	-	+	+	-	+
Tor putitora (Hamilton, 1822)	-	+	-	+	+	-	-	+	+	+	+	+	+	-	-	-	-
Tor tor (Hamilton, 1822)	-	+	-	+	+	+	-	+	-	+	-	+	-	-	-	-	-
Family Danionidae																	
Amblypharyngodon mola (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Cabdio morar (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	-	+	-	-	-	-
Barilius vagra (Hamilton, 1822)	-	-	+	+	+	+	-	+	-	+	+	-	+	-	-	-	-
Opsarius bendelisis (Hamilton, 1807)	-	-	+	+	+	-	-	+	-	-	-	-	+	-	-	-	-
Barilius modestus Day, 1872	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Chela cachius (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Devario devario (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-
Esomus danricus (Hamilton, 1822)	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Laubuka laubuca (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Rasbora danioconius (Hamilton, 1822)	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rasbora sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rasbora rasbora (Hamilton, 1822)	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-
Salmostoma bacaila (Hamilton, 1822)	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Salmostoma punjabense (Day, 1872)	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Securicula gora (Hamilton, 1822)	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Family Xenocyprinidae																	
Ctenopharyngodon idella (Valenciennes, 1844)	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Hypophthalmichthys molitrix (Valenciennes, 1844)	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-

Also, educational programs and awareness campaigns can highlight the importance of fish diversity and encourage sustainable practices that support both ecosystems and local communities (Suski & Cooke 2007; EIA EMP Report of Lakhwar Multipurpose Project 2020).

Traditional conservation methods

For generations, the Himalayan communities have used traditional fish conservation methods integrated in cultural practices and community-led initiatives to preserve aquatic biodiversity. Cultural and religious beliefs, such as bans on fishing during specific periods by Buddhist sects or in sacred places, plays a vital role in protecting threatened species and maintaining ecological balance (Gupta et al. 2016). There are over 30 temple-based fish sanctuaries, established near temples or shrines to honor the fish deity, Matsya avatar (first incarnation of Vishnu), in various Indian states and some are present in Uttarakhand and Himachal Pradesh, with ancient traditions like offering mahseer fish to honor ancestors further reinforcing conservation efforts (Jumani et al. 2023). Furthermore, sustainable fishing techniques minimize environmental impact and support healthy fish populations (Srivastava et al. 2002).

Threats to the fish diversity

The ichthyofaunal diversity in the Himalayan states of India faces severe threats from habitat degradation,

Table 3. Fish fauna of Ladakh (Suborder Cyprinoidei; family Cyprinidae, Danionidae, and Xenocyprididae).

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes Family: Cyprinidae	Indus	Zaskar	Suru	Shyok
Family: Cyprinidae				
Gymnostomus ariza (Hamilton, 1807)	+	-	-	-
Barbonymus gonionotus (Bleeker, 1849)	+	-	-	-
Cyprinus carpio Linnaeus, 1758	-	+	-	+
Tariqilabeo latius (Hamilton, 1822)	-	+	-	-
Cirrhinus reba (Hamilton, 1822)	+	-	-	-
Cirrhinus mrigala (Hamilton, 1822)	+	-	-	-
Chagunius chagunio (Hamilton, 1822)	+	-	-	-
Carassius auratus (Linnaeus, 1758)	+	-	-	-
Diptychus maculatus Steindachner, 1866	-	+	-	+
Labeo calbasu (Hamilton, 1822)	+	-	-	-
Labeo gonius (Hamilton, 1822)	+	-	-	-
Labeo rohita (Hamilton, 1822)	+	-	-	-
Labeo bata (Hamilton, 1822)	+	-	-	-
Labeo catla (Hamilton, 1822)	+	-	-	-
Osteobrama cotio (Hamilton, 1822)	+	-	-	-
Puntius sophore (Hamilton, 1822)	+	-	-	-
Puntius chola (Hamilton, 1822)	+	-	-	-
Systomus sarana (Hamilton, 1822)	+	-	-	-
Pethia conchonius (Hamilton, 1822)	+	-	-	-
Pethia ticto (Hamilton, 1822)	+	-	-	-
Pethia phutunio (Hamilton, 1822)	+	-	-	-
Ptychobarbus conirostris Steindachner, 1866	-	+	+	-
Schizothorax richardsonii (Gray, 1832)	-	+	-	-
Schizothorax plagiostomus (Heckel, 1838)	+	-	-	-
Schizothorax labiatus (McClelland, 1842)	+	+	-	-
Schizothorax esocinus (Heckel, 1838)	+	-	-	-
Schizothorax progustus (Heckel, 1838)	-	+	+	+
Schizopygopsis sp.	-	+	+	+
Tor putitora (Hamilton, 1822)	+	-	-	-
Family: Danionidae				
Amblypharyngodon mola (Hamilton, 1822)	+	-	-	-
Barilius barila (Hamilton, 1822)	+	-	-	-
Opsarius tileo (Hamilton, 1822)	+	-	-	-
Chela cachius (Hamilton, 1822)	+	-	-	-
Salmostoma bacaila (Hamilton, 1822)	+	-	-	-
Securicula gora (Hamilton, 1822)	+	-	-	-
Family: Xenocyprinidae				
Ctenopharyngodon idella (Valenciennes, 1844)	+	-	-	-
Hypophthalmichthys molitrix (Valenciennes, 1844)	+	-	-	-
Hypophthalmichthys nobilis (Richardson, 1845)	+	-	-	-

overfishing, pollution, invasive species and climate change. Human activities like dam construction, deforestation and water diversion lead to fragmentation of aquatic ecosystems, disrupting fish migration and spawning. Contaminants from agricultural runoff, domestic waste and industrial effluents deplete oxygen levels, reducing species richness. Unsustainable practices and overfishing further reduces populations, while invasive species out-compete native fishes, altering ecosystems. Moreover, climate change exacerbates these challenges by disturbing spawning cycles and threatening cold-water species. These dangers draw attention to the urgent need for conservation measures to protect Himalayan aquatic biodiversity (Raina & Petr 1999; Negi 2010; Mishra et al. 2011; Dash et al. 2020; Malik et al. 2020; Bhatt & Manish 2023; Pandey et al. 2023).

CONCLUSION

This paper examines the diversity of Cyprinidae, Danionidae, and Xenocyprinidae fish families (Suborder Cyprinoidei) present in the India's western Himalayan states. The observations showed that out of all four states Uttarakhand hosts the highest diversity of Cyprinidae species, followed by Jammu & Kashmir, Ladakh, and Himachal Pradesh. The data of 57 rivers and streams that flows across these Himalayan states have been analyzed revealing that the Ramganga River in Uttarakhand exhibits the highest genus as well as species diversity. The Ganga River system and the Indus River system form the major drainage systems in northern India, highlighting the region's rich aquatic biodiversity. While rivers like Spiti and Parbati in Himachal Pradesh and Kishanganga and Sind in Jammu & Kashmir recorded the lowest species diversity. The diversity typically increases downstream or at lower altitude. Most of the recorded species are still categorized as Least Concern but several important endemic species such as snow trout and mahseer remains under threat. Furthermore, the degradation of freshwater ecosystems due to various human-induced threats such as urbanization, water pollution and over-fishing shows a negative impact on the fish population and highlights the need for habitat focused conservation in this Himalayan region.

Table 4. Fish fauna of Uttarakhand (Suborder Cyprinoidei; family Cyprinidae, Danionidae, and Xenocyprididae).

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Song	Dulhani	Suswa	Baldi	Tons	Asan	Yamuna	Ganga	Alaknanda	Bhaghirathi	Bhilangna	Nayar	Ramganga	Kharmola stream	Indrawati stream	Pinder	Mal gad stream	Nandakini	Birahiganga	Laster Stream	Kyunja stream	Koshi	Gaula	Mandal	Palain river	Sona river	Goriganga
Family Cyprinidae																											
Bangana dero (Hamilton, 1822)	+	+	+	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	+	+	+	+
Cyprinus carpio Linnaeus, 1758	-	-	-	-	-	-	-	+	-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tariqilabeo latius (Hamilton, 1822)	+	-	+	+	+	-	+	+	+	-	-	-	+	-	-	+	-	+	-	+	-	+	-	+	+	+	-
Cirrhinus reba (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cirrhinus mrigala (Hamilton, 1822)	-	-	-	-	-	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chagunius chagunio (Hamilton, 1822)	+	+	+	+	+	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	+	-
Garra mullya (Sykes, 1839)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Garra gotyla (Gray, 1930)	+	+	+	-	+	+	-	+	+	+	+	+	+	-	-	+	-	+	+	+	+	+	+	+		+	+
Garra lamta (Hamilton, 1822)	+	+	+	+	-	-	-	-	-	-	-	-	+	-	-	+	-	-	+	+	+	+	-	+	+	+	-
Garra annandalei Hora, 1921	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo catla (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo dyocheilus (McClelland, 1839)	+	+	+	+	+	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+
Labeo pangusia (Hamilton, 1822)	+	+	+	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo calbasu (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Labeo gonius (Hamilton, 1822)	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Labeo rohita (Hamilton, 1822)	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Labeo boggut (Sykes, 1839)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo bata (Hamilton, 1822)	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Labeo angra (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo boga (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Neolissochilus hexasticus (McClelland, 1839)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	+	+	+	-
Osteobrama cotio (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Puntius sophore (Hamilton, 1822)	+	+	+	+	+	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Puntius chola (Hamilton, 1822)	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-
Systomus sarana (Hamilton, 1822)	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Puntius terio (Hamilton, 1822)	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pethia gelius (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Pethia conchonius (Hamilton, 1822)	+	+	+	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pethia ticto (Hamilton, 1822)	+	+	+	+	+	+	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	+	+	+	+

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Song	Dulhani	Suswa	Baldi	Tons	Asan	Yamuna	Ganga	Alaknanda	Bhaghirathi	Bhilangna	Nayar	Ramganga	Kharmola stream	Indrawati stream	Pinder	Mal gad stream	Nandakini	Birahiganga	Laster Stream	Kyunja stream	Koshi	Gaula	Mandal	Palain river	Sona river	Goriganga
Pethia phutunio (Hamilton, 1822)	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schizothorax richardsonii (Gray, 1832)	+	-	+	+	+	-	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	-	+	+	+	-	+
Schizothorax plagiostomus Heckel, 1838	-	-	-	-	-	-	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	-	-	-	-	-	+
Schizothorax niger Heckel, 1838	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schizothorax curvifrons (Heckel, 1838)	-	-	-	-	-	-	-	-	+	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Schizothorax kumaonensis Menon, 1971	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Schizothorax progastus (McClelland, 1839)	+	-	-	-	+	-	-	-	-	+	+	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-
Tor putitora (Hamilton, 1822)	+	+	-	-	+	+	+	-	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	-	-	-	+
Tor tor (Hamilton, 1822)	+	+	-	-	+	-	+	+	+	+	+	+	+	-	-	+	-	+	+	+	+	+	-	-	-	-	+
Tor mosal (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Naziritor chelynoides (McClelland, 1839)	-	-	-	-	-	-	-	-	-	-	+	-	-	+	+	+	+	-	+	+	+	+	-	+	+	+	+
Family Danionidae																											
Amblypharyngodon mola (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cabdio morar (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cabdio jaya (Hamilton, 1822)	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barilius vagra (Hamilton, 1822)	+	-	-	-	+	-	+	+	+	+	+	-	+	+	-	+	+	+	-	+	+	+	+	+	+	+	+
Opsarius bendelisis (Hamilton, 1807)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Opsarius barna (Hamilton, 1822)	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	-	-	+	+	+	-	+	+	+	-
Barilius barila (Hamilton, 1822)	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	+	-	-	-	-	-	+	-	+	+	+	-
Opsarius tileo (Hamilton, 1822)	-	+	+	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Opsarius shacra (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	+	-	+	+	-	+	+	+	-
Chela cachius (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Devario devario (Hamilton, 1822)	+	+	+	+	+	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Devario aequipinnatus (McClelland, 1839)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Danio rerio (Hamilton, 1822)	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Esomus danrica (Hamilton, 1822)	+	+	+	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laubuka laubuca (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Raiamas bola (Hamilton, 1822)	+	+	+	+	+	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	+	+	-	+	-	-
Rasbora danioconius (Hamilton, 1822)	+	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Salmostoma phulo (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Song	Dulhani	Suswa	Baldi	Tons	Asan	Yamuna	Ganga	Alaknanda	Bhaghirathi	Bhilangna	Nayar	Ramganga	Kharmola stream	Indrawati stream	Pinder	Mal gad stream	Nandakini	Birahiganga	Laster Stream	Kyunja stream	Koshi	Gaula	Mandal	Palain river	Sona river	Goriganga
Salmostoma bacaila (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Securicula gora (Hamilton, 1822)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Family Xenocyprinidae																											
Ctenopharyngodon idella (Valenciennes, 1844)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypophthalmichthys molitrix (Valenciennes, 1844)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypophthalmichthys nobilis (Richardson, 1845)	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. Fish fauna of Himachal Pradesh (Suborder Cyprinoidei; family Cyprinidae, Danionidae, and Xenocyprididae).

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Beas	Ravi	Maan Stream	Kunah Stream	Son Stream	Spiti	Giri	Parbati	Sutlej
Family Cyprinidae									
Bangana dero (Hamilton, 1822)	+	-	-	-	-	-	-	-	-
Cyprinus carpio (Linnaeus, 1758)	+	+	+	+	+	-	-	-	+
Cirrhinus reba (Hamilton, 1822)	+	+	-	-	-	-	-	-	-
Cirrhinus mrigala (Hamilton, 1822)	+	+	-	-	-	-	-	-	-
Chagunius chagunio (Hamilton, 1822)	+	-	-	-	-	-	-	-	-
Carassius auratus (Linnaeus, 1758)	-	+	-	-	-	-	-	-	+
Carassius carassius (Linnaeus, 1758)	-	+	-	-	-	-	-	-	-
Garra gotyla (Gray, 1930)	-	+	+	+	-	-	-	+	-
Labeo dyocheilus (McClelland, 1839)	-	+	-	-	-	-	-	-	-
Labeo calbasu (Hamilton, 1822)	+	+	-	-	-	-	-	-	-
Labeo gonius (Hamilton, 1822)	+	+	-	-	-	-	-	-	-
Labeo rohita (Hamilton, 1822)	+	+	+	-	-	-	-	-	-
Labeo boggut (Sykes, 1839)	+	-	-	-	-	-	-	-	-
Labeo bata (Hamilton, 1822)	+	+	-	-	-	-	-	-	-
Labeo catla (Hamilton, 1822)	+	-	-	-	-	-	-	-	-
Osteobrama cotio (Hamilton, 1822)	-	-	-	-	-	-	-	-	+
Puntius sophore (Hamilton, 1822)	-	+	-	-	-	-	-	-	+
Puntius chola (Hamilton, 1822)	+	-	-	-	-	-	-	-	+

TAXON Phylum: Chordata Class: Actinopterygii Order: Cypriniformes	Beas	Ravi	Maan Stream	Kunah Stream	Son Stream	Spiti	Giri	Parbati	Sutlej
Systomus sarana (Hamilton, 1822)	+	-	-	-	+	-	+	-	+
Pethia conchonius (Hamilton, 1822)	+	+	+	-	-	-	-	-	+
Pethia ticto (Hamilton, 1822)	+	+	+	+	+	-	+	-	+
Pethia phutunio (Hamilton, 1822)	-	-	+	-	-	-	-	-	-
Schizothorax richardsonii (Gray, 1832)	+	+	-	-	+	+	+	+	-
Schizothorax plagiostomus (Heckel, 1838)	+	-	-	-	-	-	-	-	-
Tariquilabeo diplochilus (Heckel, 1838)	-	+	-	+	+	-	-	-	+
Tariquilabeo latius (Hamilton, 1822)	+	+	-	-	-	-	-	-	+
Tor putitora (Hamilton, 1822)	+	+	+	+	+	-	+	-	-
Tor tor (Hamilton, 1822)	+	-	-	-	-	-	-	-	-
Family Danionidae									
Barilius vagra (Hamilton, 1822)	-	+	+	+	-	-	+	-	+
Opsarius bendelisis (Hamilton, 1807)	-	+	+	+	-	-	+	-	+
Opsarius barna (Hamilton, 1822)	-	-	-	+	-	-	-	-	-
Barilius barila (Hamilton, 1822)	-	-	-	-	-	-	+	-	+
Barilius modestus (Day, 1872)	-	-	-	-	-	-	-	-	+
Danio rerio (Hamilton, 1822)	-	-	-	-	-	-	-	-	+
Rasbora danioconius (Hamilton, 1822)	-	-	+	-	-	-	-	-	+
Salmostoma bacaila (Hamilton, 1822)	-	+	-	+	-	-	-	-	-

Table 6. Current conservation status of some fish species of the suborder Cyprinoidei reported in the western Indian Himalayan Region.

	Suborder Cyprinoidei	IUCN Red List status		Suborder Cyprinoidei	IUCN Red List status
1	*Amblypharyngodon mola* (Hamilton, 1822)	LC	39	*Labeo bata* (Hamilton, 1822)	LC
2	*Cabdio morar* (Hamilton, 1822)	LC	40	*Labeo angra* (Hamilton, 1822)	LC
3	*Cabdio jaya* (Hamilton 1822)	LC	41	*Labeo boga* (Hamilton, 1822)	LC
4	*Barilius vagra* (Hamilton, 1822)	LC	42	*Labeo catla* (Hamilton, 1822)	LC
5	*Barilius shacra* (Hamilton, 1822)	LC	43	*Laubuka laubuca* (Hamilton, 1822)	LC
6	*Barilius tileo* (Hamilton, 1822)	LC	44	*Naziritor chelynoides* (McClelland, 1839)	VU
7	*Barilius barila* (Hamilton, 1822)	LC	45	*Osteobrama cotio* (Hamilton, 1822)	LC
8	*Barilius modestus* Day, 1872	LC	46	*Opsarius bendelisis* (Hamilton, 1807)	LC
9	*Bangana dero* (Hamilton, 1822)	LC	47	*Ptychobarbus conirostris* Steindachner, 1866	LC
10	*Gymnostomus ariza* (Hamilton, 1822)	LC	48	*Puntius sophore* (Hamilton, 1822)	LC
11	*Barbonymus gonionotus* (Bleeker, 1849)	LC	49	*Puntius chola* (Hamilton, 1822)	LC
12	*Cyprinus carpio communis* (Linnaeus, 1758)	LC	50	*Pethia conchonius* (Hamilton, 1822)	LC
13	*Cyprinus carpio nudus* (Bloch, 1784)	LC	51	*Pethia ticto* (Hamilton, 1822)	LC
14	*Cyprinus carpio specularis* (Linnaeus, 1758)	LC	52	*Pethia phutunio* (Hamilton, 1822)	LC
15	*Cirrhinus reba* (Hamilton, 1822)	LC	53	*Puntius terio* (Hamilton, 1822)	LC
16	*Cirrhinus mrigala* (Hamilton, 1822)	LC	54	*Puntius gelius* (Hamilton, 1822)	LC
17	*Ctenopharyngodon idella* (Valenciennes, 1844)	LC	55	*Raiamas bola* (Hamilton, 1822)	LC
18	*Chela cachius* (Hamilton, 1822)	LC	56	*Rasbora rasbora* (Hamilton, 1822)	LC
19	*Chagunius chagunio* (Hamilton, 1822)	LC	57	*Rasbora danioconius* (Hamilton, 1822)	LC
20	*Carassius auratus* (Linnaeus, 1758)	LC	58	*Systomus sarana* (Hamilton, 1822)	LC
21	*Carassius carassius* (Linnaeus, 1758)	LC	59	*Salmostoma phulo* (Hamilton, 1822)	LC
22	*Diptychus maculatus* (Steindachner, 1866)	LC	60	*Salmostoma bacaila* (Hamilton, 1822)	LC
23	*Devario devario* (Hamilton, 1822)	LC	61	*Salmostoma punjabense* (Day, 1872)	LC
24	*Danio aequipinnatus* (McClelland, 1839)	LC	62	*Securicula gora* (Hamilton, 1822)	LC
25	*Danio rerio* (Hamilton, 1822)	LC	63	*Schizothorax richardsonii* (Gray, 1832)	VU
26	*Esomus danricus* (Hamilton, 1822)	LC	64	*Schizothorax plagiostomus* (Heckel, 1838)	VU
27	*Garra mullya* (Sykes, 1839)	LC	65	*Schizothorax niger* (Heckel, 1838)	NE
28	*Garra gotyla gotyla* (Gray, 1930)	LC	66	*Schizothorax curvifrons* (Heckel, 1838)	LC
29	*Garra lamta* (Hamilton, 1822)	LC	67	*Schizothorax labiatus* (McClelland, 1842)	LC
30	*Garra annandalei* (Hora, 1921)	LC	68	*Schizothorax esocinus* (Heckel, 1838)	VU
31	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	NT	69	*Schizothorax kumaonensis* Menon, 1971	DD
32	*Hypophthalmichthys nobilis* (Richardson, 1845)	DD	70	*Schizothorax progastus* (McClelland, 1839)	LC
33	*Labeo dyocheilus* (McClelland, 1839)	LC	71	*Schizopygopsis* sp.	NE
34	*Labeo pangusia* (Hamilton, 1822)	NT	72	*Tariqilabeo diplochilus* (Heckel, 1838)	NE
35	*Labeo calbasu* (Hamilton, 1822)	LC	73	*Tariqilabeo latius* (Hamilton, 1822)	LC
36	*Labeo gonius* (Hamilton, 1822)	LC	74	*Tor putitora* (Hamilton, 1822)	EN
37	*Labeo rohita* (Hamilton, 1822)	LC	75	*Tor tor* (Hamilton, 1822)	DD
38	*Labeo boggut* (Sykes, 1839)	LC	76	*Tor mosal* (Hamilton, 1822)	DD

NE—Not Evaluated | DD—Data Deficient | LC—Least Concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered.

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ARTICLE

Post-impoundment changes in fish diversity and community structure of the Dikrong River, Arunachal Pradesh: a comparative assessment between 2000–2001 and 2025–2026

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Abstract: A study carried out on the dam impacted Dikrong River, which is one of the major tributaries of the Brahmaputra in Arunachal Pradesh, suggests that the river has undergone significant ecological alteration following the commissioning of the Sopo dam in 2018 and increasing anthropogenic pressures. The present study attempted to assess the fish diversity, community structure, trophic composition, and conservation status in the Dikrong River during 2025–2026 and the results were compared with pre-impoundment records made in the year 2000–2001. A total of 27 fish species belonging to 24 genera, eight families, and three orders were recorded, with Cyprinidae dominating the assemblage (51.9%). *Opsarius bendelisis* was the most abundant species (44.1%). The taxonomic comparison with previous data reveals an apparent reduction in the number of species, mainly bottom feeders, which highlights their sensitivity to flow regulation and habitat modification. There was a change in the food chain from the dominance of bottom feeders to column feeders. Water release from regulation, riverbed quarrying, and runoff reduced the quality of the habitat and fish behavior. The juveniles of *Semiplotus semiplotus*, *Opsarius bendelisis*, and *Devario aequipinnatus* were found to be accumulating in the clean-connected drainage system downstream (polluted zone). The findings suggest a need for environmental flow regulation and habitat restoration to conserve remaining fish diversity. Further, the study recommends promotion of culture-based fisheries selecting some of the indigenous ornamental and food fish as a future conservation and livelihood strategy.

Keywords: Conservation status, flow regulation, habitat degradation, habitat restoration, hillstream fishes, fish assemblage, river regulation, Sopo Dam, trophic composition.

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INTRODUCTION

The natural environment provides the foundation for life by supporting energy flow, nutrient cycling, and ecological stability for the well-being of all organisms. Therefore, biodiversity is central to regulating these processes, which sustain ecosystem functions such as water purification, food production, and livelihood security (Costanza et al. 1997). Within aquatic ecosystems, fishes play a key role in maintaining trophic structure, enhancing ecosystem stability, and acts as sensitive indicators of environmental change. Globally, about 37,553 fish species have been described and 19,232 (51.2%) of these occur in freshwater ecosystems (Fricke et al. 2025). Beyond their ecological significance, fishes constitute an important source of high-quality animal protein and essential micronutrients.

Many people in developing countries depend on small indigenous species that form the backbone of food security and rural livelihoods (Dugan et al. 2006; Bell et al. 2009; Jamu et al. 2011). Similarly, as in the case of Northeast India, fishing is closely linked to the socio-cultural fabric of tribal communities, where conservation of freshwater fish diversity is utmost importance for both ecological sustainability and human well-being for the long run (Vishwanath 2017).

However, the freshwater fish biodiversity is experiencing an unprecedented decline worldwide, attributed to increasing anthropogenic pressures resulting from rapid population growth. Other factors such as urbanization, agricultural and industrial expansion, excessive application of fertilizers and pesticides, overfishing, pollution, habitat degradation, and water diversion have collectively declined freshwater fish populations (Dudgeon et al. 2006; Lakra et al. 2010).

Among these drivers, river damming and hydropower development have led to serious threats to aquatic fauna, including river regulation, habitat fragmentation, and altered flow regimes, which result in high negative impacts on freshwater ecosystems and their biodiversity (Winemiller et al. 2016; Couto & Olden 2018; Kuriqi et al. 2021). Even though, hydropower is widely considered a renewable energy source essential for human development activities. However, in the modern era, despite growing awareness among human society and management efforts on various aspects, freshwater ecosystems continue to experience biodiversity loss and ecological imbalance.

Strategic conservation approaches are therefore critical to safeguarding freshwater ecosystems and ensuring the sustained delivery of ecosystem services vital for environmental sustainability and human well-being (Margules & Pressey 2000; Saunders et al. 2002).

The state of Arunachal Pradesh, which is located within the Eastern Himalayan biodiversity hotspot, is one of the well-known biologically diverse regions of India, covering an area of approximately 83,743 km². The state is characterized by having rugged mountainous terrain, with nearly 70% of its land area under dense forest cover. The extensive network of rivers, streams, tributaries, and rivulets that drain the state provides highly suitable habitats for diverse assemblages of ichthyofauna and other aquatic organisms, rendering Arunachal Pradesh ecologically unique among the northeastern states of India.

Systematic documentation of fish diversity in Arunachal Pradesh has increased over the past two decades. The first comprehensive account reported 131 fish species from the state (Nath & Dey 2000), followed by subsequent additions by several researchers (Tamang et al. 2007; Bagra et al. 2009; Gurumayum et al. 2016; Darshan et al. 2019). Gurumayum et al. (2016) have reported 32 endemic fishes in Arunachal Pradesh, and Abujam et al. (2021) documented 52 indigenous ornamental fishes from the state. A recent assessment by Tamang and Das (2024) updated the fish checklist to 233 species, including 72 new fish species originally described from the state. This signifies that Arunachal Pradesh is a globally important hotspot of freshwater fish biodiversity. However, this exceptional diversity is increasingly threatened by rapid urbanization, land-use changes, shifting lifestyles, and the indiscriminate use of modern fishing techniques, which have collectively resulted in a noticeable decline in fish populations across many aquatic systems in the region (Chaudhry & Tamang 2007; Tamang & Shivaji 2012). For instance, Taro et al. (2022) documented severe habitat fragmentation and degradation in the Senkhi River within the Itanagar Wildlife Sanctuary, along with the local extinction of 14 fish species.

The Dikrong River, one of the major tributaries in Papum Pare district, has received limited scientific attention in recent years. Nath & Dey (2000) recorded 85 fish species from the Dikrong River at Doimukh, which also constitutes the present study area. Since that initial assessment, no comprehensive investigation has been conducted on the changes that have occurred in fish diversity or population structure within this river system. In recent years, local communities have reported a perceptible decline in fish abundance and diversity following the operation of the Sopo Dam. Given that indigenous communities in Arunachal Pradesh

predominantly depend on indigenous hillstream fishes that are closely linked with their cultural traditions and subsistence practices, such declines indicate serious hampering of ecological and socio-cultural aspects. Therefore, the present study aims to scientifically assess the perceived impacts of the Sopo Dam on fish diversity and population dynamics in the Dikrong River. In addition, among the freshwater ichthyofauna, ornamental fishes represent an important component, both ecologically and economically. Many species found in Arunachal Pradesh possess attractive coloration, distinctive body shapes, and interesting physical and behavioural traits that make them highly valuable in the aquarium trade (Abujam et al. 2021).

MATERIALS AND METHODS

Study Site

The study was conducted in the Dikrong River, a major north-bank tributary of the Brahmaputra River, which originates in the lesser Himalayan ranges beyond the Sagalee Hills (Image 1). The river is formed by the confluence of multiple tributaries and is locally known as the "Pare River" beyond Hoj Village. The Dikrong River is situated approximately about 35 km east of Itanagar near the eastern boundary of the Itanagar Wildlife Sanctuary (IWS). The Dikrong flows west to east before turning southward from Sopo Dam and then again turning to east at Doimukh and eventually merges with the Brahmaputra in Assam. The dynamic course of river and dependence on Himalayan catchments make it highly sensitive to seasonal rainfall, upstream interventions, and geomorphological changes, especially in the context of dam construction and watershed alterations. The study covered an approximately 11.5 km stretch (27.1290° N, 93.7692° E to 27.2532° N, 93.7669° E) of the Dikrong River downstream of Sopo Dam, with sampling conducted from downstream to upstream (image 1). River width was measured at 15 sites using a nylon thread and measuring tape during both low-flow and dam-release periods.

Sopo Dam

The Sopo Dam (27.2378° N, 93.8076° E to 27.2532° N, 93.8102° E), part of the Pare Hydropower Project, was commissioned in May 2018 and has been in operation for the last seven years. The project was developed by the North Eastern Electric Power Corporation Limited (NEEPCO). Water released from the Ranganadi Dam at Yazali in Lower Subansiri District is conveyed to the Dikrong Power House at Hoj village, contributing additional discharge to the Sopo Dam. Prior to dam construction, Nath & Dey (2000) documented 85 fish species from the Dikrong River.

Fish Sampling and Identification

Fish sampling was conducted using a cast net (2.3 m radius, 7 × 7 mm mesh size) over 10 days from 1–10 December 2025, primarily between 0500–0700 h, with three-night samplings from 1800–2000 h. Sampling covered various microhabitats, including shallow, deep, moderate, and torrential flow zones. The catch per unit effort (CPUE) was calculated from five replicates per hour, with the sampling intensity ranging 50–55 cast net throws/hour. Collected specimens were transported to the Laboratory of Department of Zoology, Rajiv Gandhi University, and then identified following Talwar & Jhingran (1991), Nath & Dey (2000), and Darshan et al. (2019), and subsequently deposited in the Rajiv Gandhi University Museum of Fishes (RGUMF). Valid scientific names were verified using Eschmeyer's Catalogue of Fishes (Fricke et al. 2025).

Trophic classification and conservation status

The trophic niche of each species was determined based on mouth position and categorized as: Inferior/ Sub-inferior (bottom feeders), Terminal/Sub-terminal (column feeders), Oblique/Slightly oblique (surface feeders). Species richness categories were assigned as: Abundant (91–100 %), Common (81–90 %), Frequent (61–80 %), Occasional (31–60 %), Sporadic (15–30 %), Rare (5–14 %), and Extremely Rare (<5 %) (Table 1). The conservation status of each species was assessed according to the IUCN Red List of Threatened species (2025-2) (Table 1).To assess temporal changes, the present survey was compared with the fish checklist reported by Nath & Dey (2000) (Table 2). The specimens previously identified as *Aborichthys kempi* were re-examined and following Nanda et al. (2021), correctly identified as *Aborichthys uniobarensis*. So, *Aborichthys kempi* was previously misidentified.

Data Analysis

Species abundance was determined by counting individuals collected per sampling day. The Relative Abundance (RA) of each study site was calculated by dividing the number of individuals of a species by the total number of individuals of all the species multiplying by 100. The fish diversity indices were calculated as per standard method (Shannon & Wiener 1963) by the formula: $H = -\Sigma (ni/N) \log2 (ni/N)$, where, H = Shannon-

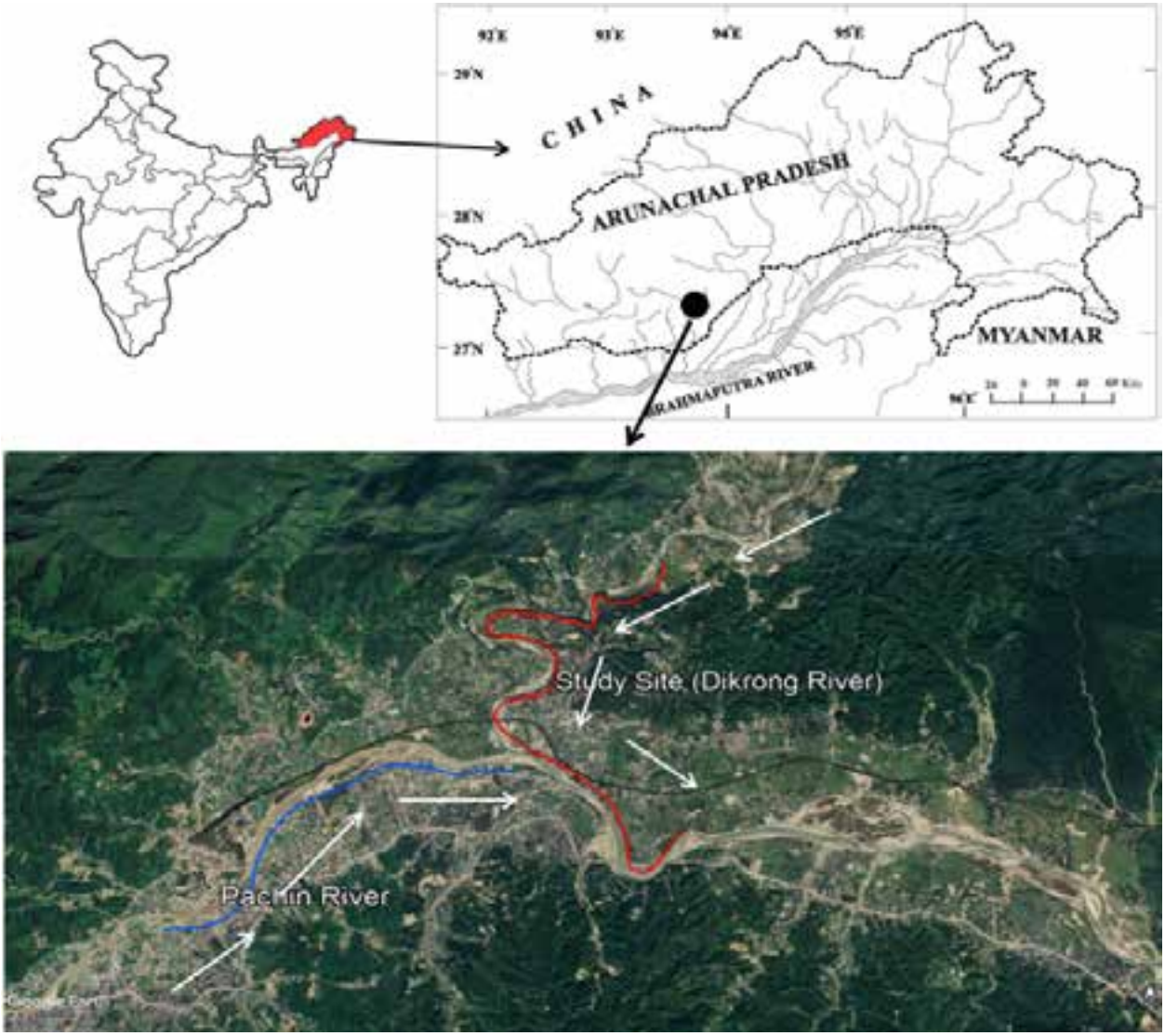

Image 1. Map of India showing Arunachal Pradesh and the study area. The red line indicates the Dikrong River (study site) and the blue line indicates the Pachin River. Both rivers converge just upstream of the Doimukh RCC bridge. Lines are drawn along the river courses, and arrows show direction of the water flow.

Image 2. Field conditions at the study site showing fish sampling activities, habitat degradation, and household debris pollution. © Minam Siram.

Wiener index of diversity, ni = total numbers of individuals of a species and N = total number of individuals of all the species. Evenness of the species was calculated following Pielou's evenness index (Pielou's 1966), i.e. J =H'max/logS, where: H'max = is the maximum value of Shannon-Wiener's index, and S = is the total number of species. The value of E falls between 0 and 1. The less variation in communities between the species, the higher would be the E value. Simpson's diversity index was calculated by the formula: D = 1-(Σn(n-1)/N(N-1)), where D = Diversity, n = number of individuals of a single species, N = total number of all species. All the diversity indices were performed using PAST (Paleontological Statistics) software version 4.02 (Hammer et al. 2001).

RESULTS AND DISCUSSION

Fish Diversity, composition, and temporal change

The present study recorded 27 fish species belonging to 24 genera, eight families, and three orders, which included Cypriniformes, Siluriformes, and Mugiliformes (Table 1, Image 3). The order Cypriniformes dominated the fish assemblage with 20 species, and Cyprinidae was the most abundant family (14 species; 51.9%), followed by Danionidae (14.8%), Nemacheilidae (11.1%), and Sisoridae (7.4%). Among these, four families, namely, Botiidae, Balitoridae, Psilorhynchidae, and Ambassidae were represented by a single species each (Table 1 and Image 4). Six additional species (*Balitora brucei*, *Glyptothorax trilineatus*, *Pseudolaguvia vespa*, *Garra birostris*, *Mustura dikrongensis*, and *Schistura scaturigina*) were new additions in the present study and were not reported by Nath & Dey (2000). Excluding these six new records, comparison with 85 species reported by Nath & Dey (2000) from the Dikrong River prior to dam construction revealed that 64 species were not encountered in the present survey, suggesting a substantial decline in fish diversity.

However, since the present sampling was limited to 10 days, it should be interpreted with caution, because the short sampling period may not capture rare, seasonal, or cryptic species. There may be differences in sampling season, sampling effort, and fishing gear between the present and previous studies, which may also have influenced species detectability. It would be more evident if an intensive survey throughout the year were conducted for better results. Despite this limitation, this sharp reduction in species richness suggests post-impoundment ecological alteration following the commissioning of the Sopo Dam in 2018 and may include other anthropogenic activities.

This pattern is partially supported by the findings of Bagra et al. (2009), who surveyed 35 rivers covering a wide range of Arunachal Pradesh, including the Dikrong River, between March 2004 and March 2008. The study showed records of 40 fish species in the Dikrong River, but the sampling duration was not given in the literature. Considering that the survey covered a large geographic area, the sampling effort was likely limited and may have been comparable to the present study (10 sampling days).

This is further supported by the findings of Gurumayum (2025), who recorded 20 fish species only after conducting two days of sampling for four hours each from a small drainage (Buka nallah), a tributary of the dam impacted Dikrong River that flows through Sopo village, during January and April 2023, which comprised mostly bottom feeders (65%). Interestingly, Gurumayum (2025) recorded 20 species within a short sampling duration, whereas we recorded 27 species from the main river despite more sampling effort. This comparison further supports a likelihood of a reduction in fish diversity in the Dikrong River.

Furthermore, in support of this interpretation, the study by Rao et al. (2021) highlighted that small hydropower projects have a substantial effect on river flow regimes, which consequently affect habitats, change the quality of water, and disrupt fish community compositions. Unpredictable alterations in downstream river water levels affect the stability of the habitats where natural flow regimes occur, which primarily affects sensitive and migratory species. Changes in breeding sites and recruitment processes are also affected by this instability. Thus, all the effects described above indicate that the influence of SHPs, including the Sopo Dam, may be degrading the riverine environment and associated aquatic ecosystems.

Relative abundance and community structure

Fish abundance was highly uneven, with *Opsarius bendelisis* dominating the assemblage (44.1%), followed by *Semiplotus semiplotus* (21.7%). A few species, such as *Bangana dero* (6.1%) and *Devario aequipinnatus* (5.4%), were relatively rare, while the majority of species (n = 23) were extremely rare, each contributing <4% of the total abundance (Image 5). This skewed distribution suggests a community under ecological stress, where only a few tolerant or opportunistic species dominate, whereas most species persist at very low frequencies.

Table 1. Taxonomic composition, IUCN Red List status, trophic niche, relative abundance (%) and abundance status of fish species recorded from the study area.

I. Order: Cypriniformes	IUCN Red List status	Trophic niche	Abundance (%)	Abundance status
i. Family: Botiidae				
1. *Botia rostrata* Gunther, 1868	Vulnerable	Sub-inferior	0.5	Extremely rare
ii. Family: Balitoridae				
2. *Balitora brucei* Gray, 1830	Near Threatened	Inferior	0.9	Extremely rare
iii. Family: Nemacheilidae				
3. *Aborichthys uniobarensis* Nanda et al., 2021	Not Evaluated	Inferior	0.5	Extremely rare
4. *Schistura scaturigina* (McClelland, 1839)	Least Concern	Inferior	1.1	Extremely rare
5. *Mustura dikrongensis* Lokeshwor & Vishwanath, 2012	Not Evaluated	Inferior	0.2	Extremely rare
iv. Family: Psilorhynchidae				
6. *Psilorhynchus balitora* (Hamilton, 1822)	Least Concern	Inferior	3.6	Extremely rare
v. Family: Cyprinidae				
7. *Chagunius chagunio* (Hamilton, 1822)	Least Concern	Sub-terminal	0.7	Extremely rare
8. *Barilius vagra* (Hamilton, 1822)	Least Concern	Terminal	0.9	Extremely rare
9. *Labio pangusia* (Hamilton, 1822)	Near Threatened	Sub-terminal	0.7	Extremely rare
10. *Tor putitora* (Hamilton, 1822)	Endangered	Terminal	2.5	Extremely rare
11. *Neolissochilus hexagonolepis* (McClelland, 1839)	Near Threaten	Terminal	0.5	Extremely rare
12. *Bangana dero* (Hamilton, 1822)	Least Concern	Sub-terminal	6.1	Rare
13. *Cabdio morar* (Hamilton, 1822)	Least Concern	Sub-terminal	0.5	Extremely rare
14. *Garra annandalei* Hora, 1921	Least Concern	Inferior	1.6	Extremely rare
15. *Garra birostris* Nebeshwar & Vishwanath, 2013	Not Evaluated	Inferior	0.9	Extremely rare
16. *Puntius conchonius* (Hamilton, 1822)	Least Concern	Terminal	0.2	Extremely rare
17. *Puntius sophore* (Hamilton, 1822)	Least Concern	Terminal	1.8	Extremely rare
18. *Pethia ticto* (Hamilton, 1822)	Least Concern	Terminal	0.7	Extremely rare
19. *Raiamas bola* (Hamilton, 1822)	Least Concern	Terminal	1.6	Extremely rare
20. *Semiplotus semiplotus* (McClelland, 1839)	Vulnerable	Terminal	21.7	Sporadic
vi. Family: Danionidae				
21. *Danio rerio* (Hamilton, 1822)	Least Concern	Oblique	1.1	Extremely rare
22. *Devario aequipinnatus* (McClelland, 1839)	Least Concern	Oblique	5.4	Rare
23. *Opsarius barna* (Hamilton, 1822)	Least Concern	Slightly oblique	1.4	Extremely rare
24. *Opsarius bendelisis* (Hamilton, 1807)	Least Concern	Terminal	44.1	Occassional
II. Siluriformes				
vii. Sisoridae				
25. *Glyptothorax trilineatus* Blyth 1860	Least Concern	Inferior	0.5	Extremely rare
26. *Pseudolaguvia vespa* Praveenraj et al., 2021	Not Evaluated	Inferior	0.2	Extremely rare
III. Mugiliformes				
viii. Ambassidae				
27. *Chanda nama* Hamilton, 1822	Least Concern	Oblique	0.2	Extremely rare

Diversity indices supported this pattern (Table 3). Moderate Shannon diversity (H' = 2.004) and evenness (E = 0.608), together with a relatively high Simpson's index of diversity (1 − D = 0.748), indicate that although species richness has declined, the remaining community still retains moderate diversity but is strongly dominated by a few species.

Trophic structure and ecological shifts

The functional ecological guilds provide greater

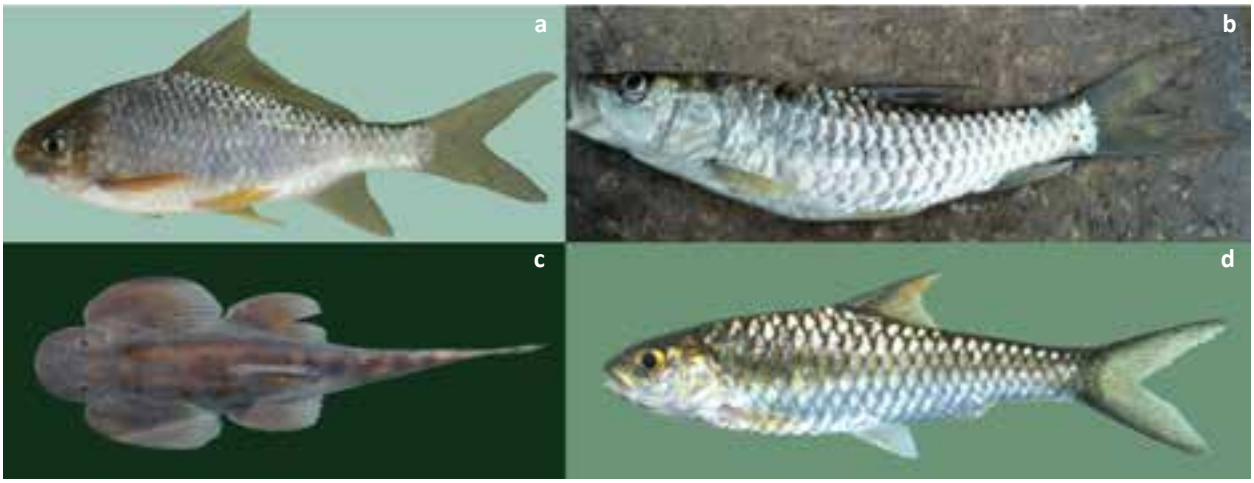

Image 3. Fish species of conservation concern recorded from the study site (Dikrong River): a—*Semiplotus semiplotus* (Vulnerable) | b—*Tor putitora* (Endangered) | c—*Balitora brucei* (Near Threatened) | and d—*Neolissochilus hexagonolepis* (Near Threatened). Photographed by- Lakpa Tamang (Museum Attendant, RGUMF).

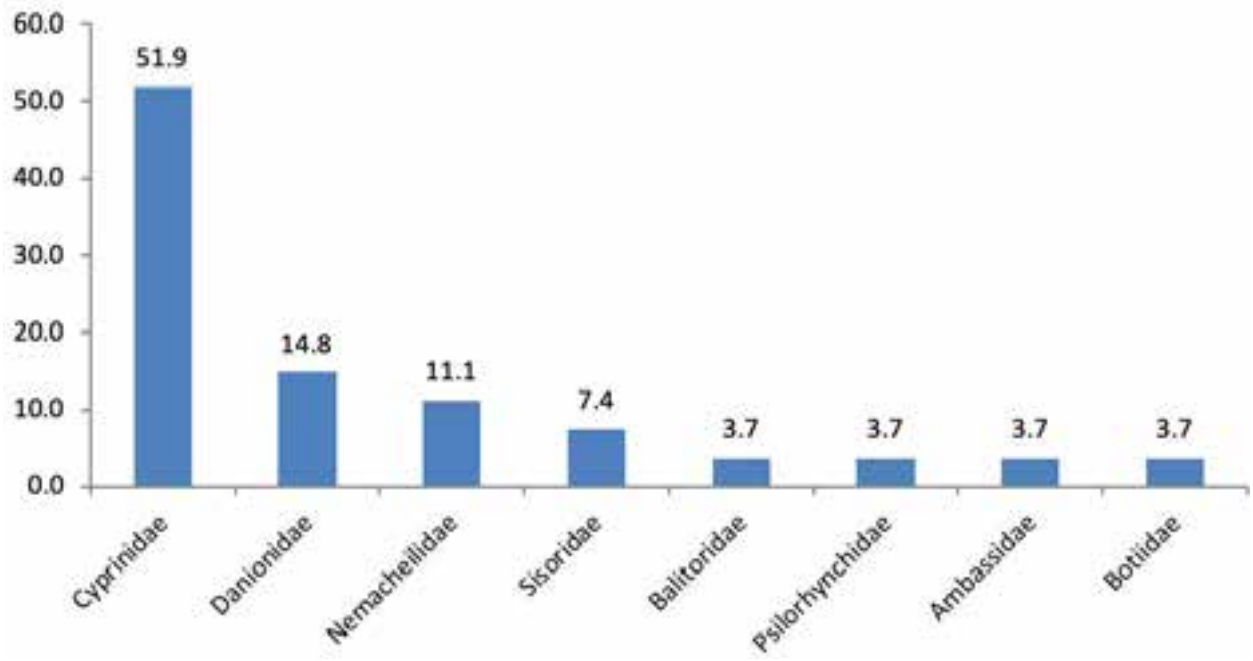

Image 4. Percentage composition of fish species among families in the Dikrong River, showing the dominance of Cyprinidae.

insight into fish community structure, and it is easier to examine the trophic state and environmental stresses affecting the rivers (Deegan et al. 1997; Mathieson et al. 2000; Elliott et al. 2007; Henriques et al. 2008; Keila et al. 2014). Trophic guild analysis revealed clear shifts in feeding structure. Among the 21 comparable species recorded in the present study (excluding six newly recorded species), column feeders dominated (62%), while bottom feeders and surface feeders each accounted for 19% (Image 6). In contrast, Nath & Dey (2000) reported a higher proportion of bottom feeders, reflecting a benthic-resource-rich system prior to dam construction. Remarkably, among the 64 species not encountered from the present study, bottom feeders constituted the largest proportion (52%), followed by column feeders (36%) and surface feeders (12%) (Image 7). The above loss of some benthic fish species shows that the bottom-feeding fishes are quite sensitive to alterations in flow regimes, sediment dynamics, and substrate composition, all of which are characteristic

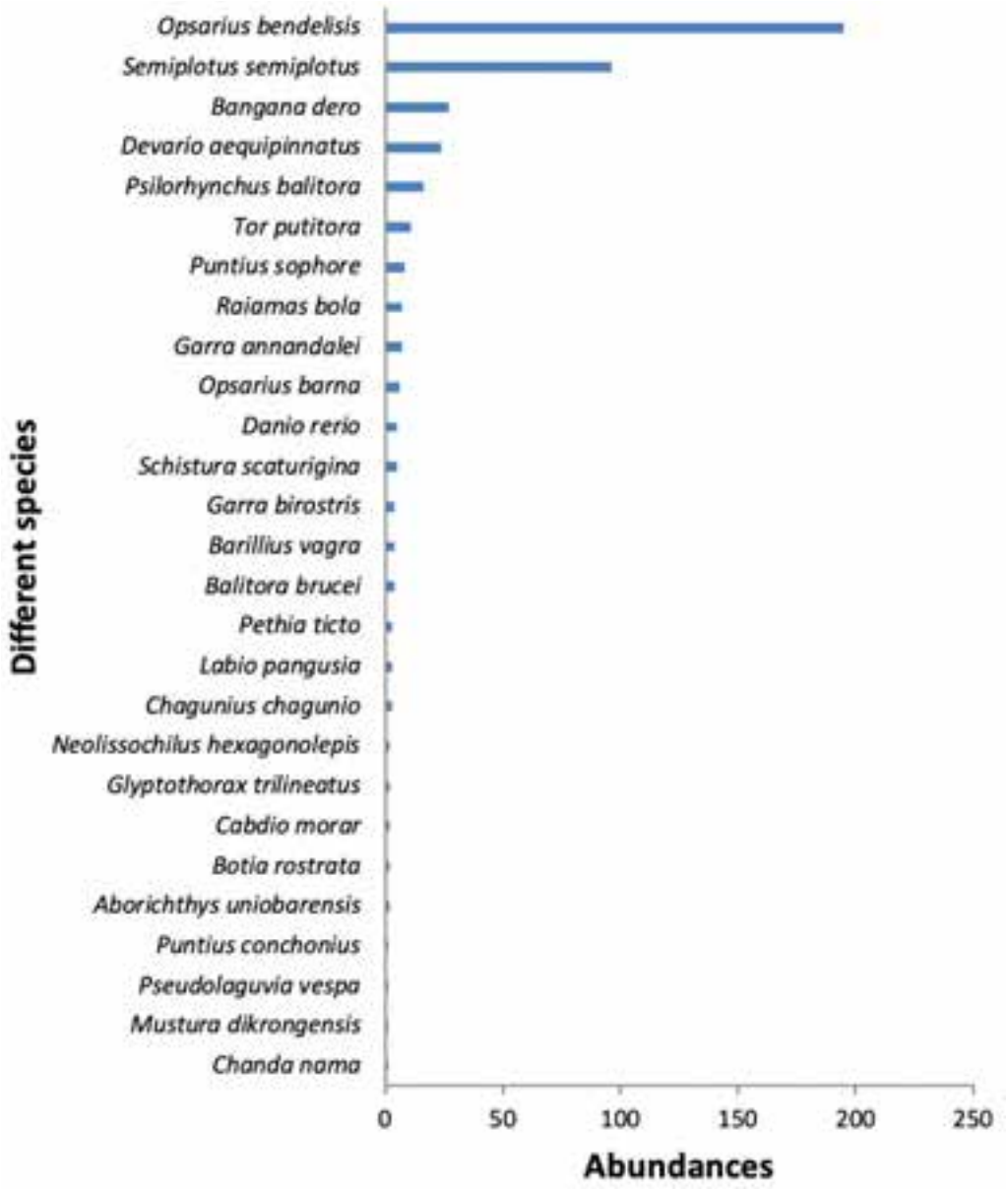

Image 5. Species-wise abundance of fishes recorded from the site (Dikrong River) during the present study.

effects of dam construction. As indicated in Table 1, extremely rare hillstream bottom feeders included multiple taxa such as *Botia rostrata*, *Balitora brucei*, *Aborichthys uniobarensis*, *Schistura scaturigina*, *Mustura dikrongensis*, *Psilorhynchus balitora*, *Garra annandalei*, *Garra birostris*, *Glyptothorax trilineatus*, and *Pseudolaguvia vespa*. The disproportionate loss of bottom-feeding species highlights their vulnerability to flow regulation, sediment modification, and habitat homogenization associated with dam operations.

Influence of Sopo Dam and flow regulation

Rheophilic and bottom-dwelling fish species are among the most vulnerable to hydropeaking due to their constant exposure to fluctuating river regimes (García et al. 2011; Moreira et al. 2019). These populations have been reported to declined over the past 50 years (Deinet et al. 2020) as river fragmentation obstructs the natural migration process required to complete their life cycles (Ovidio & Philippart 2008; Branco et al. 2017; Pfauserová et al. 2020). Low flow causes fish stranding and egg dewatering (Nagrodski et al. 2012), while high flow cause fish to find shelter and egg dislodging (Costa et al. 2019; Baladrón et al. 2021). Moreover, variability in flow and temperature impacts prey abundance by eliminating benthic invertebrates (Bruno et al. 2013).

Table 2. Comparative checklist of fish species of the Dikrong River current status based on Nath & Dey (2000) and the present study (2025).

	Family/Species	Revised nomenclature	Dikrong River (Nath & Dey 2000)	Dikrong River (present study)
	i. Family: Anguillidae			
1	*Anguilla bengalensis* (Gray, 1839)	-	+	0
	ii. Family: Clupeidae			
2	*Gudusia chapra* (Hamilton, 1822)	-	+	0
	iii. Family: Botiidae			
3	*Botia dario* (Hamilton, 1822)	-	+	0
4	*Botia rostrata* (Günther)	-	+	+
	iv. Family: Cobitidae			
5	*Lepidocephalus guntea* (Hamilton, 1822)	*Lepidocephalichthys guntea*	+	0
6	*Lepidocephalus annandalei* (Hora, 1921)		+	0
	v. Family: Balitoridae			
7	*Balitora brucei*(Gray, 1830)	-	0	+
	vi. Family: Nemacheilidae			
8	*Aborichthys elongatus* (Hora)	-	+	0
9	*Aborichthys kempi* (Chaudhuri, 1912)	*Aborichthys uniobarensis* Nanda et al., 2021	+	+
10	*Acanthocobitis botia* (Hamilton, 1822)	*Paracanthocobitis botia*	+	0
11	*Mustura dikrongensis* Lokeshwor & Vishwanath, 2012	-	0	+
12	*Noemacheilus* arunachalensis (Dutta & Barman)	*Schistura tirapensis,* Kottelat, 1990	+	0
13	*Schistura scaturigina* (McClelland, 1839)	-	0	+
14	*Shistura sikmaiensis* (Hora, 1921)	-	+	0
	vii. Family: Psilorhynchidae			
15	*Psilorhynchus balitora* (Hamilton, 1822)	-	+	+
	viii. Family: Cyprinidae			
16	*Acrossocheilus hexagonolepis* (McClelland, 1839)	*Neolissochilus hexagonolepis*	+	+
17	*Amblypharyngodon mola* (Hamilton, 1822)	-	+	0
18	*Aspidoparia jaya* (Hamilton, 1822)	*Cabdio jaya*	+	0
19	*Aspidoparia morar* (Hamilton, 1822)	*Cabdio morar*	+	+
20	*Barilius bola* (Hamilton, 1822)	*Raiamas bola*	+	+
21	*Barilius tileo* (Hamilton, 1822)	*Opsarius tileo*	+	0
22	*Barilius vagra* (Hamilton, 1822)	-	+	+
23	*Chagunius chagunio* (Hamilton, 1822)	-	+	+
24	*Chela laubuca* (Hamilton, 1822)	*Laubuka laubuca*	+	0
25	*Cirrhinus reba* (Hamilton, 1822)	-	+	0
26	*Crossocheilus latius latius* (Hamilton, 1822)	*Tariqilabeo latius*	+	+
27	*Garra annandalei* Hora, 1921	-	+	+
28	*Garra birostris* Nebeshwar & Vishwanath, 2013	-	0	+
29	*Garra gotyla gotyla* (Gray, 1830)	*Garra gotyla*	+	0
30	*Garra kempi* Hora, 1921	-	+	0
31	*Garra lissorhynchus* (McClelland, 1842)	-	+	0
32	*Garra mcclellandi* (Jerdon, 1849)	-	+	0
33	*Labeo dero* (Hamilton, 1822)	*Bangana dero*	+	+
34	*Labeo pangusia* (Hamilton, 1822)	-	+	+
35	*Puntius chola* (Hamilton, 1822)	-	+	0
36	*Puntius conchonius* (Hamilton, 1822)	-	+	+
37	*Puntius sarana sarana* (Hamilton, 1822)	*Puntius sarana*	+	0

	Family/Species	Revised nomenclature	Dikrong River (Nath & Dey 2000)	Dikrong River (present study)
38	*Puntius sophore* (Hamilton, 1822)	-	+	+
39	*Puntius ticto* (Hamilton, 1822)	*Pethia ticto*	+	+
40	*Rasbora daniconius* (Hamilton, 1822)	-	+	0
41	*Rasbora elanga* (Hamilton, 1822)	-	+	0
42	*Rasbora rasbora* (Hamilton, 1822)	-	+	0
43	*Salmostoma bacaila* (Hamilton, 1822)	-	+	0
44	*Schizothorax richardsonii* (Gray)	-	+	0
45	*Semiplotus semiplotus* (McClelland, 1839)	-	+	+
46	*Tor putitora* (Hamilton, 1822)	-	+	+
47	*Tor tor* (Hamilton, 1822)	-	+	0
	ix. Family: Danionidae			
48	*Barilius barna* (Hamilton, 1822)	*Opsarius barna*	+	+
49	*Barilius bendelisis* (Hamilton, 1807)	*Opsarius bendelisis*	+	+
50	*Brachydanio rerio* (Hamilton, 1822)	*Danio rerio*	+	0
51	*Danio aequipinnatus* (McClelland, 1839)	*Devario aequipinnatus*	+	+
52	*Danio dangila* (Hamilton, 1822)	-	+	0
53	*Danio devario* (Hamilton, 1822)	*Devario devario*	+	0
	x. Family: Clariidae			
54	*Clarias batrachus* (Linnaeus, 1758)	-	+	0
	xi. Family: Siluridae			
55	*Ompok pabda* (Hamilton, 1822)	-	+	0
56	*Ompok pabo* (Hamilton, 1822)	-	+	0
57	*Silurus afghana* (Günther, 1864)	*Pterocryptis indica*	+	0
58	*Somileptes gongota* (Hamilton, 1822)	*Canthophrys gongota*	+	0
59	*Wallago attu* (Bloch & Schneider 1801)	-	+	0
	xii. Family: Bagridae			
60	*Mystus bleekeri* (Day)	-	+	0
61	*Mystus cavasisus* (Hamilton, 1822)	-	+	0
62	*Mystus montanus* (Jerdon, 1849)	-	+	0
63	*Mystus vittatus* (Bloch, 1794)	-	+	0
64	*Olyra longicaudata* (McClelland, 1842)	-	+	0
	xiii. Family: Amblycipitidae			
65	*Amblyceps apangi* (Nath & Dey, 1989)	-	+	0
66	*Amblyceps arunachalensis* (Nath & Dey)	-	+	0
67	*Amblyceps mangois* (Hamilton, 1822)	-	+	0
	xiv. Family: Heteropneustidae			
68	*Heteropneustes fossilis* (Bloch)	-	+	0
	xv. Family: Sisoridae			
69	*Bagarius bagarius* (Hamilton, 1822)	-	+	0
70	*Glyptothorax trilineatus* Blyth, 1860	-	0	+
71	*Pseudolaguvia vespa* Praveenraj et al., 2021	-	0	+
	xvi. Family: Mastacembelidae			
72	*Macrognathus aral* (Bloch & Schneider)	-	+	0
73	*Macrognathus pancalus* (Hamilton, 1822)	-	+	0
74	*Mastacembelus armatus* (Lacépède)	-	+	0
	xvii. Family: Chaudhuriidae			
75	*Pillaia indica* Yazdani, 1972	-	+	0

	Family/Species	Revised nomenclature	Dikrong River (Nath & Dey 2000)	Dikrong River (present study)
	Family: Synbranchidae			
76	*Monopterus cuchia* (Hamilton, 1822)	*Opichthys cuchia*	+	0
	xviii. Family: Anabantidae			
77	*Anabas testudineus* (Bloch, 1792))	-	+	0
	xix. Family: Channidae			
78	*Channa marulius* (Hamilton, 1822)	-	+	0
79	*Channa orientalis* (Schneider)	-	+	0
80	*Channa punctatus* (Bloch, 1793)	*Channa punctata*	+	0
81	*Channa striatus* (Bloch)	-	+	0
	xx. Family: Nandidae			
82	*Nandus nandus* (Hamilton, 1822)	-	+	0
	xxi. Family: Badidae			
83	*Badis badis* (Hamilton, 1822)	-	+	0
	xxii. Family: Belonidae			
84	*Xenentodon cancila* (Hamilton, 1822)	-	+	0
	xxiii. Family: Ambassidae			
85	*Chanda nama* (Hamilton, 1822)	-	+	+
86	*Parambassis baculis* (Hamilton, 1822)	*Chanda baculis*	+	0
87	*Parambassis ranga* (Hamilton, 1822)	*Chanda ranga*	+	0
	xxiv. Family: Gobiidae			
88	*Glossogobius giuris* (Hamilton, 1822)	-	+	0
	xxv. Family: Erethitidae			
89	*Erethistes pussilus* Müller & Troschel, 1849	-	+	0
90	*Hara hara* (Hamilton, 1822)	-	+	0
	xxvi. Family: Notopteridae			
91	*Notopterus notopterus* (Pallas, 1769)	-	+	0
		Total species	**85**	**27**

+—presence | 0—absence | -—valid species (no change).

Table 3. Species diversity indices of the study site (Dikrong River), Papum Pare District, Arunachal Pradesh.

Species richness	27
Evenness (E)	00.608
Shannon-Weiner Index 9H)	2.004
Simpson's Index (D)	00.252
Simpson's Index of Diversity (1-D)	00.748

Table 4. Physico-chemical characteristics of water of the study site (Dikrong River), Papum Pare District, Arunachal Pradesh.

Water quality	Range	Mean ± SD
BOD (mg/L)	3.5–4.5	4.2 ± 1.5
Dissolved oxygen (mg/L)	7.7–8.5	8.08 ± 3.2
TDS (ppm)	25.7–66.7	46.77 ± 17.6
Temperature (°C)	13.3–17.7	15.56 ± 5.8

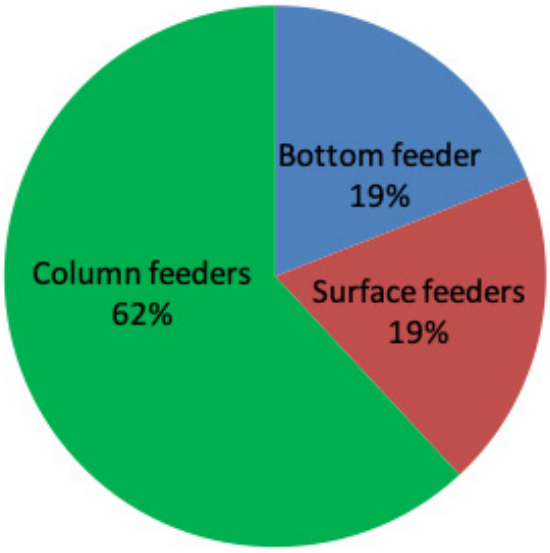

Image 6. Trophic niches of 21 fish species encountered in the present study (Dikrong River).

Our field observations downstream of the Sopo Dam indicated pronounced flow regulation effects. Water releases, typically occurring in the late afternoon (~1700 h), caused rapid increases in water level and were associated with transient increases in catches of *Opsarius bendelisis*, likely due to forced displacement toward river margins. Conversely, prolonged low-flow conditions (December 2025) during mornings and daytime resulted in minimal fish activity and very low catch rates, even in structurally complex habitats beneath boulders. Based on 15 replicate measurements across the study site, river width decreased by 10–56 m (mean ± SD = 29.9 ± 12.6 m) during low-flow periods, compared to 69–150 m (mean ± SD = 92.7 ± 21.8 m) during dam release periods.

Habitat structure, water quality, and anthropogenic pressures

The riverbed substrate composition consisted mainly of boulders, cobbles, pebbles, and gravels, whereas sandy substrates were found beyond the border between Arunachal Pradesh and Assam at Banderdewa. The limited presence of riparian vegetation along the study site can be attributed to low bank stability due to the lack of sufficient vegetation cover in comparison with the upstream sections of the river. Dissolved oxygen concentration (DO: 7.7–8.5 mg/L) and temperature (13.3–17.7 °C) were favorable for hillstream fish species (Table 4). In contrast, high biological oxygen demand (BOD) values (3.5–4.5 mg/L) observed in the area where the Pachin and Dikrong confluence occurs (Image 1) suggest that the water is contaminated by organic domestic waste that originates from the western side through Naharlagun and Itanagar complexes, accounting for about one-quarter of the entire study area. However, before the meeting point, the water is clear because of the sparse human population. In the study site frequent water-level fluctuations likely reduce algal growth and aquatic insect colonization, thereby reducing food availability and compromising spawning habitats. We observed that most of the substratum was clean and showed little to no algal growth throughout the study site. Additional anthropogenic pressures, including intensive quarrying (using heavy machinery, e.g., JCB excavators) and indiscriminate disposal of domestic and market waste, have further degraded habitat quality (image 2). Several studies have reported the existence of heterogeneously contaminated landscapes, where pollution concentrations vary in different connected aquatic habitats. In such conditions, if aquatic organisms can sense contaminants and interpret associated chemical cues (Tierney 2016; Dominoni et al. 2020),

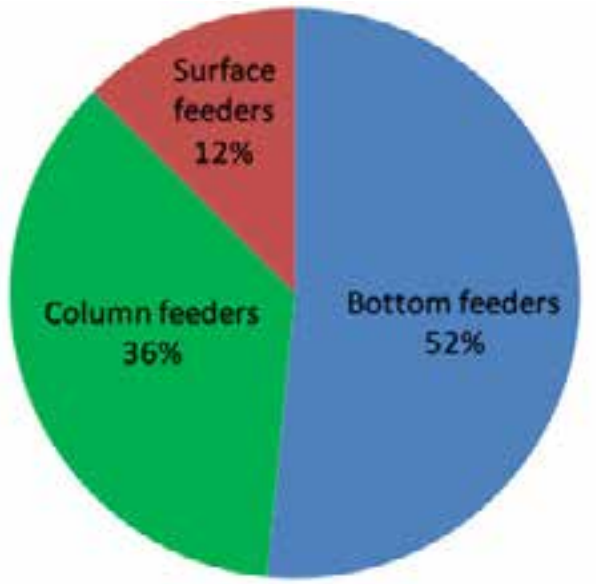

Image 7. Trophic niches of 64 fish species listed by Nath & Dey (2000) that were not recorded in the present study (Dikrong River). Image 4. Trophic niches of 64 fish species listed by Nath & Dey (2000) that were not recorded in the present study (Dikrong River).

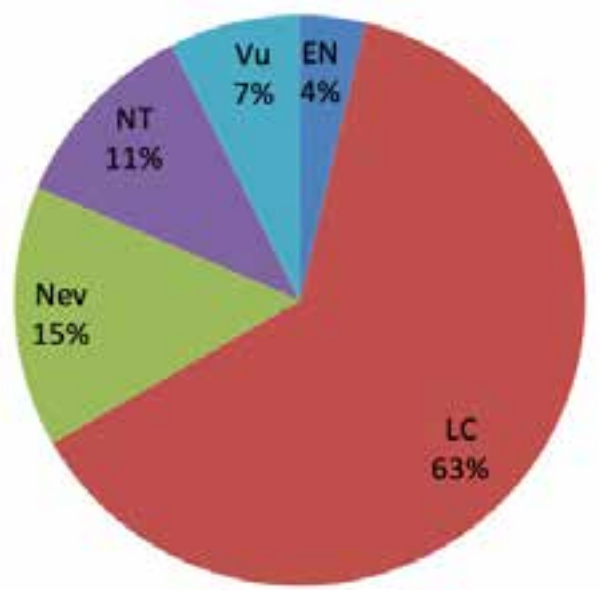

Image 8. IUCN Red List status of fish species recorded in the study site (Dikrong River).

they locally shift from polluted water patches and move toward more suitable adjacent habitats (Cairns & Niederlehner 1996; Johnson 2002; Tierney et al. 2011). Such behavioral response reflects the ability of organisms to track spatial variation in habitat quality and relocate when local environmental conditions become unfavorable. A similar pattern has been observed in this study where juveniles *Semiplotus semiplotus*,

Devario aequipinnatus, and *Opsarius bendelisis* moved into nearby cleaner drainages, indicating behavioral responses to habitat degradation and pollution stress.

Conservation Implications

Most of the known species were categorized as Least Concern (63%) on the basis of the IUCN Red List of Threatened Species (2026); however, the inclusion of Near Threatened (11%), i.e., *Balitora brucei* and *Neolissochilus hexagonolepis*, Vulnerable (7%), i.e., *Semiplotus semiplotus*, and Endangered species (4%), i.e., *Tor putitora*, underscores the conservation value of the Dikrong River (Table 1, Image 8). The local extinction of several species, especially the bottom feeders, underlines the critical necessity for the proper management of flows, rehabilitation of habitats, and control of human activities to preserve the rest of the ichthyofaunal diversity.

CONCLUSION

The present study documents a marked decline in fish diversity in the Dikrong River following the commissioning of the Sopo Dam in 2018 in addition to other anthropogenic activities. Comparison with pre-impoundment records indicates that 64 previously reported species were not encountered, despite the addition of six new records. However, these species are likely to occur upstream beyond Sopo Dam, in other connected drainages and other river systems within the Itanagar Wildlife Sanctuary. This net loss reflects significant ecological alteration of the riverine system as per our limited sampling period of 10 days. Changes in community structure were evident from the strong dominance of a few species, particularly *Opsarius bendelisis*, and the extremely low abundance of most remaining bottom-feeding species (Table 1). Moreover, the trophic guild analysis revealed a pronounced shift from bottom-feeder dominance prior to dam construction to a present-day assemblage dominated by column feeders, indicating degradation of benthic habitats.

Field observations and habitat assessments confirmed that abrupt and irregular water releases from the dam disrupt downstream habitat stability, influencing fish distribution and activity patterns. Although water quality remained generally suitable for hillstream fishes, frequent water-level fluctuations, reduced benthic productivity, organic pollution, quarrying, and waste disposal collectively led to habitat degradation and ecological stress.

The presence of highly threatened species suggests the high conservation priority of the Dikrong River. Our findings highlight an urgent need for ecologically sensitive flow management, the mitigation of anthropogenic disturbances such as regulation on river substrate mining, and long-term monitoring to preserve and restore aquatic biodiversity in dam-regulated Dikrong River systems. Based on our observations, such damage may be too difficult to be rectified through standard mitigation, such as the installation of fish ladders or side-river bypasses.

A promising opportunity is the development of the ornamental fish trade, which contributes 80% of India's indigenous fish exports from Northeast India, primarily through wild collection (Dhar & Ghosh, 2015) However, wild collection is unsustainable for long run that may lead to biodiversity loss, and is regulated by the Biodiversity Authority of the state and continued reliance on wild harvests is economically and legally risky. The state possesses 52 ornamental fish species (Abujam et al. 2021), it would be highly beneficial to include potential ornamental species such as *Botia rostrata, Channa pomanensis, Aborichthys uniobarensis*, and *Devario aequipinnatus* along with other food fishes like *Tor putitora, Neolissochilus hexagonolepis, Bangana dero, Semiplotus semiplotus,* and *Labeo pangusia* in culture-based fisheries. The establishment of cage culture system over the reservoir of dam and ornamental fish unit nearby would help in providing entrepreneurship as well as proper fishery management. This strategy will further assist in boosting economic upliftment, decreasing unemployment levels, as well as food security of the rural populace for long run.

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ARTICLE

An annotated district-wise account of Odonata (Dragonflies and Damselflies) from Uttarakhand, India

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Abstract: This study presents a list of 135 odonate species recorded from Uttarakhand, based on an extensive and critical review of published literature. Notes on the present status of some recorded taxa are included. The documented diversity includes 15 families and 73 genera, comprising 84 species of Anisoptera and 51 species of Zygoptera. Among the districts, Dehradun has the highest recorded species richness, followed by Nainital and Pauri Garhwal. Five species recorded are endemic to India. The majority of species are categorized as 'Least Concern' on the IUCN Red List, with a small proportion listed as 'Data Deficient' or 'Near Threatened'. The list also provides an account of ecological assessments and biogeographical comparisons in the region.

Keywords: Anisoptera, checklist, distribution, diversity, endemism, nomenclatural changes, taxonomic revisions, western Himalaya, Zygoptera.

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Author contribution: MKA—supervision, conceptualization, formal analysis and writing original draft; MM—review of literature and writing of original draft

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INTRODUCTION

The order Odonata, comprising the dragonflies and damselflies, represents one of the most ancient and ecologically significant groups of insects (Kohli et al. 2020). There are two main suborders, Anisoptera and Zygoptera, along with Anisozygoptera, a relic group closer to Anisoptera but exhibiting intermediate features (Subramanian & Babu 2020), often placed in its own suborder. Paulson et al. (2026) recognise 6,485 species in 823 genera globally. Of these, India is home to 504 species, in 157 genera representing 17 families (Subramanian & Babu 2024). Odonates serve multiple ecological roles such as predators and prey, and many species are recognized as sensitive bioindicators of freshwater ecosystem health due to their intolerance to pollution and habitat degradation (Samways & Steytler 1996; Kadoya et al. 2004; Weisser & Siemann 2004; Oertli 2008; Ali & Niaz 2011; May 2019). The Indian Himalayan region, including Uttarakhand, offers a unique mosaic of habitats such as rivers, streams, wetlands, forests, and high-altitude lakes that host diverse odonate fauna. However, studies documenting Odonata diversity in Uttarakhand remain limited. Regional studies that have contributed to our knowledge of Odonata diversity in Uttarakhand include: Prasad & Singh (1976), Prasad & Singh (1995), Kumar & Mitra (1998), Mitra (2000), Vashishth et al. (2002), Farooq & Arya (2018), and De et al. (2021), yet no comprehensive study has been conducted to evaluate species composition and distribution across all the districts of the state. Hence, the present study aims to systematically document and list the Odonata of Uttarakhand.

MATERIALS AND METHODS

Study area

The present review focuses on the western Himalayan Indian state of Uttarakhand. The state covers an area of approximately 53,483 km² (1.63% of India's total geographical area) and is situated between 28.716–31.466 °N and 77.566–81.05 °E. Uttarakhand shows considerable altitudinal variation, ranging from about 100 m in the Tarai plains to 7,816 m at Nanda Devi peak. The region receives an average annual rainfall of nearly 1,500 mm, and temperatures range from below 0 °C at higher elevations to around 43 °C in the plains. Administratively, the state comprises two sub-divisions: Garhwal (seven districts) and Kumaon (six districts), and includes the Trans-Himalayan, Greater Himalayan, Lesser Himalayan, Bhabar, and Tarai physiographic zones. Table 1 presents the districts of the two administrative divisions of Uttarakhand along with their geographic and meteorological attributes.

The present list of Odonata (dragonflies and damselflies) of Uttarakhand was compiled by an extensive review of existing scientific literature. This included many publications, including: Fraser (1933, 1934, 1936), Prasad & Singh (1976), Singh & Prasad (1976), Kumar & Prasad (1981), Kumar (1982), Bisht & Das (1988), Kaushal & Joshi (1988), Hämäläinen (1989), Kumar (1995), Mitra (1999, 2000), Joshi et al. (2002, 2004, 2008), Vashishth et al. (2002), Kumar & Sharma (2003), Tewari & Kaushal (2007), Dev et al. (2009), Prasad & Mondal (2010), Prasad & Sinha (2010), Arya (2015), Subramanian & Babu (2017), Farooq & Arya (2018), Husain (2018), Verma & Arya (2020), Arya et al. (2021, 2023, 2024), De et al. (2021), and Singh (2022). It should be noted that several locality records reported by Fraser are expressed in broad geographical terms (e.g., "Kumaon", "Dehra Dun"), which do not always correspond to present-day administrative districts. Such records have therefore been interpreted cautiously when assigning district-level distributions in the present study. The taxonomic status and systematic position of all recorded species were verified and updated according to the modern classification system first established by Dijkstra et al. (2013), while the taxonomic updates, including species revisions and nomenclatural changes, were incorporated based on online databases, namely the World Odonata List (Paulson et al. 2026) and iNaturalist (2025), and recent revisions. The global conservation status of each species was based on the IUCN Red List of Threatened Species (IUCN 2025). Information on the endemic status of the species was derived from Kalkman et al. (2020).

The presence of each species in various districts was catalogued based on records from the published literature. These data were organized into tables to facilitate a comparison of species diversity and distribution across all districts of Uttarakhand. The compiled data were analyzed to quantify the odonate diversity of Uttarakhand. The present analysis focuses on species-level diversity. In cases where the literature reported infra-specific taxa (e.g., *Neurobasis chinensis chinensis*), these records were catalogued alongside their specific localities. However, for the purpose of calculating total species richness and conducting comparative analyses, all named subspecies were subsumed under their respective nominal species (e.g., *Neurobasis chinensis*). This species-level enumeration approach prevents taxonomic inflation in diversity metrics and

ensures that the results are comparable with other odonatological studies that may not recognize or may treat these infra-specific categories differently. Thus, a species is counted only once, regardless of the number of its subspecies reported within the state.

RESULTS AND DISCUSSION

Species Richness and Taxonomic Composition

A total of 135 species of Odonata were documented from Uttarakhand (Table 2). These are distributed across two suborders, 15 families, and 73 genera. Suborder Zygoptera (Damselflies) comprised 51 species (37.8%), belonging to eight families. The most speciose family within Zygoptera was Coenagrionidae with 20 species, followed by Platycnemididae (11 species), Lestidae (6 species), Chlorocyphidae (7 species), Euphaeidae (3 species), Platystictidae (2 species), Calopterygidae (1 species) and Synlestidae (1 species). Suborder Anisoptera (Dragonflies) was represented by 84 species (62.2%), spread across seven families. The family Libellulidae dominated with 46 species, making it the most species-rich family overall. Other families included Gomphidae (18 species), Aeshnidae (10 species), Cordulegastridae (6 species), Macromiidae (2 species), Chlorogomphidae (1 species), and Corduliidae (1 species). Overall, Libellulidae contributed the highest recorded odonate fauna of Uttarakhand with 46 species (34.1% of the total odonate fauna of Uttarakhand) (Image 1).

District-wise Distribution

The distribution analysis revealed marked variation across districts. Dehradun emerged as the most species-rich district, with 103 species, representing 76.3% of the total odonate fauna of Uttarakhand. Other high-diversity districts included Nainital (76 species), Pauri Garhwal (55 species), and Uttarkashi (42 species). On the other hand, districts such as Champawat (16 species), Rudraprayag (8 species), and Udham Singh Nagar (3 species) recorded comparatively lower diversity, likely reflecting low sampling effort rather than actual low diversity (Image 2).

Dominant and Widespread Species

Several common and widespread species were also widely distributed across the state, occurring in eight or more districts. These included: *Orthetrum taeniolatum* (12 districts), *Orthetrum glaucum* (11 districts), *Orthetrum pruinosum* (11 districts), *Orthetrum sabina* (11 districts), *Crocothemis servilia* (10 districts), *Orthetrum triangu*lare (10 districts), *Pantala flavescens* (10 districts), *Trithemis festiva* (10 districts), *Ischnura forcipata* (9 districts), *Palpopleura sexmaculata* (9 districts), *Paracypha unimaculata* (9 districts), *Anisopleura comes* (8 districts), *Ischnura rubilio* (8

Table 1. Geographic and meteorological attributes of the districts belonging to the two divisions of Uttarakhand (G.B. Pant National Institute of Himalayan Environment 2020; Forest Survey of India 2023; Arya et al. 2025a,b; NASA 2025).

Division	Districts	Elevational range (in m)	Total Geographical Area (GA) (in km²)	Total Forest Area (FA) (in km²)	Average monthly temperature (2020-2024) (in °C)	Average monthly humidity (2020-2024) (in %)	Average monthly rainfall (2020-2024) (in mm/day)	No. of odonate species
Garhwal	Chamoli	698–7,512	8030	2,641.30	5.90	63.92	80.17	27
	Rudraprayag	576–6,741	1,984	1,146.61	12.46	61.83	107.88	08
	Tehri Garhwal	335–6,596	3,642	2,222.68	12.46	61.84	107.88	38
	Pauri Garhwal	253–3,097	5,329	3,360.55	17.96	61.23	111.94	55
	Uttarkashi	697–6,903	8,016	3,023.86	-0.49	70.86	79.88	42
	Dehradun	290–3,185	3,088	1,640.30	16.81	61.59	124.16	103
	Haridwar	222–870	2,360	564.76	22.29	57.98	111.59	19
Kumaon	Almora	482–2,744	3,144	1,722.96	19.42	59.51	107.43	40
	Nainital	210–2,623	4,251	2,866.55	19.42	59.51	107.44	76
	Champawat	260–2,174	1,766	1,219.39	16.98	62.07	115.10	16
	Bageshwar	220–2,159	2,241	1,263.37	11.90	61.28	92.91	17
	Udham Singh Nagar	181–387	2,542	494.17	24.2	56.61	100.57	03
	Pithoragarh	428–6,895	7,090	2,137.33	5.88	67.71	78.23	33

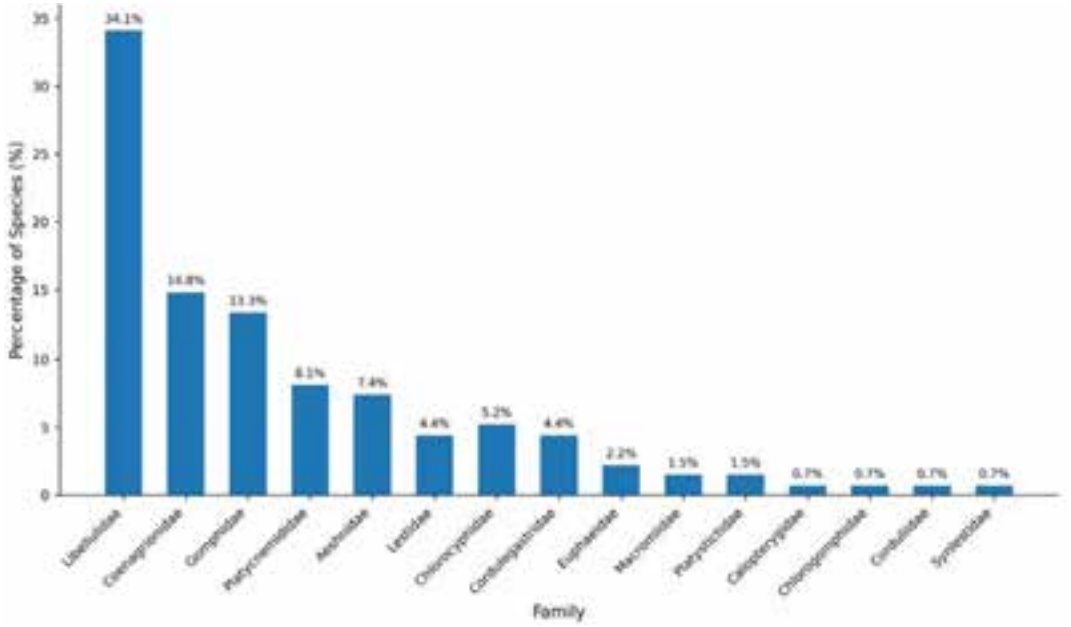

Image 1. Species richness of Odonata in Uttarakhand by family.

Image 2. Species richness of Odonata in Uttarakhand by district.

Table 2. List of significant Odonata records from Uttarakhand.

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
I. ODONATA: ZYGOPTERA							
1. Superfamily: Lestoidea Calvert, 1901							
i. Family: Synlestidae Tillyard, 1917							
Genus: *Megalestes*							
1	*Megalestes major* Selys, 1862	Giant Green Spreadwing	DDN, NTL, AL, PTG, CML	700–3,000	Fraser (1933), Kumar & Prasad (1981), Kumar (1982), Hämäläinen (1989), Husain (2018), Arya et al. (2021), De et al. (2021), Farooq & Arya (2018), Arya et al. (2024), Kumar (1995), Prasad & Mondal (2010),	LC	
ii. Family: Lestidae Calvert, 1901							
Genus: *Indolestes*							
2	*Indolestes cyaneus* (Selys, 1862)	Blue Reedling	DDN, NTL, UTK		De et al. (2021), Prasad & Mondal (2010), Singh (2022)	LC	
Genus: *Lestes*							
3	*Lestes concinnus* Hagen in Selys, 1862	Dusky Spreadwing	DDN, NTL		De et al. (2021), Singh (2022)	LC	
4	*Lestes decipiens* Kirby, 1893		DDN, UTK		De et al. (2021), Husain (2018), Prasad & Mondal (2010)	NE	
5	*Lestes thoracicus* Laidlaw, 1920		DDN		Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010)	LC	
6	*Lestes umbrinus* Selys, 1891	Brown Spreadwing	UKD		Prasad & Mondal (2010)	DD	
7	*Lestes viridulus* Rambur,1842	Emerald-striped Spreadwing	DDN, PG, NTL	0–1,000	De et al. (2021), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
2. Superfamily: Platystictoidea Kennedy, 1920							
iii. Family: Platystictidae Kennedy, 1920							
Genus: *Drepanosticta*							
8	*Drepanosticta carmichaeli* (Laidlaw, 1915)	Himalayan Shadowdamsel or Indo-Chinese Blue Reedtail	DDN, CML, PG, TG, UTK, AL	350–2,100	De et al. (2021), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Protosticta*							
9	*Protosticta davenporti* Fraser, 1931	Anamalai Reedtail	UKD		Prasad & Mondal (2010)	LC	EN IND
3. Superfamily: Calopterygoidea Selys, 1850							
iv. Family: Calopterygidae Selys, 1850							
Genus: *Neurobasis*							
10	*Neurobasis chinensis* (Linnaeus, 1758)	Green Metalwing or Stream Glory	DDN, PG, TG, NTL, AL, PTG, CPT, UTK		De et al. (2021), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Arya et al. (2024), Arya et al. (2023)	LC	
	Neurobasis chinensis chinensis (Linnaeus, 1758)		DDN, PG, TG, NTL, PTG, UTK		Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
v. Family: Chlorocyphidae Cowley, 1937							
Genus: *Aristocypha*							
11	*Aristocypha fenestrella* Rambur,1842	Peacock Jewel	NTL, CPT		Arya et al. (2024), Arya et al. (2023)	LC	
12	*Aristocypha quadrimaculata* (Selys, 1853)	Lesser Black Jewel or Black Emperor	DDN, HD, PG, TG, NTL, BG, AL, CPT, UTK	300–1,400	De et al. (2021), Husain (2018), Prasad & Singh (1976), Vashishth et al. (2002), Arya et al. (2024), Arya et al. (2023), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
13	*Aristocypha spuria* Selys, 1879	Greater Black Jewel	NTL		Kumar (1995), Prasad & Mondal (2010)	LC	

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
14	*Aristocypha trifasciata* (Selys, 1853)	Three-banded Emerald Jewel	DDN, PG, TG, NTL, BG, AL, PTG	600–1,700	De et al. (2021), Husain (2018), Kumar (1982), Kumar (1995), Prasad & Mondal (2010)	LC	
Genus: *Heliocypha*							
15	*Heliocypha biforata* (Selys, 1859)	Magenta Jewel	DDN, PG		De et al. (2021), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995)	LC	
Genus: *Libellago*							
16	*Libellago lineata* spp. (Burmeister, 1839)	Golden Gem or River Heliodor	DDN, PG, NTL, UDM	0–920	De et al. (2021), Singh (2022)	LC	
	Libellago lineata lineata (Burmeister, 1839)		DDN, PG, NTL		Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
Genus: *Paracypha*							
17	*Paracypha unimaculata* (Selys, 1853)		DDN, PG, TG, NTL, AL, PTG, UTK, CML, BG	440–1,800	De et al. (2021), Husain (2018), Prasad & Singh (1976), Arya et al. (2023), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
vi. Family: Euphaeidae Yakobson & Bianchi, 1905							
Genus: *Anisopleura*							
18	*Anisopleura comes* Hagen, 1880	Himalayan Mountaindart	DDN, TG, PTG, CML, AL, NTL, PG, UTK	400–2,600	De et al. (2021), Husain (2018), Kumar (1982), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
19	*Anisopleura lestoides* Selys, 1853	Indian Mountaindart	DDN, PG, NTL, BG, CML, AL, UTK	640–2,500	De et al. (2021), Hämäläinen (1989), Husain (2018), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Bayadera*							
20	*Bayadera indica* (Selys, 1853)	Indian Velveteen	DDN, PG, TG, NTL, AL, CML, UTK		De et al. (2021), Husain (2018), Prasad & Singh (1976), Arya et al. (2021), Arya et al. (2024), Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
vii. Family: Platycnemididae Yakobson & Bianchi, 1905							
Genus: *Calicnemia*							
21	*Calicnemia doonensis* ssp. Sangal & Tyagi, 1984	Doon Oread	DDN, HD, TG, UTK	350–1,700	Singh (2022)	LC	
	Calicnemia doonensis doonensi Sangal & Tyagi, 1984		DDN		De et al. (2021), Hämäläinen (1989), Husain (2018)		
22	*Calicnemia eximia* Selys, 1863	Scarlet Oread or Scarlet Openwing	DDN, NTL, TG, AL, PTG, CML, UTK	300–2,900	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
23	*Calicnemia miles* (Laidlaw, 1917)	Red Oread	DDN, PG, TG, PTG, CML, UTK		De et al. (2021), Husain (2018), Prasad & Singh (1976), Kumar (1995), Kumar & Prasad (1981)	LC	
24	*Calicnemia mortoni* (Laidlaw, 1917)		NTL		Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
25	*Calicnemia pulverulans* (Selys, 1886)	Powdery Oread	TG, AL, UTK, CML, DDN		Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Coeliccia*							
26	*Coeliccia renifera* (Selys, 1886)	Kidney-spotted Sylvan	AL	410–1,830	Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
Genus: *Pseudocopera*							
27	*Pseudocopera ciliata* (Selys, 1863)	Black-kneed Featherleg or Pied Bush Dart	UKD		Prasad & Mondal (2010)	LC	
Genus: *Copera*							
28	*Copera marginipes* (Rambur, 1842)	Yellow Featherleg, Yellow Bush Dart, Yellow Rimmed Featherleg	DDN, PG, NTL, UDM	0–900	De et al. (2021), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
29	*Copera vittata* ssp. Selys, 1863	Blue Bush Dart	DDN	0–1,100	Prasad & Singh (1976), Kumar (1995), Kumar & Prasad (1981)	LC	
	Copera vittata serapica Selys, 1863		DDN		Husain (2018), Prasad & Mondal (2010)		
Genus: *Elattoneura*							
30	*Elattoneura campioni* ssp. (Fraser, 1922)		DDN		De et al. (2021), Prasad & Mondal (2010)	DD	
	Elattoneura campioni campioni (Fraser, 1922)	Blue Threadtail			Singh (2022)		
Genus: *Prodasineura*							
31	*Prodasineura autumnalis* (Fraser, 1922)	Black Threadtail	DDN, NTL		De et al. (2021), Prasad & Mondal (2010), Singh (2022)	LC	
4. Superfamily: Coenagrionoidea Kirby, 1890							
viii. Family: Coenagrionidae Kirby, 1890							
Genus: *Aciagrion*							
32	*Aciagrion pallidum* Selys, 1891	Pale Slender Dartlet	NTL, BG, PTG, PG		Kumar (1982), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Agriocnemis*							
33	*Agriocnemis clauseni* Fraser, 1922	Blue-spotted Wisp	DDN, NTL, PG	200–640	De et al. (2021), Mitra (2000), Meena & Sharma (2025), Kumar & Sharma (2003), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
34	*Agriocnemis pygmaea* (Rambur, 1842)	Wandering Wisp	DDN, NTL, PG, TG, BG, AL, UTK	0–1,700	De et al. (2021), Hamalainen (1989), Husain (2018), Kumar & Sharma (2003), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Amphiallagma*							
35	*Amphiallagma parvum* (Selys, 1876)	Azure Dartlet or Little Blue	DDN, NTL, CPT		De et al. (2021), Hamalainen (1989), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Ceriagrion*							
36	*Ceriagrion cerinorubellum* (Brauer, 1865)	Orange-tailed Marsh Dart or Painted Waxtail	DDN	0–250	De et al. (2021), Kumar & Sharma (2003), Mitra (2000), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
37	*Ceriagrion coromandelianum* (Fabricius, 1798)	Coromandel Marsh Dart or Yellow Waxtail	DDN, HD, TG, NTL, CML, UTK, PG		De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Singh (1976), Vashishth et al. (2002), Arya et al. (2024), Arya et al. (2023), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
38	*Ceriagrion fallax* Ris, 1914	Black-tailed Marsh Dart	DDN, UTK	2,000	De et al. (2021), Husain (2018), Singh (2022)	LC	
Genus: *Coenagrion*							
39	*Coenagrion exclamationis* (Fraser, 1919)		UKD		Prasad & Mondal (2010)	DD	
Genus: *Ischnura*							
40	*Ischnura forcipata* Morton, 1908	Forcipate Dartlet or Forked Bluetail	DDN, HD, PG, TG, NTL, AL, PTG, CML, UTK		Fraser (1933), Prasad & Singh (1976), Mitra (2000), De et al. (2021), Meena & Sharma (2025), Hämäläinen (1989), Husain (2018), Kumar (1982), Kumar & Sharma (2003), Vashishth et al. (2002), Kumar (1995), Prasad & Mondal (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
41	*Ischnura nursei* Morton, 1907	Pixie Dartlet	DDN, HD, NTL, PG, PTG, UDM		Kumar & Prasad (1981), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), De et al. (2021), Vashishth et al. (2002), Singh (2022)	LC	
42	*Ischnura pumilio* (Charpentier, 1825)	Scarce Blue-tailed Damselfly or Small Bluetail	UKD	0–2,300	Singh (2022)	LC	
43	*Ischnura rubilio* Selys, 1877	Western Golden Dartlet	DDN, NTL, AL, PG, PTG, TG, UTK, CML		Hämäläinen (1989), Kumar (1995), Prasad & Singh (1995), Mitra (2000), Kumar & Sharma (2003), Prasad & Mondal (2010), Husain (2018), De et al. (2021), Singh (2022), Arya et al. (2023), Arya et al. (2024), Meena & Sharma (2025)	LC	
44	*Ischnura rufostigma* Selys, 1876	Red Bluetail	NTL	0–1,580	Kumar (1995), Prasad & Mondal (2010), Kumar & Prasad (1981)	LC	
45	*Ischnura senegalensis* Rambur, 1842	Common Bluetail, Marsh Bluetail, Ubiquitous Bluetail, African Bluetail, Senegal Golden Dartlet, Tropical Bluetail	DDN, TG, NTL	0–3,100	De et al. (2021), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Paracercion*							
46	*Paracercion calamorum* (Ris, 1916)	Dusky Lillysquatter	DDN, NTL		De et al. (2021), Arya et al. (2024), Prasad & Singh (1976), Singh (2022)	LC	
Genus: *Pseudagrion*							
47	*Pseudagrion australasiae* Selys, 1876	Look-alike Sprite or Blue-headed Sprite	NTL		Arya et al. (2023), Arya et al. (2024)	LC	
48	*Pseudagrion decorum* (Rambur, 1842)	Elegant Sprite, Three Striped Blue Dart	DDN, HD, NTL, PG		De et al. (2021), Hämäläinen (1989), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Singh (1976), Vashishth et al. (2002), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
49	*Pseudagrion laidlawi* Fraser, 1922	Dusky Sprite	DDN, PG	400–600	De et al. (2021), Mitra (2000), Prasad & Singh (1976), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
50	*Pseudagrion rubriceps* Selys, 1876	Orange-faced Sprite or Saffron-faced blue dart	DDN, HD, PG,TG, NTL, UTK	300–1,800	Prasad & Singh (1976), Husain (2018), Meena & Sharma (2025), Vashishth et al. (2002), Arya et al. (2023), Kumar (1995), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
	Pseudagrion rubriceps rubriceps Selys, 1876		DDN, NTL, PG		De et al. (2021), Hämäläinen (1989), Kumar & Sharma (2003), Mitra (2000), Arya et al. (2024), Prasad & Mondal (2010), Singh (2022)		
51	*Pseudagrion spencei* Fraser, 1922	Brook Sprite	DDN, NTL, CPT		De et al. (2021), Hämäläinen (1989), Kumar (1995), Prasad & Mondal (2010), Singh (2022), Kumar & Prasad (1981)	LC	
II. ODONATA: ANISOPTERA							
5. Superfamily: Aeshnoidea Leach, 1815							
ix. Family: Aeshnidae Leach, 1815							
Genus: *Anax*							
52	*Anax ephippiger* (Burmeister, 1839)	Vagrant Emperor	UKD	0–2,500	Prasad & Sinha (2010)	LC	
53	*Anax guttatus* (Burmeister, 1839)	Pale-spotted Emperor or Lesser Green Emperor	DDN		De et al. (2021), Singh & Prasad (1976), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Kumar (1995), Prasad & Sinha (2010)	LC	
54	*Anax immaculifrons* Rambur, 1842	Magnificent Emperor or Blue Darner	DDN, PG, BG, AL, PTG, CML, NTL		De et al. (2021), Husain (2018), Singh & Prasad (1976), Arya (2015), Joshi et al. (2004), Joshi et al. (2018), Arya et al. (2021), Farooq & Arya (2018), Arya et al. (2024), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
55	*Anax imperator* Leach, 1815	Blue Emperor or Emperor Dragonfly	DDN		Kumar (1995), Prasad & Sinha (2010)	LC	
56	*Anax nigrolineatus* Fraser, 1935	Blue-spotted Emperor	DDN, NTL, BG, AL, PTG, UTK		De et al. (2021), Husain (2018), Kumar (1982), Joshi et al. (2004), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
57	*Anax parthenope* spp. (Selys, 1839)	Lesser Emperor	DDN, NTL		De et al. (2021), Meena & Sharma (2025), Singh (2022)	LC	
	Anax parthenope parthenope (Selys, 1839)		DDN, NTL		Kumar & Sharma (2003), Mitra (2000), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)		
Genus: *Cephalaeschna*							
58	*Cephalaeschna orbifrons* Selys, 1883		BG	1,950–3,200	Arya (2015), Joshi et al. (2018)	LC	
Genus: *Gynacantha*							
59	*Gynacantha bayadera* Selys, 1891	Parakeet Darner or Small Duskhawker	DDN	0–2,100	De et al. (2021)	LC	
60	*Gynacantha khasiaca* MacLachlan, 1896	Green Darner or Long-tailed Duskhawker	UKD, NTL	200–1,000	Prasad & Sinha (2010), Kumar & Prasad (1981)	DD	
Genus: *Gynacanthaeschna*							
61	*Gynacanthaeschna sikkima* (Karsch, 1891)		DDN, CML, UTK		De et al. (2021), Hämäläinen (1989), Husain (2018), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
6. Superfamily: Gomphoidea Rambur, 1842							
x. Family: Gomphidae Rambur, 1842							
Genus: *Anisogomphus*							
62	*Anisogomphus bivittatus* Selys, 1854	Himalayan Longleg	PG, PTG, CML, DDN, UTK	700–3,600	Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
63	*Anisogomphus caudalis* Fraser, 1926	Black-tailed Longleg	PTG		Kumar (1982), Prasad & Sinha (2010)	DD	
64	*Anisogomphus occipitalis* (Selys, 1854)	Shivalik Clubtail	DDN, PG, TG, PTG, CML, UTK	460–1,830	De et al. (2021), Hämäläinen (1989), Kumar (1982), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Anormogomphus*							
65	*Anormogomphus heteropterus* Selys, 1854		DDN		De et al. (2021), Husain (2018), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
66	*Anormogomphus kiritshenkoi* Barteneff, 1913		DDN		De et al. (2021), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	NT	
Genus: *Burmagomphus*							
67	*Burmagomphus hasimaricus* Fraser, 1926		DDN	760–920	De et al. (2021), Kumar (1995), Prasad & Sinha (2010)	DD	
68	*Burmagomphus sivalikensis* Laidlaw, 1922		DDN	600	Fraser (1934), Kumar & Prasad (1981), Kumar (1995), De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Sinha (2010)	LC	EN IND
Genus: *Davidius*							
69	*Davidius aberrans* spp. Selys, 1873			1,300–3,130		LC	
	Davidius aberrans aberrans Selys, 1873		UKD, AL, NTL		Fraser (1934), Kumar & Prasad (1981), Prasad & Sinha (2010)		
70	*Davidius kumaonensis* Fraser, 1926		UKD		Prasad & Sinha (2010)	DD	EN IND
Genus: *Ictinogomphus*							
71	*Ictinogomphus rapax* (Rambur, 1842)	Rapacious Flangetail or Indian Common Clubtail	DDN	0–1,700	De et al. (2021), Singh & Prasad (1976), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	

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Genus: *Nepogomphus*							
72	*Nepogomphus modestus* (Selys, 1878)	Modest Pincertail	DDN, PG, TG, PTG, AL, UTK	1,000	De et al. (2021), Singh & Prasad (1976), Husain (2018), Kumar (1982), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Lamelligomphus*							
73	*Lamelligomphus biforceps* (Selys, 1878)	Shiva Grabtail	DDN, UTK, NTL	1,800	De et al. (2021), Husain (2018), Kumar (1995), Singh (2022), Kumar & Prasad (1981)	LC	
64	*Lamelligomphus risi* (Fraser, 1922)		DDN	670–1,220	De et al. (2021), Singh & Prasad (1976), Kumar (1995), Kumar & Prasad (1981)	DD	
Genus: *Nychogomphus*							
75	*Nychogomphus duaricus* (Fraser, 1924).	Duar Tongtail	DDN, HD, AL	50–1,500	De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Vashishth et al. (2002), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Scalmogomphus*							
76	*Scalmogomphus bistrigatus* (Hagen in Selys, 1854)	Toothed Pincertail	DDN, TG, PTG, RDP, CML, UTK, NTL		De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
77	*Scalmogomphus schmidti* Fraser, 1937		DDN		De et al. (2021), Hämäläinen (1989)	NE	
Genus: *Ophiogomphus*							
78	*Ophiogomphus cerastis* Selys, 1854		DDN		De et al. (2021), Husain (2018), Singh & Prasad (1976), Kumar (1995)	DD	
Genus: *Paragomphus*							
79	*Paragomphus lineatus* (Selys, 1850)	Lined Hooktail	DDN, NTL, AL, PG		De et al. (2021), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995)	LC	
7. Superfamily: Cordulegastroidea Hagen, 1875							
xi. Family: Chlorogomphidae Needham, 1903							
Genus: *Chlorogomphus*							
80	*Chlorogomphus atkinsoni* (Selys, 1878)	Atkinson's Skydragon	NTL		Singh (2022)	LC	
xii. Family: Cordulegastridae Hagen, 1875							
Genus: *Anotogaster*							
81	*Anotogaster basalis* ssp. Selys, 1854	Yellow-veined Goldenring	NTL, AL, PTG, UTK, DDN, TG		Kumar (1982), Prasad & Sinha (2010), Singh (2022)	DD	
	Anotogaster basalis basalis Selys, 1854		NTL, AL, UTK		Fraser (1936), Kumar & Prasad (1981)		
82	*Anotogaster nipalensis* (Selys 1854)	Nepal Goldenring	PG, TG		Prasad & Sinha (2010), Singh (2022)	LC	
Genus: *Cordulegaster*							
83	*Cordulegaster parvistigma* (Selys, 1873)		UKD	2,660–2,730	Prasad & Sinha (2010)	DD	EN IND
Genus: *Neallogaster*							
84	*Neallogaster hermionae* (Fraser, 1927)		UKD		Singh (2022)	LC	
Genus: *Thecagaster*							
85	*Thecagaster bidentata* (Selys, 1843)	Sombre Goldenring	AL		Farooq & Arya (2018)	LC	
86	*Thecagaster brevistigma* spp. (Selys, 1854)	Yellow-Faced Goldenring	DDN	2,000–3,000	De et al. (2021), Prasad & Sinha (2010)	LC	
	Thecagaster brevistigma brevistigma (Selys, 1854)		NTL		Kumar & Prasad (1981)		
	Thecagaster brevistigma folia (Selys, 1854)		NTL		Fraser (1936), Kumar & Prasad (1981), Kumar (1995), Prasad & Sinha (2010)		

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8. Superfamily: Libelluloidea Leach, 1815							
xiii. Family: Macromiidae Needham, 1903							
Genus: *Epophthalmia*							
87	*Epophthalmia vittata* Burmeister, 1839	Common Torrent Hawk	AL		Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Macromia*							
88	*Macromia moorei* Selys, 1874		DDN, TG, NTL, BG, AL, PTG, UTK	600–2,380	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Singh & Prasad (1976), Arya (2015), Joshi et al. (2004), Joshi et al. (2018), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
xiv. Family: Corduliidae Kirby, 1890							
Genus: *Hemicordulia*							
89	*Hemicordulia asiatica* Selys, 1878	Asian Emerald	UKD	915–2,300	Prasad & Sinha (2010)	LC	
xv. Family: Libellulidae Leach, 1815							
Genus: *Acisoma*							
90	*Acisoma panorpoides* spp. Rambur, 1842	Asian Pintail, Grizzled Pintail or Trumpet tail	DDN, NTL, PG, UTK		De et al. (2021), Meena & Sharma (2025), Arya et al. (2023), Kumar (1995)	LC	
	Acisoma panorpoides panorpoides Rambur, 1842		DDN, NTL, PG, UTK		Hämäläinen (1989), Mitra (2000), Singh & Prasad (1976), Arya et al. (2021), Arya et al. (2024), Prasad & Sinha (2010), Kumar & Prasad (1981)		
Genus: *Aethriamanta*							
91	*Aethriamanta brevipennis* (Rambur, 1842)	Scarlet Adjudant or Scarlet Marsh Hawk	NTL, CPT		Arya et al. (2023), Arya et al. (2024)	LC	
Genus: *Brachydiplax*							
92	*Brachydiplax sobrina* (Rambur, 1842)	Little Blue Marsh Hawk	DDN		De et al. (2021), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Brachythemis*							
93	*Brachythemis contaminata* (Fabricius, 1793)	Ditch Jewel, Common Amberwing or Orange-winged Groundling	DDN, PG, NTL, CPT		De et al. (2021), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Arya et al. (2024), Dev et al. (2009), Arya et al. (2023), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Bradinopyga*							
94	*Bradinopyga geminata* (Rambur, 1842)	Indian Rockdweller or Granite Ghost	DDN, NTL, PG		De et al. (2021), Husain (2018), Meena & Sharma (2025), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Cratilla*							
95	*Cratilla lineata* spp. (Brauer, 1878)	Emerald-Banded Skimmer or Lined Forest-Skimmer	DDN, NTL, PG		Singh & Prasad (1976), Singh (2022)	LC	
	Cratilla lineata calverti Forster, 1903		DDN, PG, NTL		De et al. (2021), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
Genus: *Crocothemis*							
96	*Crocothemis erythraea* spp. (Brullé, 1832)	Broad Scarlet, Common Scarlet-darter or Scarlet Darter	DDN		De et al. (2021)	LC	
	Crocothemis erythraea erythraea (Brullé, 1832)		DDN		Hämäläinen (1989), Prasad & Sinha (2010)		

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97	*Crocothemis servilia* (Drury, 1770)	Oriental Scarlet or Scarlet Skimmer	DDN, HD, PG, TG, NTL, BG, AL, PTG, CPT, CML, UTK	0–1,000	De et al. (2021), Husain (2018), Kumar (1982), Meena & Sharma (2025), Arya et al. (2023), Joshi et al. (2004), Joshi et al. (2018), Arya (2015), Arya et al. (2021), Farooq & Arya (2018)	LC	
	Crocothemis servilia servilia (Drury, 1770)		DDN, HD, PG, NTL, AL, PTG, CML, UTK		Kumar & Sharma (2003), Mitra (2000), Singh & Prasad (1976), Vashishth et al. (2002), Arya et al. (2024), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
Genus: *Diplacodes*							
98	*Diplacodes lefebvrii* (Rambur, 1842)	Black Percher or Black Ground Skimmer	DDN, AL, NTL		De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (1999), Mitra (2000), Prasad & Sinha (2010), Singh (2022)	LC	
99	*Diplacodes nebulosa* (Fabricius, 1793)	Black-tipped Percher, Charcoal-winged Percher or Black tipped Percher	DDN, NTL, PG, TG		De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Dev et al. (2009), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
100	*Diplacodes trivialis* Rambur, 1842	Chalky Percher, Blue Percher	DDN, NTL, PG	0–3,000	De et al. (2021), Kumar & Sharma (2003), Mitra (2000), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Hylaeothemis*							
101	*Hylaeothemis gardeneri* Fraser, 1927		DDN		De et al. (2021), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	DD	EN IND
Genus: *Neurothemis*							
102	*Neurothemis fulvia* (Drury, 1773)	Russet Parasol, Fulvous Forest Skimmer	DDN, HD, TG, NTL, UTK, PG	0–2,390	Mitra (2000), De et al. (2021), Singh & Prasad (1976), Hämäläinen (1989), Meena & Sharma (2025), Husain (2018), Kumar & Sharma (2003), Vashishth et al. (2002), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
103	*Neurothemis intermedia* spp. (Rambur, 1842)	Paddyfield Parasol or Ruddy Meadow Skimmer		0–1,000		LC	
	Neurothemis intermedia intermedia (Rambur, 1842)		DDN, PG		De et al. (2021), Husain (2018), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)		
104	*Neurothemis tullia* spp. (Drury, 1773)	Pied Paddy Skimmer	DDN, NTL		Meena & Sharma (2025), De et al. (2021)	LC	
	Neurothemis tullia tullia (Drury, 1773)		DDN		Singh & Prasad (1976), Hämäläinen (1989), Kumar & Sharma (2003), Mitra (2000), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)		
Genus: *Orthetrum*							
105	*Orthetrum coerulescens anceps* (Schneider, 1845)	Keeled Skimmer	PG, UTK		Prasad & Sinha (2010), Singh (2022)	LC	
106	*Orthetrum brunneum* spp. (Fonscolombe, 1837)	Southern Skimmer	DDN, PG		De et al. (2021), Singh (2022)	LC	
	Orthetrum brunneum brunneum (Fonscolombe, 1837)		DDN, PG, TG, NTL, AL, UTK		Husain (2018), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
107	*Orthetrum glaucum* Brauer, 1865	Common Blue Skimmer or Blue Marsh Hawk	DDN, PG, TG, NTL, BG, AL, PTG, CPT, RDP, CML, UTK		De et al. (2021), Hämäläinen (1989), Meena & Sharma (2025), Husain (2018), Kumar (1982), Singh & Prasad (1976), Arya et al. (2023), Arya et al. (2024) Arya (2015), Joshi et al. (2004), Joshi et al. (2018), Arya et al. (2021) Farooq & Arya (2018), Verma and Arya (2020), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
108	*Orthetrum internum* McLachlan, 1894		DDN, PG, NTL		De et al. (2021), Husain (2018), Singh & Prasad (1976), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	NE	

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109	*Orthetrum luzonicum* (Brauer, 1868)	Tri-coloured Marsh Hawk or Slender Blue Skimmer	DDN, HD, PG, TG, NTL, PTG, UTK	0–1,500	De et al. (2021), Husain (2018), Singh & Prasad (1976), Hämäläinen (1989), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Vashishth et al. (2002), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
110	*Orthetrum pruinosum* ssp. (Burmeister, 1839)	Crimson-tailed Marsh Hawk	DDN, NTL, CPT		Arya et al. (2023), Arya et al. (2024), Verma and Arya (2020)	LC	
	Orthetrum pruinosum neglectum (Burmeister, 1839)		DDN, HD, PG, TG, NTL, BG, AL, PTG, RDP, CML, UTK		Mitra (2000), De et al. (2021), Singh & Prasad (1976), Hämäläinen (1989), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Husain (2018), Vashishth et al. (2002), Arya et al. (2024), Arya (2015), Joshi et al. (2004), Joshi et al. (2018), Arya et al. (2021), Farooq & Arya (2018), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
111	*Orthetrum sabina* (Drury, 1770)	Slender Skimmer or Green Marsh Hawk	DDN, NTL, CPT	0–2,300	Singh & Prasad (1976), Arya et al. (2023), Prasad & Singh (1995)	LC	
	Orthetrum sabina sabina (Drury, 1770)		DDN, HD, PG, TG, NTL, BG, AL, PTG, CML, RDP, UTK		De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Vashishth et al. (2002), Arya et al. (2024), Arya (2015), Joshi et al. (2004), Joshi et al. (2018), Arya et al. (2021), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)		
112	*Orthetrum taeniolatum* (Schneider, 1845)	Small Skimmer or Little Skimmer	DDN, HD, PG, TG, NTL, BG, AL, PTG, CPT, RDP, CML, UTK	0–2,700	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Arya et al. (2024), Arya et al. (2023), Joshi et al. (2002), Joshi et al. (2004), Arya et al. (2021), Verma and Arya (2020), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
113	*Orthetrum triangulare* ssp. (Selys, 1878)	Blue-Tailed Forest Hawk	DDN, NTL, CPT		Arya et al. (2023), Verma & Arya (2020), Farooq & Arya (2018)	LC	
	Orthetrum triangulare triangulare (Selys, 1878)		DDN, HD, PG, TG, NTL, AL, PTG, CML, UTK, RDP		De et al. (2021), Hämäläinen (1989), Husain (2018), Singh & Prasad (1976), Meena & Sharma (2025), Mitra (2000), Vashishth et al. (2002), Kumar (1982), DayakArya et al. (2024), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)		
Genus: *Palpopleura*							
114	*Palpopleura sexmaculata* ssp. (Fabricius, 1787)	Asian Widow or Blue-tailed Yellow Skimmer	DDN, NTL, BG, PG, TG, AL, CML, PTG, UTK		De et al. (2021), Meena & Sharma (2025), Kumar & Sharma (2003), Dev et al. (2009), Arya et al. (2023), Arya (2015), Singh (2022)	LC	
	Palpopleura sexmaculata sexmaculata (Fabricius, 1787)		DDN, HD, PG, TG, NTL, BG, PTG, CML, UTK		Singh & Prasad (1976), Hämäläinen (1989), Kumar (1982), Mitra (2000), Vashishth et al. (2002), Arya et al. (2024), Joshi et al. (2004), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)		
	Palpopleura sexmaculata octomaculata (Fraser, 1935)		DDN, PG, TG, NTL, AL, CML, UTK		Husain (2018)		
Genus: *Pantala*							
115	*Pantala flavescens* (Fabricius, 1798)	Wandering Glider or Globe Skimmer	DDN, PG, HD, NTL, AL, CPT, PTG, CML, TG, UTK		De et al. (2021), Husain (2018), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Arya et al. (2023), Arya et al. (2024), Joshi et al. (2004), Farooq & Arya (2018), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	

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Genus: *Potamarcha*							
116	*Potamarcha congener* (Rambur, 1842)	Yellow-tailed Ashy Skimmer, Swampwatcher or Common Chaser	DDN, PG	0–1,700	De et al. (2021), Singh & Prasad (1976), Prasad & Sinha (2010), Singh (2022), Prasad & Singh (1995)	LC	
Genus: *Rhodothemis*							
117	*Rhodothemis rufa* (Rambur, 1842)	Rufous Marsh Glider, Spine-legged Redbolt or Common Redbolt	NTL	0–600	Arya et al. (2023), Arya et al. (2024)	LC	
Genus: *Rhyothemis*							
118	*Rhyothemis variegata* ssp. (Linnaeus, 1763)	Common Picture Wing or Variegated flutterer	DDN		Kumar & Sharma (2003)	LC	
	Rhyothemis variegata variegata (Linnaeus, 1763)		DDN		De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)		
Genus: *Sympetrum*							
119	*Sympetrum commixtum* (Selys,1884)	Mountain Meadowhawk	DDN, PG, NTL, BG, AL, PTG, RDP	1,490–3,660	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
120	*Sympetrum striolatum* (Charpentier, 1840)	Common Darter	AL, DDN		Farooq & Arya (2018), Singh (2022)	LC	
121	*Sympetrum fonscolombii* Selys, 1840	Red-veined Darter	PTG, AL		Prasad & Sinha (2010), Singh (2022)	LC	
122	*Sympetrum speciosum* Oguma, 1915		NTL		Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
123	*Sympetrum hypomelas* (Selys, 1884)	Yellow-banded Darter	CML, AL, UTK	0–2,850	Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Tetrathemis*							
124	*Tetrathemis platyptera* Selys, 1878	Pigmy Skimmer	DDN, NTL, PG	0–900	De et al. (2021), Kumar (1995), Prasad & Sinha (2010), Singh (2022), Kumar & Prasad (1981)	LC	
Genus: *Tholymis*							
125	*Tholymis tillarga* (Fabricius, 1798)	Coral-tailed Cloudwing or Twister	DDN, NTL		De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Arya et al. (2024), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Tramea*							
126	*Tramea basilaris* ssp. (Palistot de Beauvois, 1817)	Keyhole Glider, Red Marsh trotter or Wheeling Glider	DDN		De et al. (2021)	LC	
	Tramea basilaris burmeisteri Kirby, 1889		UKD, DDN		Prasad & Sinha (2010), Kumar & Prasad (1981)		
127	*Tramea virginia* (Rambur, 1842)	Saddlebag Glider	DDN, NTL, PG	0–1,000	De et al. (2021), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	
Genus: *Trithemis*							
128	*Trithemis annulata* (Palisot de Beauvois, 1807)	Violet Dropwing, Violet-marked darter, Purple-blushed Darter or Plum-coloured Dropwing	NTL		Kaushal and Joshi (1988)	LC	
129	*Trithemis aurora* (Burmeister, 1839)	Crimson Dropwing or Crimson Marsh Glider	DDN, HD, PG, TG, NTL, PTG	1,500	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Vashishth et al. (2002), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	

	Species composition	Common name	Distribution	Altitudinal range (in m)	Recent/ Old confirmation by authors	Global IUCN Red List status	Endemic status
130	*Trithemis festiva* (Rambur, 1842)	Indigo Dropwing or Black Stream Glider	DDN, HD, PG, TG, NTL, AL, PTG, CPT, CML, UTK	0–2,000	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar (1982), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Vashishth et al. (2002), Arya et al. (2023), Arya et al. (2024), Kumar (1995), Prasad & Sinha (2010), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
131	*Trithemis kirbyi* ssp. Selys, 1891	Orange-winged Dropwing, Scarlet Rock Glider or Kirby's dropwing	DDN		De et al. (2021)	LC	
	Trithemis kirbyi kirbyi Selys, 1891		DDN		Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)		
132	*Trithemis pallidinervis* (Kirby, 1889)	Dancing Dropwing or Long-legged Marsh Glider	DDN, PG, NTL, CPT	0–800	De et al. (2021), Hämäläinen (1989), Husain (2018), Kumar & Sharma (2003), Meena & Sharma (2025), Mitra (2000), Singh & Prasad (1976), Arya et al. (2023), Arya et al. (2024), Kumar (1995), Prasad & Singh (1995), Kumar & Prasad (1981)	LC	
Genus: *Urothemis*							
133	*Urothemis signata* ssp. (Rambur, 1842)	Greater Crimson Glider	DDN		De et al. (2021), Meena & Sharma (2025)	LC	
	Urothemis signata signata (Rambur, 1842)		DDN		Kumar & Sharma (2003), Mitra (1999), Mitra (2000), Prasad & Sinha (2010)		
Genus: *Zygonyx*							
134	*Zygonyx torridus* ssp. (Kirby, 1889)	Ringed Cascader	DDN, TG		Singh (2022), Kumar & Prasad (1981)	LC	
	Zygonyx torridus isis Fraser, 1924		DDN, TG, RDP		De et al. (2021), Husain (2018), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010)		
Genus: *Zyxomma*							
135	*Zyxomma petiolatum* Rambur, 1842	Dingy Dusk-darter, Long-tailed Duskdarter or Brown Dusk Hawk	DDN		De et al. (2021), Singh & Prasad (1976), Kumar (1995), Prasad & Sinha (2010), Kumar & Prasad (1981)	LC	

AL—Almora | BG—Bageshwar | CML—Chamoli | CPT—Champawat | DDN—Dehradun | HD—Haridwar | NTL—Nainital | PG—Pauri Garhwal | PTG—Pithoragarh | RDP—Rudraprayag | TG—Tehri Garhwal | UDM—Udham Singh Nagar | UTK—Uttarkashi; UKD—Uttarakhand | DD—Data Deficient | LC—Least Concern | NE—Not Evaluated | NT—Near Threatened | EN IND—Endemic to India.

districts), *Neurobasis chinensis* (8 districts).

IUCN Global Red List Status and Endemic Status

According to the IUCN Red List assessments, the majority of odonate species recorded from Uttarakhand fall under the 'Least Concern' (LC) category, comprising 119 species (88.1%) of the total documented fauna. A further 12 species (8.9%) are classified as 'Data Deficient' (DD), reflecting the need for additional research on their population status and distribution. Three species (2.2%) remain 'Not Evaluated' (NE), while a single species (0.7%), namely, *Anormogomphus kiritshenkoi* Barteneff, 1913, is listed as 'Near Threatened' (NT). Five species are endemic to India.

Taxonomic Revisions and Infra-specific Records

The checklist incorporates recent taxonomic changes. In addition, 28 infra-specific taxa were noted (e.g., *Neurobasis chinensis chinensis*, *Crocothemis servilia servilia*, *Orthetrum sabina sabina*), but for the purpose of quantitative analysis, all subspecies were consolidated under their respective nominal species. This avoided artificial inflation of the diversity count and ensured the tally remained at 135 valid species.

Taxonomic revisions and nomenclatural changes

- *Amphiallagma parvum* (Selys, 1876) was previously treated as *Enallagma parvum* (Selys, 1876)

- Specimens from the Indian subcontinent that were previously identified as *Ischnura aurora* are now considered *Ischnura rubilio*, as the latter is the only species known to occur in this region (Kalkman et al. 2020).

- *Lestes praemorsus decipiens* Kirby, 1893 is treated as *Lestes decipiens* (Kirby, 1893) in 2025. *Lestes decipiens* was elevated from a subspecies of *Lestes praemorsus*

by Hopkins et al. (2025). Therefore, *Lestes praemorsus* Hagen in Selys, 1862 is no longer considered part of the fauna of the Indian Subcontinent, and previous records of it pertain to *L. decipiens*, as discussed in Kalkman et al. (2020), based on the analysis of Lieftinck (1949).

- *Aristocypha quadrimaculata* (Selys, 1853) was originally described as *Rhinocypha quadrimaculata* and subsequently transferred to the genus *Aristocypha* by Laidlaw (1950).

- *Scalmogomphus bistrigatus* (Hagen in Selys, 1854) was previously treated as *Onychogomphus bistrigatus* (Hagen in Selys, 1854).

- *Scalmogomphus schmidti* (Fraser, 1937) was previously treated as *Onychogomphus schmidti* Fraser, 1937.

- *Orthetrum anceps* (Schneider, 1845) was treated as *Orthetrum coerulescens anceps* (Schneider, 1845) by Kalkman et al. (2020).

- *Nychogomphus duaricus* was originally described by Fraser in 1924 in the genus *Onychogomphus*. Its presently accepted name is *Nychogomphus duaricus* (Fraser, 1924).

- Fraser described *Coenagrion exclamationis* as *Himalagrion exclamationis* in 1919. Subsequently, it was removed to the genus *Coenagrion*, and its presently accepted name is *Coenagrion exclamationis* (Fraser, 1919).

- *Agriocnemis corbeti* Kumar & Prasad, 1978 is treated as a synonym of *Agriocnemis pygmaea* (Rambur, 1842) by Kalkman et al. (2020).

- *Copera ciliata* Selys, 1863 was transferred to *Pseudocopera ciliata* (Selys, 1863) by Dijkstra et al. (2014).

- *Hemianax ephippiger* Burmeister, 1839 was treated as *Anax ephippiger* (Burmeister, 1839) by Kalkman et al. (2020).

- *Cordulegaster bidentata* Selys, 1843 was replaced with *Thecagaster bidentata* (Selys, 1843) in 2024 (Schneider et al., 2024).

- *Sympetrum haematoenura* Fraser, 1924 was synonymised with *Sympetrum speciosum* Oguma, 1915 by Kalkman et al. (2020).

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ARTICLE

Study of Odonata in the coastal-influenced area of Purba Medinipur District with a note on seasonal fluctuations and species composition

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Abstract: The present study provides an updated record checklist of Odonata in the coastal regions of Purba Medinipur District, West Bengal. A total of 60 species (59 identified to species level and one unidentified *Agriocnemis* sp.) belonging to 40 genera and seven families were recorded. Twenty-five species of Zygoptera (damselflies) were classified under three families: Coenagrionidae, Lestidae, and Platycnemididae, represented by 17, three, and five species, respectively. Thirty-five species of Anisoptera (dragonflies) were classified under four families, with Libellulidae accounting for 28 species, Aeshnidae and Gomphidae for three species each, and Macromiidae for one species. Notably, *Disparoneura quadrimaculata* was recorded for the first time from Purba Medinipur, District, extending its known range within southern West Bengal. The highest species richness and density were observed during the monsoon season.

Keywords: Anisoptera, checklist, coastal wetland, damselfly, *Disparoneura quadrimaculata*, dragonfly, habitat preference, pond size, water quality, Zygoptera.

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Author contributions: SK—conceptualization, investigation, methodology, photography, writing (original draft), writing (review & editing). SJ—investigation, methodology, software, writing (review & editing). SB—software, writing (Original draft), writing (review & editing). SKG—supervision, validation, writing (review & editing).

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INTRODUCTION

The order Odonata encompasses two main groups of insects: dragonflies (Anisoptera) and damselflies (Zygoptera) (Mitra 1999), carnivorous insects belonging to the group of uniramian arthropods. Odonata are aquatic paleopterous insects that are commonly known as amphibious insects due to their semi-aquatic life cycle. Their larvae live in water, while the adults are aerial predators (Corbet 1980). Odonate larvae and adults function as important intermediate predators in aquatic and terrestrial ecosystems, respectively. By preying on a wide range of smaller invertebrates while also serving as prey to birds, spiders, fish, and amphibians, they play a key role in maintaining the trophic balance and energy flow within ecosystems (Chovanec & Waringer 2001). Additionally, these larvae prey on mosquito larvae and other pest insects. Adult odonates also contribute to pest control by preying on harmful insects in crop fields and other blood-sucking pests (Samways & Steytler 1996). Odonates have been present since the Permian era (Corbet 1999).

There are currently 6,442 known species worldwide (Paulson et al. 2025), of which 504 are found in India, with 175 being endemic (Subramanian & Babu 2024). Odonates are among the most ancient extant lineages of winged insects and are widely used as indicator taxa, because their sensitivity to pollution, habitat quality and hydrological change makes them reliable reporters of overall ecosystem health (Pattanayak et al. 2020). The main habitats for odonates include rain-fed canals, ponds, swamps, lowlands, and lakes in the study area and its surroundings. During the monsoon season, odonates also utilize paddy fields and other grasslands as breeding grounds. Due to their carnivorous feeding habits, odonates play a crucial role in biological control measures against insect pests, particularly in areas where agriculture is the primary source of livelihood (Rana & Bhatia 2025). The larval stages of odonates are equally significant for controlling mosquito larvae (Priyadarshana & Slade 2023).

The present study aimed to assess the current status of Odonata diversity in coast-influenced areas of Purba Medinipur. Additionally, an attempt has been made to investigate the condition of certain aquatic ecosystems in the study area that are experiencing significant threats to the larvae of aquatic Odonata, as well as other aquatic insects.

Some previous studies have been conducted on adult odonates in Purba Medinipur District. One of the distinct works has been done by Payra & Tiple (2016) on the diversity of Odonata in Purba Medinipur District. Another remarkable work which shows the community structure of Odonata has been done by Pahari et al. (2019). The diversity and abundance of Odonata larvae in freshwater lentic systems have been well studied by Pattanayak et al. (2020). Odonata diversity in Egra and its adjoining blocks has been studied by Samanta et al. (2023). Purba Medinipur is the southernmost district in West Bengal and is influenced by the marine environment, which impacts the diversity of many species. The present study was carried out in the coast-influenced area of Purba Medinipur District.

MATERIALS AND METHODS

The study was conducted from June 2021 to May 2023. Initially, many sites were randomly visited and from these, nine: Egra-1, Khar-2, Panchetgarh-3, Kudi-4, Panchol-5, Depal-6, Pakarghat-7, Kourda-8, and Erenda-9, were selected for repeated sampling (Image 1) (Table 1). In each study area there are several types of water bodies and land features (Image 2). Pond habitats were categorized based on surface area: small ponds (< 0.3 ha), medium ponds (0.3–0.8 ha), and large ponds (> 0.8–1.5 ha). Small ponds were mostly seasonal, while medium and large ponds were perennial with varying degrees of vegetation and human activity. The study area comprises a mosaic of aquatic and terrestrial habitats. Expressed as a percentage of the total mapped surface area of the nine sites, large ponds occupy approximately 13%, medium-sized ponds 7%, and small ponds together with seasonal puddles 33%. Wetlands cover 10%, low-lying areas 5%, and polluted ponds a further 10%. Agricultural land comprises rice fields (6%) and peanut fields (9%), while plantations and forested patches together account for the remaining 7%, these nine categories sum to 100% (Image 3). To assess seasonal variation in odonatan abundance, field surveys were conducted across all nine sampling sites throughout the year. Each site was visited four times per month during the study period, ensuring consistent and continuous monitoring. For analytical purposes, data were categorized into three seasonal phases: pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–February). This seasonal classification was based on regional climatic patterns to evaluate shifts in species composition and abundance across seasons.

To accommodate different habitat types, multiple methods were applied. In terrestrial zones like rice fields,

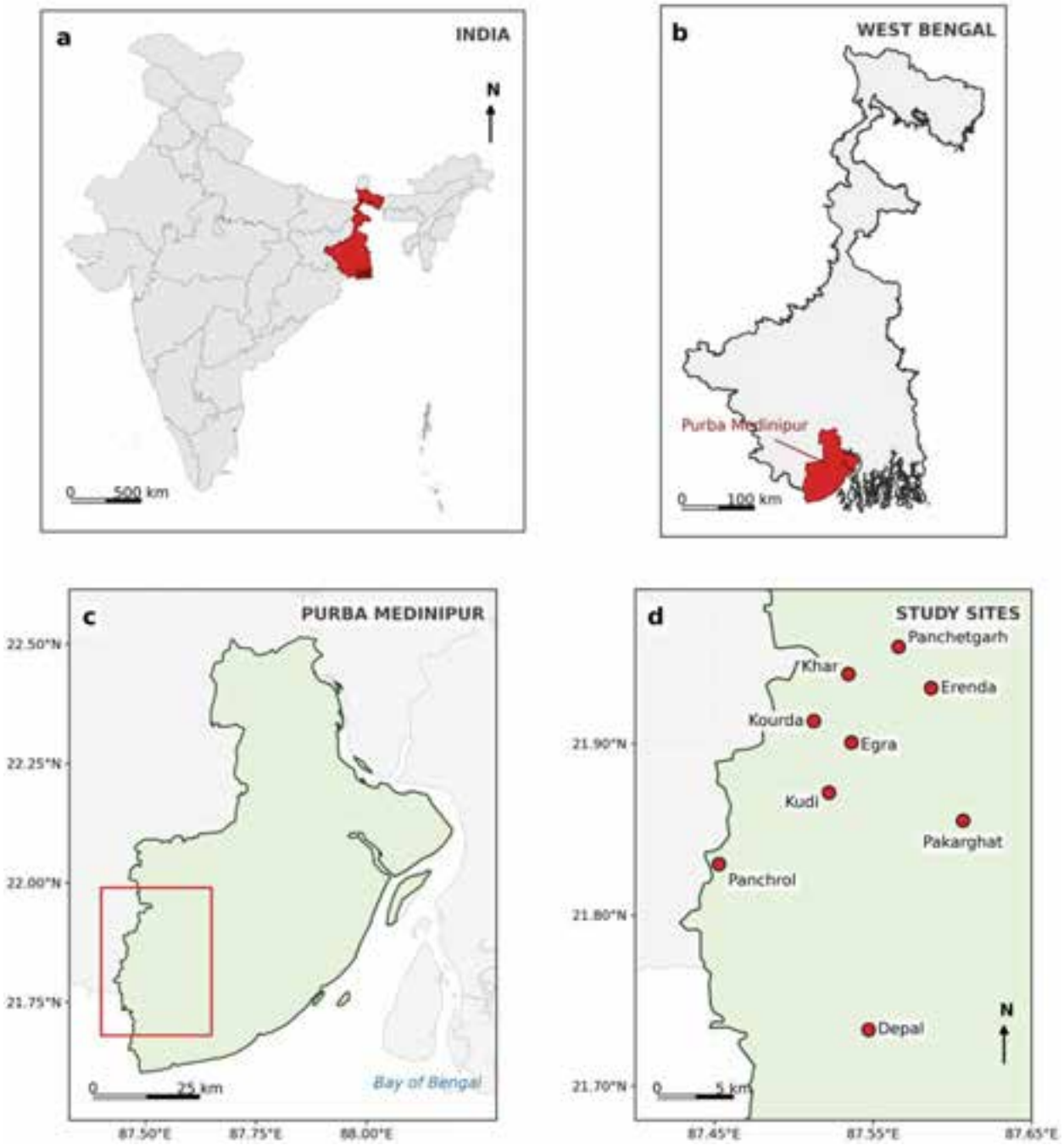

Image 1. Map showing the selected study sites in the coastal-influenced region of Purba Medinipur district, West Bengal. Nine sites—Egra, Khar, Panchetgarh, Kudi, Panchol, Depal, Pakarghat, Kourda, and Erenda—were chosen for repeated sampling between June 2021 and May 2023.

plantations, and forest edges, 500 m line transects were combined with Pollard walks, where observers recorded odonates within a fixed width while walking at a steady pace. For aquatic habitats such as ponds and wetlands, the belt transect method (10 × 100 m) was used along the shoreline to effectively observe species active near water. These methods ensured comprehensive coverage across diverse microhabitats and were conducted during different seasons and times of day. Photographic documentation was carried out in the field using Canon 90D DSLR with 18–55 mm and 70–250 mm lens. In some cases species identification was challenging due to the presence of cryptic species with similar morphological features. Most of the site sampling was conducted at 0800–1400 h, as odonates exhibit peak activity during this time to regulate their body temperature in sunlight

(Subramanian 2014; Koli et al. 2015).

The Margalef's index was used as a simple measure of species richness, calculated using the formula: Margalef's index = (S - 1) / ln(N)

S = Total number of species

N = Total number of individuals in the sample

In = Natural logarithm

Specimens were captured using an insect net, and abundance was recorded through visual encounter surveys and noted in a field notebook. Captured specimens were euthanized using ethyl acetate in a killing jar to minimize damage to morphological features, which is essential for accurate identification. After euthanasia, adult specimens were pinned and dried for long-term preservation. Larval forms were collected using hand nets and scooping methods from submerged vegetation, pond edges, and shallow water zones. Collected larvae were then fixed in 70% ethanol for long-term storage. Identification was carried out based on standard larval identification keys (Corbet 1999; Subramanian 2005; Hacet et al. 2010; Nesemann et al. 2011), considering morphological features such as labial mask, caudal gills, and wing pad development.

Aquatic plants were collected from the field for subsequent identification because plant composition is one of the key determinants of the community structure of Odonata (Samways & Steytler 1996). The identification of aquatic plants was performed using the i-Naturalist field guide ((iNaturalist 2024).

The common plants present in the study sites are *Marsilea minuta* L., *Nelumbo nucifera* Gaertn., *Nymphaea* sp., *Monochoria hastata* Solms, *Scirpus articulatus* L., *Cyanotis axillaris* Roem. & Schult., *Aeschynomene aspera* L., *Hygroryza aristata* Nees, *Hydrocotyle asiatica* Nees, *Hygrophila difformis* L.f., *Utricularia stellaris* L.f., *Jussiaea repens* L., *Nymphoides indica* L., *Eichhornia crassipes* (Mart.) Solms, *Hydrilla verticillata* Casp., *Chara* sp., *Nitella* sp., *Pistia stratiotes* L., *Lemna* sp., *Cyperus* sp., *Ipomoea aquatica* Forsk., *Enhydra fluctuans* Lour., *Sphenoclea zeylanica* Gaertn., *Trapa* sp., *Ceratophyllum demersum* L., *Polygonum* sp., *Alternanthera* sp., and *Gomphrena sessilis* L.

A measuring tape was used to record the dimensions of the waterbodies (length and breadth) at each study site to estimate surface area and categorize pond sizes. Water parameters such as CO_2, alkalinity and dissolve oxygen were measured following different methods. CO_2 was measured using the acid-base titration method (APHA 2017), alkalinity was measured using Anderson & Robinson (1946) titrimetric method, and dissolved oxygen (DO) was measured using the Winkler method (Grasshoff et al. 2009). Identification of species was conducted with the help of field identification guide given by Andrew et al. (2008), Nair (2011), and Subramanian (2014). Data analysis was performed using PAST software version 3.02. The abundance status of species was categorized based on field observations across multiple sites: Very Common (VC) indicates presence in more than 50% of sites, Common (C) refers to species found in 20–50 % of sites, Occasional (O) for those found in less than 20% but more than 5% of sites refers to species that are commonly found only in specific locations, Rare (R) indicates occurrence in less than 5% of the sites, and Very Rare (VR) includes species recorded only once or twice during the entire study period.

RESULTS

A total of 60 species of odonata (59 identified to species level and one unidentified *Agriocnemis* sp.) were recorded, belonging to 40 genera and seven families. Among these, 25 species of Zygoptera have been classified under three families, and 35 species of Anisoptera have been categorized under four families. Within the Zygoptera, Coenagrionidae was represented by 17 species, Platycnemididae by five and Lestidae by three. Within the Anisoptera, Libellulidae was represented by 28 species, Aeshnidae and Gomphidae by three species each, and Macromiidae by one (Image 5). Anisoptera accounted for 58.3% and Zygoptera for 41.7% of the total taxa recorded (Image 4). Coenagrionidae showed the highest diversity among the Zygoptera, and Libellulidae among the Anisoptera.

The abundance of species during different seasons has been studied: pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–January) (Image 6). The monsoon season has exhibited a higher density of species abundance, while the post-monsoon period has shown lower abundance levels.

Diversity is also influenced by the seasonal changes. The monsoon season tends to display greater diversity, whereas the post-monsoon season shows lower diversity. Among the areas under study, medium ponds exhibit the highest diversity, followed by forests and plantations as the second most diverse regions. In contrast, peanut fields display lower diversity compared to the other study areas. Interestingly, both polluted ponds and forest areas demonstrate similar levels of diversity throughout the year (Image 7).

To study species composition in various habitats, five ponds of different sizes with varying vegetation were

Table 1. Geographical coordinates, altitude, and habitat types of the nine selected study sites in the coastal-influenced region of Purba Medinipur District, West Bengal. These sites represent a range of aquatic and semi-aquatic habitats including ponds, wetlands, rice fields, plantations, forests, and polluted water bodies.

	Name	Latitude (° N)	Longitude (° E)	Altitude (m)	Habitat types
1.	Egra	21.900	87.538	170	Large pond, medium pond, low land, polluted pond.
2.	Khar	21.874	87.542	4	Forest, plantation, medium And small pond.
3.	Ponchet	21.943	87.570	30	Large pond, medium pond, plantation, peanut field, rice field.
4.	Kudi	21.871	87.522	19	Forest, plantation, rice field, wet land, medium and small pond.
5.	Panchrol	21.832	87.455	19	Small cannel, medium and small pond, rice field, polluted pond, peanut field, low land.
6.	Depal	21.733	87.547	4	Forest, plantation, small pond, polluted pond wet land.
7.	Pakarghat	22.085	87.026	5	Wet land, low land, small pond, polluted pond, peanut field.
8.	Kourda	21.912	87.512	19	Medium and small pond, forest, rice field, peanut field.
9.	Erenda	21.931	87.586	5	Large and medium pond, forest, rice field, peanut field.

Image 2. Photographs of different study sites surveyed in the coastal-influenced region of Purba Medinipur District, West Bengal: a—agricultural field during harvesting | b—eucalyptus plantation near waterlogged habitat | c—temporary water pools in open fields | d—vegetated canal with slow-flowing water | e—urban polluted waterbody adjacent to settlements | f—irrigated paddy field | g—moist grassy field with shallow water | h—large village pond surrounded by vegetation | i—natural pond with floating vegetation (water lilies). © © Suvabrata Khatua.

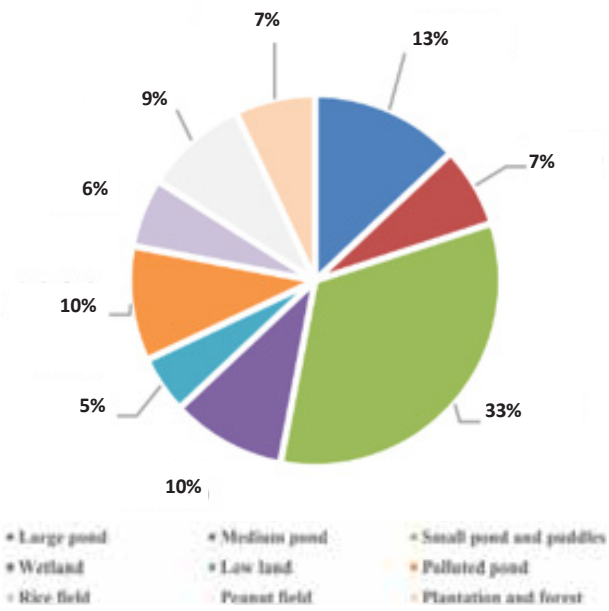

Image 3. Percentage contribution of each habitat type to the total mapped surface area of the nine study sites (values are percentages of area, not of species).

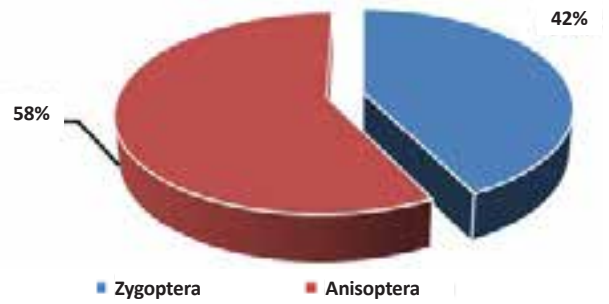

Image 4. Suborder-wise composition of the recorded Odonata, expressed as the percentage of the 60 taxa recorded.

selected.

Study site 1 is located at Kudi, Rason. It is a medium-sized pond with abundant vegetation, including free-floating plants. The dissolved oxygen (DO) concentration at this site measures around 10 ppt. The most abundant species observed here are *Rhodothemis rufa* and *Urothemis signata.*

Pond 2 is located at Pakarghat, and it is a medium-sized pond with a high abundance of emergent plants. The dissolved oxygen (DO) concentration at this pond is approximately 3.8 ppt. The dominant species observed in this habitat are *Acisoma panorpoides*, *Brachydiplax sobrina*, and *Ceriagrion coromandelianum.*

Pond 3 is located at Egra and is a large-sized pond with very little vegetation, primarily comprising floating plants. The dissolved oxygen (DO) concentration at this pond is 7 ppm. The dominant species observed in this habitat are *Pseudagrion rubriceps*, *Ischnura senegalensis*, and *Agriocnemis kalinga.*

Pond 4 is located at Panchetgarh, and it is a medium-sized pond with no vegetation. The dissolved oxygen (DO) concentration at this pond is approximately 24 ppm. The dominant species observed in this habitat are *Crocothemis servilia and Ictinogomphus rapax*.

Pond 5 is located at Kourda, and it is a small pond with a dense growth of vegetation, including floating leaf plants. The dissolved oxygen (DO) concentration at this pond is around 3 ppm. The dominant species observed in this habitat are *Ceriagrion coromandelianum*, *Brachydiplax ephippiger*, *Brachydiplax sobrina*, and *Acisoma panorpoides*.

The comparative analysis of Anisoptera and Zygoptera at the five study ponds shows clear variation in their

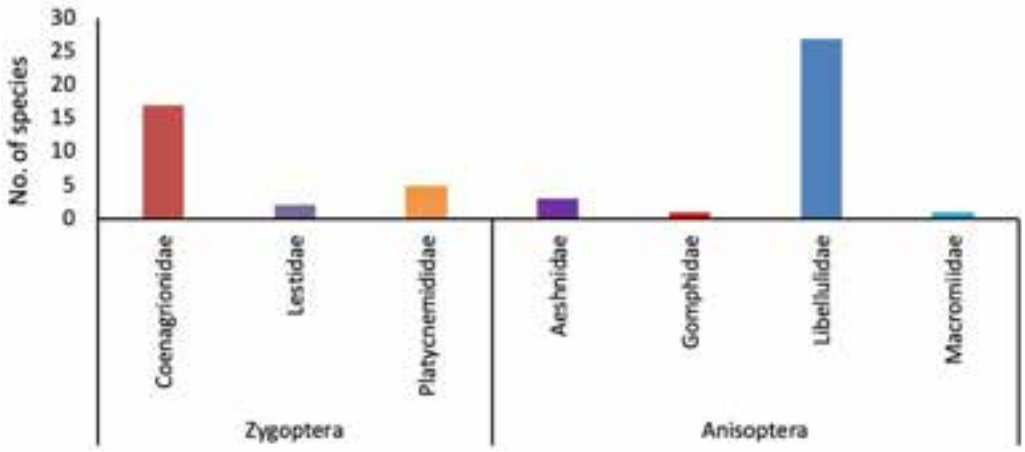

Image 5. Family-wise composition of the recorded Odonata, expressed as the number of species per family.

Table 2. List of Odonata fauna of coastal influenced area of Purba Medinipur District: VC—Very Common (>50%) | C—Common (20–50 %) | O—Occasional (5–20 %) | R—Rare (< 5%) | VR—Very Rare | *—first time reported from district.

	Scientific name	Common name	IUCN Red List status	Local status	Egra	Khar	Panchet Garh	Kudi	Panchrol	Depal	Pakarghat	Kourda	Erenda
Suborder: Zygoptera Family: Coenagrionidae													
1.	*Agriocnemis pygmaea* (Rambur, 1842)	Pygmy Dartlet	LC	VC	+	+	+	+	+	-	+	+	+
2.	*Agriocnemis kalinga* (Nair & Subramanian, 2014)	Indian Hooded Dartlet	NE	VC	+	+	+	+	+	-	+	+	+
3.	*Agriocnemis femina** (Brauer, 1868)	Pinhead Wisp	LC	CE	+	+	+	+	+	-	+	+	+
4.	*Agriocnemis lacteola* (Selys, 1877)	Milky Dartlet	LC	O	+	-	-	+	+	-	+	-	+
5.	*Agriocnemis pieris* (Laidlaw, 1919)	Indian White Dartlet	LC	R	+	-	-	-	-	-	-	-	+
6.	*Agriocnemis* sp.	-	-	VR	-	-	-	-	-	-	-	-	+
7.	*Ceriagrion coromandelianum* (Fabricius, 1798)	Coromendel Marsh Dart	LC	VC	+	+	+	+	+	+	+	+	+
8.	*Ceriagrion cerinorubellum* (Brauer, 1865)	Orange Tailed Murshed Dart	LC	C	+	+	+	+	+	-	+	+	+
9.	*Ceriagrion olivaceum* (Laidlaw, 1914)	Rushty Mursh Dart	LC	R	+	-	-	-	+	-	-	-	-
10.	*Pseudagrion microcephalum* (Rambur, 1842)	Blue Dart	LC	C	+	-	-	+	-	-	-	-	+
11.	*Pseudagrion decorum* (Rambur, 1842)	Three-lined Dart	LC	C	-	-	-	-	-	-	-	-	+
12.	*Pseudagrion rubriceps* (Selys, 1876)	Saffron-faced Blue Dart	LC	C	+	-	-	+	-	-	+	-	+
13.	*Ischnura senegalensis* (Rambur, 1842)	Senegal Golden Dartlet	LC	VC	+	-	+	+	+	-	+	-	-
14.	*Ischnura rubilio** (Selys, 1876)	Western Golden Dartlet	LC	C	+	+	+	+	-	-	-	-	+
15.	*Paracercion malayanum* (Selys, 1876)	Malayan Lilly Squatter	LC	C	-	-	-	+	+	+	-	-	-
16.	*Aciagrion pallidum* (Selys, 1891)	Pale Slender Dartlet	LC	O	-	+	-	+	-	+	-	+	+
17.	*Mortonagrion aborense* (Laidlaw, 1914)	-	LC	R	+	-	-	-	-	-	-	-	+
Family: Lestidae													
18.	*Lestes concinnus* (Hagen in Selys, 1862)	Brown Spread Wing	DD	R	-	-	-	-	-	+	-	-	-
19.	*Lestes viridulus* (Rambur, 1842)	Emerald Striped Spread Wing	LC	R	-	-	-	-	-	+	-	-	-
20.	*Lestes elatus* (Hagen in Selys, 1862)	Emerald Spread Wing	LC	R	-	-	-	-	-	+	-	-	+
Family: Platycnemididae													
21.	*Pseudocopera ciliata* (Selys, 1863)	Pied Bush Dart	LC	O	+	-	-	+	+	-	-	-	+
22.	*Copera marginipes* (Rambur, 1842)	Yellow Bush Dart	LC	O	+	-	-	-	-	+	-	-	-
23.	*Copera vittata* (Selys, 1863)	Blue Bush Dart	LC	O	-	-	-	-	-	-	+	-	-
24.	*Onychargia atrocyana* (Selys, 1865)	Black Mash Dart	LC	R	+	-	-	+	-	-	-	-	+
25.	*Disparoneura quadrimaculata** (Rambur, 1842)	Black-winged Bamboo Tail	LC	VR	-	-	-	-	-	+	-	-	-
Suborder: Anisoptera Family: Aeshnidae													
26.	*Anaciaeschna jaspidea* (Burmeister, 1839)	Rusty Darner	LC	R	+	-	-	+	-	-	-	-	-
27.	*Gynacantha dravida* (Lieftinck, 1960)	Brown Darner	DD	VR	-	-	-	+	-	-	-	-	-
28.	*Anax guttatus* (Burmeister, 1839)	Blue Tail Green Darner	LC	O	-	-	-	+	+	-	-	-	-
Family: Gomphidae													
29.	*Ictinogomphus rapax* (Rambur, 1842)	Common Clubtail	LC	C	+	-	+	+	+	+	-	-	+
30.	*Macrogomphus annulatus* (Selys, 1854)	Deccan Bowtail	DD	R	+	-	-	-	-	-	-	-	+
31.	*Paragomphus lineatus* (Selys, 1850)	Lined Hooktail	LC	C	+	-	-	-	-	-	-	-	+
Family: Libellulidae													
32	*Acisoma panorpoides* (Rambur, 1842)	Trumpet Tail	LC	VC	+	+	-	+	+	+	+	+	-

	Scientific name	Common name	IUCN Red List status	Local status	Egra	Khar	Panchet Garh	Kudi	Panchrol	Depal	Pakarghat	Kourda	Erenda
33.	*Aethriamanta brevipennis* (Rambur, 1842)	Scarlet Marsh Hawk	LC	C	-	-	-	+	-	+	-	-	+
34.	*Brachydiplax sobrina* (Rambur, 1842)	Little Blue Marsh Hawk	LC	VC	+	+	-	+	-	+	+	+	+
35.	*Brachydiplax chalybea* (Brauer, 1868).	Rufous-backed Marsh Hawk	LC	VC	+	-	-	+	-	-	+	+	-
36.	*Brachydiplax farinosa* (Kruger, 1902)	Emerald-flanked Marsh Hawk	LC	C	+	-	-	-	-	-	-	-	+
37.	*Brachythemis contaminata* (Fabricius, 1793)	Ditch Jewel	LC	VC	+	+	+	+	+	+	+	+	+
38.	*Diplacodes trivialis* (Rambur, 1842)	Ground Skimmer	LC	VC	+	+	+	+	+	-	+	+	+
39.	*Diplacodes nebulosa* (Fabricius, 1793)	Black-tipped Ground Skimmer	LC	VC	+	-	-	-	-	-	+	-	-
40.	*Orthetrum sabina* (Drury, 1770)	Green Marsh Hawk	LC	R	+	+	+	+	+	-	+	+	+
41.	*Orthetrum pruinosum* (Burmister, 1839)	Crimson-tailed Marsh Hawk	LC	R	+	-	-	-	-	-	+	+	+
42.	*Neurothemis tullia* (Drury, 1773)	Pied Paddy Skimmer	LC	C	+	-	-	-	-	+	-	-	+
43.	*Neurothemis fulvia* (Drury, 1773)	Fulvous Forest Skimmer	LC	O	-	+	-	+	-	+	-	+	-
44.	*Neurothemis intermedia* (Rambur, 1842)	Paddy Field Parasol	LC	C	-	-	-	-	-	+	-	-	+
45.	*Crocothemis servilia* (Drury, 1770)	Ruddy Marsh Skimmer	LC	C	+	+	+	+	+	-	+	+	+
46.	*Urothemis signata* (Rambur, 1842)	Greater Crimson Glider	LC	C	-	-	-	+	-	-	-	-	+
47.	*Pantala flavescens* (Fabricius, 1798)	Wandering Glider	LC	C	+	+	+	+	+	+	+	+	+
48.	*Rhodothemis rufa* (Rambur, 1842)	Rufous Marsh Glider	LC	C	+	+	-	+	+	-	-	+	-
49.	*Rhyothemis variegata* (Linnaeus, 1763)	Common Picture Wing	LC	R	+	+	+	+	+	+	+	+	+
50.	*Zyxomma petiolatum* (Rambur, 1842)	Brown Dusky Hawk	LC	VR	-	+	-	-	-	+	-	+	-
51.	*Bradinopyga geminata* (Rambur, 1842)	Granite Ghost	LC	VR	+	-	-	-	-	+	-	-	-
52.	*Potamarcha congener* (Rambur, 1842)	Yellow-tailed Ashy Skimmer	LC	R	+	-	-	+	-	-	-	-	+
53.	*Tholymis tillarga* (Fabricius, 1798)	Coral-tailed Cloud Wing	LC	C	+	-	-	+	-	-	-	-	-
54.	*Cratilla lineata* (Foerster, 1903)	Emerald Banded Skimmer	LC	VR	-	-	-	-	+	-	-	-	-
55.	*Macrodiplax cora* (Brauer, 1867)	Estuarian Skimmer	LC	R	-	-	-	-	+	-	-	-	+
56.	*Tramea basilaris* (Palisot de Beauvois, 1805)	Red Marsh Torter	LC	C	-	-	+	+	-	-	-	-	-
57.	*Tramea limbata* (Desjardins, 1832)	Black Marsh Torter	LC	O	-	-	+	+	-	-	-	-	-
58.	*Trithemis pallidinervis* (Kirby, 1889)	Long-tailed Marsh Glider	LC	C	+	-	+	-	+	-	+	-	+
59.	*Lathrecista asiatica* (fabricius, 1798)	Asiatic Blood Tail	LC	VR	-	-	-	+	-	+	-	-	-
Family: Macromiidae													
60.	*Epophthalmia vittata* (Burmeister, 1839)	Common Torrent Hawk	LC	R	+	-	-	+	-	+	-	-	-

relative abundance (Image 8). Anisoptera predominated at Panchetgarh (59 of 72 individuals, 81.9%), Pakarghat (90 of 126, 71.4%) and Kudi (73 of 127, 57.5%), whereas Zygoptera predominated at Egra (198 of 307, 64.5%) and Kourda (31 of 54, 57.4%). The Zygoptera-dominated ponds were those with dense marginal or floating vegetation and appreciable shade, whereas open ponds with little vegetation supported proportionally more Anisoptera. These results highlight the influence of local habitat structure on Odonata community composition.

DISCUSSION

The results of the present study indicate that the study area in southern parts of West Bengal, India, exhibits a rich diversity of dragonflies and damselflies, with a total of 60 species identified. The study also provides essential baseline information for future quantitative research on odonate diversity in this specific region. During the study, habitat preference studies were conducted for various species throughout the research period. The observed habitat preferences

of zygopterans for vegetated zones and anisopterans for more open water habitats may be influenced not only by vegetation structure but also by other interacting factors such as pond size and water quality parameters, which together contribute to shaping Odonata assemblages. The behavioural study has revealed that most aeshnids were crepuscular. They tend to perch in dense forested areas and often appear near light sources in the evening. *Anax guttatus* (Burmeister, 1839) was observed to be active throughout the day, continuously flying over water and seldom perching on twigs. On the other hand, *Ictinogomphus rapax* (Rambur, 1842) was found alongside large ponds or lakes, frequently perching on sticks near the water.

Libellulids are the most abundant and diverse group in any habitat. Dragonfly species like *Aethriamanta brevipennis* (Rambur, 1842), *Brachydiplax farinosa* (Kruger, 1902), *Lathrecista asiatica* (Fabricius, 1798), and *Neurothemis fulvia* (Drury, 1773) are generally found inside well-shaded forested areas, sometimes away from water. Conversely, *Urothemis signata* (Rambur, 1842), *Rhodothemis rufa* (Rambur, 1842), *Crocothemis servilia* (Drury, 1770), and *Brachydiplax chalybea* Brauer, 1868 are very common near open water bodies. *Pantala flavescens* (Fabricius, 1798), *Rhyothemis variegata* (Linnaeus, 1763), and *Tramea basilaris* (Palisot de Beauvois, 1805) are sometimes seen flying in swarms at considerable heights. Odonates with weak flight, such as *Acisoma panorpoides* Rambur, 1842, *Neurothemis tullia* (Drury, 1773), and *Diplacodes nebulosa* (Fabricius, 1793) are often found residing in grasslands with long grasses associated with water bodies. *Bradinopyga geminata* (Rambur, 1842) is always found near man-made water reservoirs or seen perched on dirty walls. *Orthetrum sabina* (Drury, 1770), *Orthetrum pruinosum* (Burmeister, 1839), and *Diplacodes trivialis* (Rambur, 1842) are commonly seen sitting on the ground or on twigs very close to the ground. On the other hand, *Potamarcha congener* (Rambur, 1842) and *Cratilla lineata* Foerster, 1903 are mostly found perched on electrical fixtures. Some dragonflies, such as *Zyxomma petiolatum* Rambur, 1842, *Macrodiplax cora* (Brauer, 1867), and *Tholymis tillarga* (Fabricius, 1798), frequently visit lights at night.

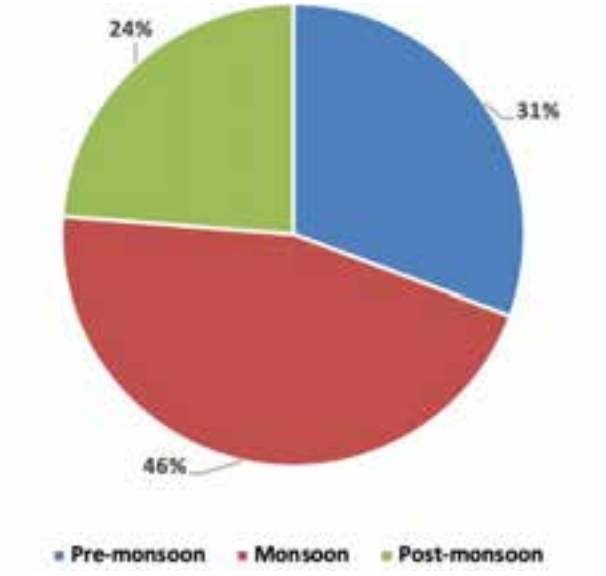

Image 6. Seasonal variation in Odonata abundance, expressed as the percentage of the total number of individuals recorded across all nine study sites.

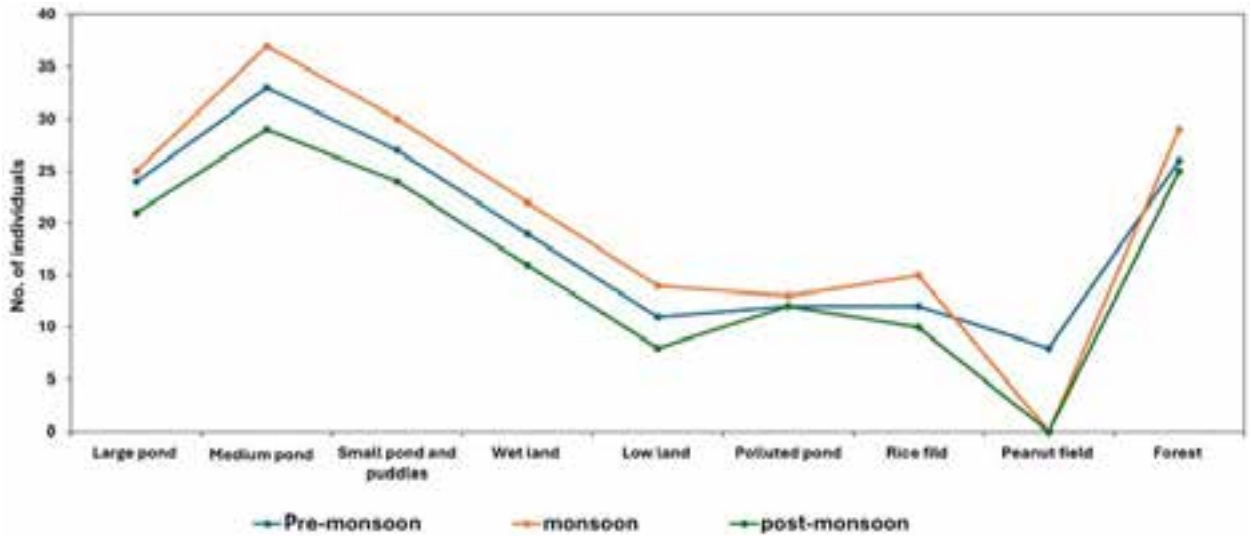

Image 7. Habitat wise graphical representation of seasonal fluctuation of Odonata species.

Table 3. List of Odonata in five different sized ponds.

	Egra	Pakarghat	Ponchetgarh	Kourda	Kudi
Pond size	Large	Medium	Medium	small	Medium
vegetation	very less vegetation with floating plant	maximum vegetation with emergent plant	no vegetation	maximum vegetation with floating leaves plant	maximum vegetation with free floating plant
DO	7 ppm	3.8 ppm	24 ppm	3 ppm	10 ppm
Co_2	6	28	3	23	10
Alkalinity	80 ppm	160 ppm	90 ppm	190 ppm	70 ppm
Brachythemis contaminata	71	3	28	5	5
Diplacodes trivialis	14	3	4	0	0
Orthetrum sabina	8	0	4	0	0
Crocothemis servilia	12	7	11	0	0
Ictinogomphus rapax	4	0	2	0	0
Agriocnemis pygmaea	30	4	0	10	18
Agriocnemis kalinga	21	1	0	2	4
Agriocnemis femina	17	1	0	0	11
Ceriagrion coromandelianum	32	27	3	13	13
Ischnura senegalensis	48	0	5	0	0
Ischnura rubilio	13	0	1	0	0
Pseudagrion rubriceps	37	0	4	0	0
Rhyothemis variegata	0	7	0	0	4
Brachydiplax sobrina	0	13	0	3	5
Brachydiplax chalybea	0	5	0	6	0
Acisoma panorpoides	0	45	0	7	4
Aethriamanta brevipennis	0	7	0	0	4
Ceriagrion cerinorubellum	0	3	0	6	0
Tramea limbata	0	0	3	0	0
Trithemis pallidinervis	0	0	7	0	0
Rhodothemis rufa	0	0	0	2	25
Urothemis signata	0	0	0	0	22
Tholymis tillarga	0	0	0	0	4
Onychargia atrocyana	0	0	0	0	8

Damselflies such as *Agriocnemis pygmaea* (Rambur, 1842), *Agriocnemis lacteola* Selys, 1877, and *Ischnura aurora* (Brauer, 1865) were commonly found in fields with small grasses. Species like *Copera ciliata* (Selys, 1863) and *Copera marginipes* (Rambur, 1842) were restricted to shaded bushes or ponds. *Ceriagrion coromandelianum* (Fabricius, 1798), *Onychargia atrocyana* (Selys, 1865), and *Ischnura senegalensis* (Rambur, 1842) were sometimes seen visiting forests or gardens away from water, but *Pseudagrion decorum*, *Pseudagrion microcephalum* (Rambur, 1842), *Pseudagrion rubiceps* (Selys, 1876), and *Paracercion malayanum* (Selys, 1876) were typically confined near water bodies. These damselflies were observed flying over more or less clear water with some water lilies or other submerged vegetation. They were often seen perched on twigs, flowers, or floating leaves of these plants. A few species, namely, *Ceriagrion cerinorubellum* (Brauer, 1865) and *Agriocnemis femina* (Brauer, 1868), were mainly found near ponds covered with water hyacinths.

Habitat preferences differed markedly within the Libellulidae. *Rhodothemis rufa* preferred large open ponds, while *Brachydiplax sobrina* and *Acisoma panorpoides* were associated with well-vegetated ponds. *Neurothemis fulvia* preferred shaded forest interiors,

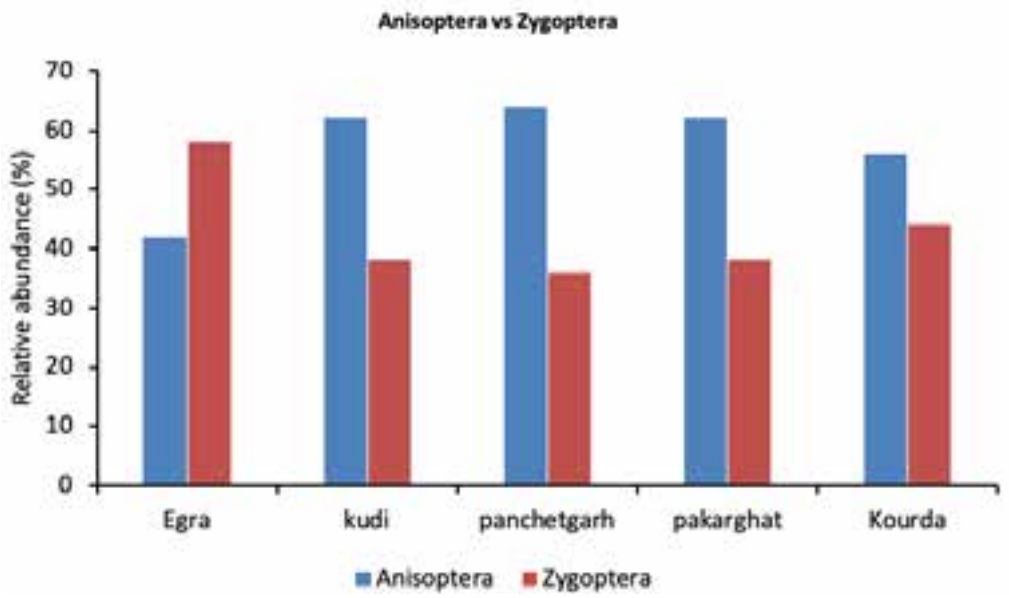

Image 8. Suborder-wise relative abundance of Odonata at the five study ponds. Y-axis—relative abundance (% of individuals recorded at each pond) | X-axis—study pond.

whereas *Brachythemis contaminata* preferred open ponds without vegetation; within the narrow range of values recorded here, the measured water parameters did not appear to be a significant factor influencing their abundance. The Gomphidae (*Ictinogomphus rapax*, *Macrogomphus annulatus*, and *Paragomphus lineatus*) were confined to the margins of large perennial ponds and canals. The crepuscular species were most active at dusk, when they largely avoided overlap with the diurnally active and frequently encountered species, namely *Agriocnemis pygmaea*, *Agriocnemis kalinga*, *Ceriagrion coromandelianum*, & *Ischnura senegalensis* among the Zygoptera and *Acisoma panorpoides*, *Brachythemis contaminata*, *Diplacodes trivialis*, *Orthetrum sabina*, & *Crocothemis servilia* among the Anisoptera. Conversely, *Disparoneura quadrimaculata* among the Zygoptera and *Gynacantha dravida* & *Lathrecista asiatica* among the Anisoptera were very rare in field observations. Of the 60 taxa recorded, 10 (16.7%) were very common, 19 (31.7%) common, eight (13.3%) occasional, 15 (25.0%) rare, and seven (11.7%) very rare; the local status of *Agriocnemis femina* remains to be assigned. According to the IUCN Red List, 55 of the recorded species are assessed as 'Least Concern', three as 'Data Deficient', and one as 'Not Evaluated', while the unidentified *Agriocnemis* sp. cannot be assessed.

CONCLUSION

The present study area, located along the coastal influenced area of southern Purba Medinipur, is supplied with water through small canals, reservoirs, and a good number of ponds and lakes. These water bodies serve as excellent breeding grounds for aquatic and semi-aquatic insects, including Odonata. The study reveals significant differences in the distribution of odonatan species among different types of habitats within the study area. During the course of this study, it became evident that several species previously reported from this region were not recorded, and some species were only rarely observed throughout the study period. The aquatic ecosystem used for pisciculture showed a noticeable decline in odonatan diversity due to habitat modifications such as the clearing of aquatic vegetation and other associated anthropogenic pressures. Pesticides were directly applied to submerged crop fields to control pest insects, leading to insecticide effluent entering adjacent water bodies, posing a serious threat to the aquatic fauna across the region. Further taxonomic and ecological studies on Odonata in this region may unveil additional interesting information. Some prior work has been conducted in Purba Medinipur, but this study represents the updated record checklist from the coastal influenced areas of the district and reports the zygopteran *Disparoneura quadrimaculata* (Platycnemididae) for the first time from Purba Medinipur District. This record extends the

Image 9. A—*Anax guttatus* | B—*Anaciaeschna jaspidea* | C—*Gynacantha* sp. | D—*Gynacantha dravida* | E—*Ictinogomphus rapax* | F—*Macrogomphus annulatus* | G—*Paragomphus lineatus* | H—*Acisoma panorpoides* (Male) | I—*Acisoma panorpoides* (Female) | J—*Aethriamanta brevipennis* | K—*Brachydiplax chalybea* | L—*Brachydiplax sobrina* (Male) | M—*Brachydiplax sobrina* (Female) | N—*Brachythemis contaminata* (Male) | O—*Brachythemis contaminata* (Female) | P—*Bradinopyga geminata*. © Suvabrata Khatua.

known distribution of the species within southern West Bengal; it is a range extension of a previously described species and not a new taxon. This finding underscores the need for more extensive research to develop an updated checklist for Purba Medinipur. Odonata species in the area display activity patterns influenced by various times of the day and temperature conditions. Therefore, careful observation of photoperiodicity and additional experiments are necessary to better understand their behaviour.

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Image 10. A—*Crocothemis servilia* (Male) | B—*Crocothemis servilia* (Female) | C—*Diplacodes trivialis* (Male) | D—*Diplacodes trivialis* (Female) | E—*Lathrecista asiatica* | F—*Macrodiplax cora* | G—*Neurothemis fulvia* (Male) | H—*Neurothemis fulvia* (Female) | I—*Neurothemis tullia* (Male) | J—*Neurothemis tullia* (Female) | K—*Orthetrum luzonicum* | L—*Orthetrum pruinosum* | M—*Orthetrum sabina* | N—*Pantala flavescens* | O—*Potamarcha congener* | P—*Rhodothemis rufa*. © Suvabrata Khatua.

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Image 11. A—*Rhyothemis variegata* (Male) | B—*Tramea basilaris* | C—*Tramea limbata* | D—*Trithemis aurora* | E—*Trithemis pallidinervis* | F—*Tholymis tillarga* (Male) | G—*Urothemis signata* (Male) | H—*Urothemis signata* (Female) | I—*Zyxomma petiolatum* (Male) | J—*Zyxomma petiolatum* (Female) | K—Copula of *Epophthalmia vittata* | L—*Agriocnemis kalinga* (Male) | M—*Agriocnemis kalinga* (Female) | N—*Agriocnemis lacteola* | O—*Agriocnemis pygmaea* | P—*Ceriagrion cerinorubellum*. © Suvabrata Khatua.

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Image 12. A—*Ceriagrion coromandelianum* | B—*Amphiallagma parvum* | C—*Ischnura aurora* | D—*Ischnura senegalensis* | E—*Mortonagrion aborense* (Male) | F—*Mortonagrion aborense* (Female) | G—*Pseudagrion decorum* | H—*Pseudagrion microcephalum* | I—*Pseudagrion rubriceps* | J—*Pseudagrion spencei* | K—*Lestes elatus* | L—*Lestes umbrinus* | M—*Lestes viridulus* | N—*Pseudocopera ciliata* | O—*Copera marginipes* | P—*Onychargia atrocyana*. © Suvabrata Khatua.

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ARTICLE

Species richness and distribution of Hymenophyllaceae in Mindanao Island, Philippines

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Abstract: Hymenophyllaceae is the largest basal family of leptosporangiate ferns and is recognized as one of the major components of the epiphytic communities in tropical rainforests. Members of the family are distinguished morphologically from other ferns by their marginal involucre and lamina's single-cell thickness. The specific environmental requirements of Hymenophyllaceae render them vulnerable to ecological and anthropogenic threats, as well as climate change. With the alarming rate of deforestation and the escalating climate crisis, this fern family faces extreme risk of population decline. Despite these challenges, Hymenophyllaceae remain understudied due to difficulties in identification; thus, data on their richness and distribution continue to be insufficient for conservation assessment. To address this, an extensive inventory of Hymenophyllaceae was conducted, supplemented by herbarium studies, to identify the species of Hymenophyllaceae and document their distribution in Mindanao, Philippines. Results revealed that 69% (42 taxa) of the total Hymenophyllaceae recorded in the Philippines were documented thriving in Mindanao including two endemic species *Abrodictyum extravagans* and *Hymenophyllum edanoi*. Elevational distribution of Hymenophyllaceae showed a hump-pattern, with increasing richness toward montane vegetation and gradually declining at higher mossy vegetation. *Cephalomanes* species has a restricted distribution, limited only to lower elevations (500–1000 m.) while the genera *Abrodictyum*, *Crepidomanes*, and *Hymenophyllum* were well-represented across varying elevations. The results of this study provide a comprehensive account of Hymenophyllaceae in Mindanao, highlighting the importance of conducting an extensive survey of this less-studied fern taxon.

Keywords: Elevation gradient, endemism, growth forms, filmy ferns, hygrophilous, hymenophylloid, involucre, microhabitat, trichomanoid.

Editor: Anonymity requested.

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INTRODUCTION

Philippines is recognized globally for its high degree of species richness and endemism (Heaney & Regalado 1998; Myers et al. 2000). Despite being a megabiodiverse country, it is recorded as one of the world's biodiversity hotspots due to severe threats to its ecosystem and biodiversity (Langenberger 2004; Coritico et al. 2020). It is home to an estimate of 1,100 species of fern and lycophytes, and 24% (264 species) of which is endemic to the country (Pelser et al. 2011; Amoroso et al. 2016).

Numerous pteridophytes studies has been conducted in the Philippines (Aribal & Buot 2009; Amoroso et al. 2015; Delos & Buot 2015; Coritico et al. 2020; Rufila et al. 2022; Coritico et al. 2024), however there are still a few fern taxa that have been less represented in research, one of which is the filmy fern family Hymenophyllaceae. Hymenophyllaceae is the largest of the earliest diverging families of heterosporous leptosporangiate ferns, comprising around 464 species globally. They are distinguished from other fern taxa based on their marginal sori and the single-cell thickness of its delicate fronds (Smith et al. 2006). Due to their uniseriate lamina, filmy ferns are extremely hygrophilous and susceptible to desiccation; thus, they are typically found in shady and humid forests, with greatest abundance and diversity attained in the tropical montane vegetation (Kromer & Kessler 2006; Proctor 2012). The specific environmental requirements for Hymenophyllaceae make these ferns vulnerable to ecological and anthropogenic threats and with the alarming rate of deforestation and the worsening climate crisis, this fern family faces extreme vulnerability to population decline (Fernando et al. 2008).

In spite of the current ecological challenges to Hymenophyllaceae, this fern family remained understudied due to difficulty in identification (Dubuisson 1997; Hennequin 2003) thus data on its richness and distribution continues to be insufficient for conservation assessment (Parra et al. 2009). The current records of Hymenophyllaceae in the Philippines account for 61 taxa (Pelser et al. 2011). In Mindanao, the last comprehensive listing for this family was the work of Copeland (1958) which was done more than six decades ago. With the recent revisions on the classification and species circumscription (e.g., Ebihara et al. 2006; PPGI 2016) an updated checklist of the species is needed. There is also a demand for more recent explorations to further assess the status of Hymenophyllaceae, especially in Mindanao which remains to be less explored due to political instability and inaccessibility of its mountainous areas (Aribal & Buot 2009; Coritico et al. 2020; Obemio & Buot 2021). Due to these research constraints, this leaves a great gap in the data for the flora of this island. Thus, this study aimed to conduct an extensive inventory of Hymenophyllaceae to identify the filmy ferns in this island and document the distribution of Hymenophyllaceae species in the mountain ecosystems of Mindanao, Philippines.

METHODS

Species inventory and Herbarium studies

An inventory of Hymenophyllaceae was conducted in two mountain sites of Mindanao, viz., Mt. Timolan (Zamboanga del Sur) and Mt. Matutum (South Cotabato) (Image 1). These two mountain ecosystems are among the protected areas in Mindanao known for rich biodiversity. These areas have been less explored in fern research, especially for Hymenophyllaceae. Opportunistic sampling was done from the jump-off area to the peak of Mt. Timolan (553–1,143 m) and Mt. Matutum (1,042–2,274 m). Global positioning system (GPS) was used to determine the exact elevation and location of the species. Species observed during the opportunistic sampling in each mountain site were recorded and collected for identification and listing. Herbarium studies on all species of Hymenophyllaceae from 31 sites in Mindanao that are deposited at Central Mindanao University Herbarium (CMUH) were also done to enrich the data on the species richness and distribution of filmy ferns in Mindanao, Philippines.

Collection and Identification of samples

A maximum of three individuals for each species of Hymenophyllaceae were collected, pressed and dried as herbarium specimens. All species from actual fieldwork and herbarium studies were identified using taxonomic keys from the monographs, flora and other publications: Flora Malesiana Hymenophyllaceae (Iwatsuki & Ebihara 2023), Fern Flora of the Philippines (Copeland 1958), and Ebihara et al. (2006) were the major references for the identification.

RESULTS AND DISCUSSION

The current study documented a total of 42 taxa (39 species and three varieties) of filmy ferns from different sites in Mindanao (31 sites) (Table 1). These taxa were

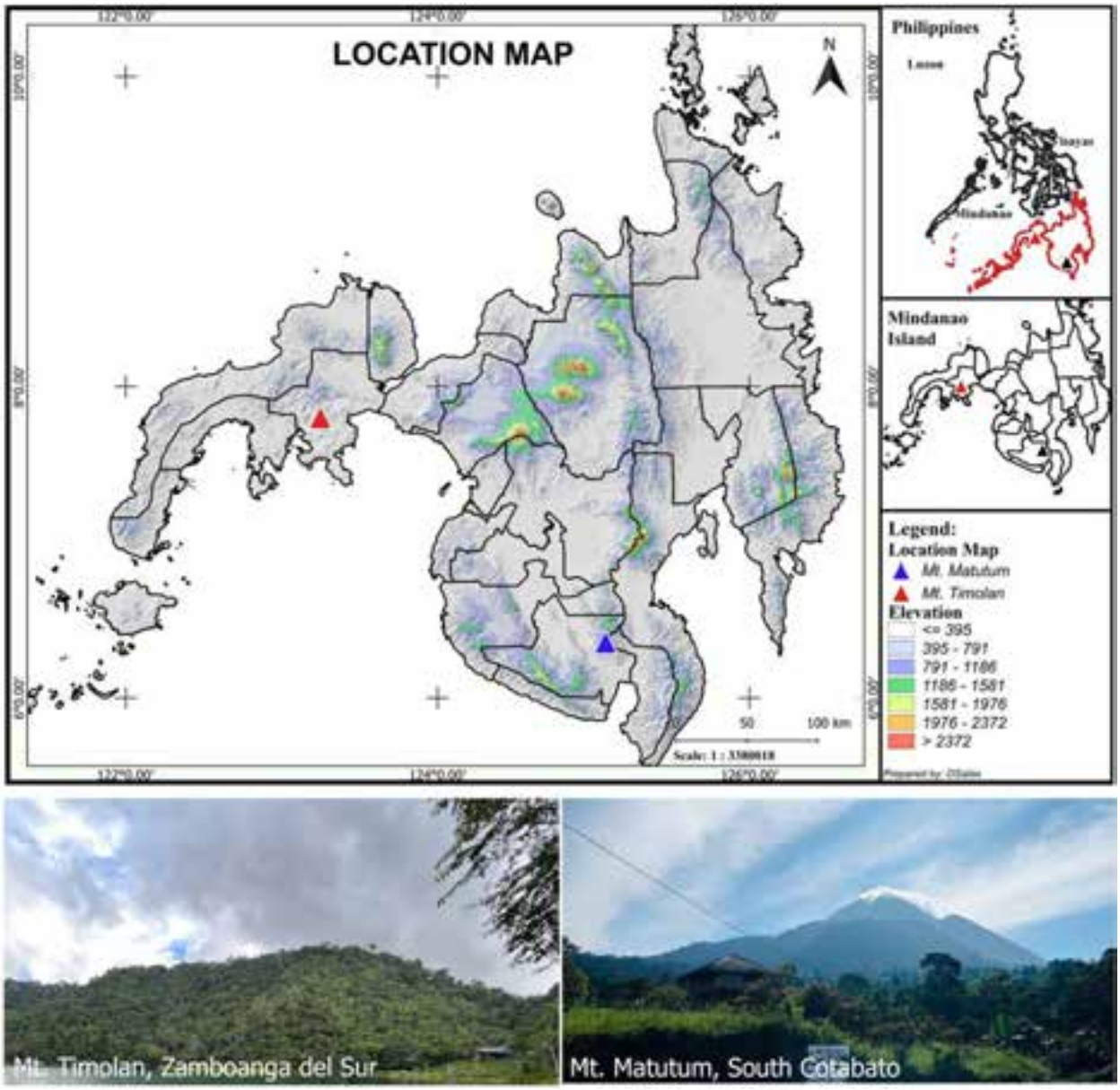

Image 1. Map of the study sites for the actual field collection of Hymenophyllaceae.

classified into six genera following the nine genera classification made by Ebihara et al. (2006) as a revision of the multigeneric system of classification of this family. The result of the study comprised 69% of the total filmy fern taxa in the Philippines.

The extensive number of Hymenophyllaceae in Mindanao is credited to the numerous mountain ecosystems found on the island, characterized by its tropical and moist conditions. Filmy ferns are typical plants of shady and constantly humid environments, especially in tropical forests where they achieve the greatest abundance (Proctor 2012). According to Proctor (2003) Hymenophyllaceae exhibits distinct ecological preferences as these species are strongly hygrophilous, showing a preference for environments that are predominantly shaded or partially shaded, where optimal levels of humidity, light, and water are available (Proctor 2003, 2010). These specific ecological requirements are necessary for the survival of filmy ferns, considering the single-cell thickness of its lamina that makes it prone to dehydration (Kromer & Kessler 2006; Proctor 2012). The large forest cover in Mindanao comprises primarily of primary forest in mountain ecosystems, forest patches, regenerated forests, and plantations, providing a wide array of conducive habitats for Hymenophyllaceae. It is essential to note that forest cover varies within different

Table 1. Distribution of Hymenophyllaceae taxa across different sites in Mindanao.

	Mt. Apo	Mt. Apulang	Mt. Bagalbal	Mt. Binalabag	Mt. Ginanlajan	Mt. Hamiguitan	Mt. Kaatuan	Mt. Kalatungan	Mt. Kiamo	Mt. Kinasalapi	Mt. Kitanglad
I. Abrodictyum											
1. *Abrodictyum cumingii* C.Presl											+
2. *Abrodictyum obscurum* (Blume) Ebihara & K.Iwats.	+					+					+
3. *Abrodictyum obscurum* var. *siamense* (Christ) K.Iwats.											
4. *Abrodictyum extravagans* (Copel.)	+					+			+		+
5. *Abrodictyum pluma* (Hook.) Ebihara & K.Iwats.	+					+			+		+
6. *Abrodictyum* sp. 1	+										+
II. Callistopteris											
7. *Callistopteris apiifolia* (C.Presl) Copel.	+		+				+			+	+
III. Cephalomanes											
8. *Cephalomanes javanicum* var. *asplenoides* (C.Presl) K.Iwats.				+		+					+
9. *Cephalomanes javanicum* var. *sumatranum* (Alderw.) K.Iwats.											
10. *Cephalomanes atrovirens* C.Presl						+					
IV. Crepidomanes											
11. *Crepidomanes bipunctatum* (Poir.) Copel.						+		+			+
12. *Crepidomanes minutum* (Blume) K.Iwats.	+										
13. *Crepidomanes intermedium* (Bosch) Ebihara & K.Iwats.											
14. *Crepidomanes* sp.				+							+
V. Hymenophyllum											
15. *Hymenophyllum acanthoides* (Bosch) Rosenst.											
16. *Hymenophyllum angulosum* Christ	+		+								+
17. *Hymenophyllum badium* Hook. & Grev.	+					+					+
18. *Hymenophyllum blandum* Racib.											+
19. *Hymenophyllum bontocense* Copel.	+					+	+		+		+
20. *Hymenophyllum denticulatum* Sw.			+			+					
21. *Hymenophyllum digitatum* (Sw.) Fosberg											+
22. *Hymenophyllum edanoi* (Copel.) C.V.Morton						+					+
23. *Hymenophyllum emarginatum* Sw.	+	+			+				+		+

24. *Hymenophyllum fimbriatum* J.Sm.								+			+
25. *Hymenophyllum imbricatum* Blume	+					+		+		+	+
26. *Hymenophyllum javanicum* Spreng.											+
27. *Hymenophyllum johorense* Holttum											
28. *Hymenophyllum nitidulum* C.Presl						+					+
29. *Hymenophyllum pachydermicum* Ces.	+					+					+
30. *Hymenophyllum pallidum* (Blume) Ebihara & K.Iwats.	+	+	+			+			+		+
31. *Hymenophyllum paniculiflorum* C.Presl	+										+
32. *Hymenophyllum penangianum* Matthew & Christ ex Christ											
33. *Hymenophyllum pilosissimum* C.Chr.	+										+
34. *Hymenophyllum polyanthos* (Sw.) Sw.	+										+
35. *Hymenophyllum productum Kunze*	+										+
36. *Hymenophyllum reinwardtii* Bosch	+							+			+
37. *Hymenophyllum serrulatum* (C.Presl) C.Chr.									+		
38. *Hymenophyllum* cf. *serrulatum* (C.Presl) C.Chr.	+										+
39. *Hymenophyllum thuidium* Harr.	+					+					
40. *Hymenophyllum* sp. 1											
VI. Vandenboschia											
41. *Vandenboschia auriculata* (Blume) Copel.	+										+
42. *Vandenboschia maxima* (Blume) Copel.	+			+							+
TOTAL	**22**	**2**	**4**	**3**	**1**	**15**	**2**	**4**	**6**	**2**	**30**
	Mt. Kulabog	**Mt. Limbawon**	**Mt. Mahuson**	**Mt. Malambo**	**Mt. Malindang**	**Mt. Malimumu**	**Mt. Matutum**	**Mt. Nabugkasan**	**Mt. Natampod**	**Mt. Pantaron**	**Mt. Pasian**
I. Abrodictyum											
1. *Abrodictyum cumingii* C.Presl									+	+	+
2. *Abrodictyum obscurum* (Blume) Ebihara & K.Iwats.	+	+	+	+	+		+	+	+	+	+
3. *Abrodictyum obscurum* var. siamense (Christ) K.Iwats.							+				
4. *Abrodictyum extravagans* (Copel.)		+						+			
5. *Abrodictyum pluma* (Hook.) Ebihara & K.Iwats.		+			+	+					
6. *Abrodictyum* sp. 1											
II. Callistopteris											
7. *Callistopteris apiifolia* (C.Presl) Copel.	+		+	+	+		+		+		

III. Cephalomanes											
8. a. *Cephalomanes javanicum* var. *asplenoides* (C.Presl) K.Iwats.	+		+					+	+	+	+
9. *Cephalomanes javanicum* var. *sumatranum* (Alderw.) K.Iwats.	+										
10. *Cephalomanes atrovirens* C.Presl								+			
IV. Crepidomanes											
11. *Crepidomanes bipunctatum* (Poir.) Copel.	+						+		+		+
12. *Crepidomanes minutum* (Blume) K.Iwats.							+		+		
13. *Crepidomanes intermedium* (Bosch) Ebihara & K.Iwats.							+				
14. *Crepidomanes* sp.					+				+		
V. Hymenophyllum											
15. *Hymenophyllum acanthoides* (Bosch) Rosenst.	+								+		
16. *Hymenophyllum angulosum* Christ				+					+		
17. *Hymenophyllum badium* Hook. & Grev.		+	+		+				+		
18. *Hymenophyllum blandum* Racib.		+									
19. *Hymenophyllum bontocense* Copel.	+	+			+	+	+	+	+		
20. *Hymenophyllum denticulatum* Sw.			+		+		+	+	+		
21. *Hymenophyllum digitatum* (Sw.) Fosberg											
22. *Hymenophyllum edanoi* (Copel.) C.V.Morton											
23. *Hymenophyllum emarginatum* Sw.		+	+		+		+		+	+	
24. *Hymenophyllum fimbriatum* J.Sm.				+			+				
25. *Hymenophyllum imbricatum* Blume	+						+		+		
26. *Hymenophyllum javanicum* Spreng.				+							
27. *Hymenophyllum johorense* Holttum											
28. *Hymenophyllum nitidulum* C.Presl	+										
29. *Hymenophyllum pachydermicum* Ces.		+	+			+			+		
30. *Hymenophyllum pallidum* (Blume) Ebihara & K.Iwats.		+		+	+	+			+	+	
31. *Hymenophyllum paniculiflorum* C.Presl							+				
32. *Hymenophyllum penangianum* Matthew & Christ ex Christ							+				
33. *Hymenophyllum pilosissimum* C.Chr.					+						
34. *Hymenophyllum polyanthos* (Sw.) Sw.							+				

35. *Hymenophyllum productum Kunze*							+				
36. *Hymenophyllum reinwardtii* Bosch							+				
37. *Hymenophyllum serrulatum* (C.Presl) C.Chr.		+			+				+		
38. *Hymenophyllum* cf. *serrulatum* (C.Presl) C.Chr.											
39. *Hymenophyllum thuidium* Harr.											
40. *Hymenophyllum* sp. 1											
VI. Vandenboschia											
41. *Vandenboschia auriculata* (Blume) Copel.							+				
42. *Vandenboschia maxima* (Blume) Copel.	+		+		+		+		+		
TOTAL	**10**	**10**	**8**	**6**	**12**	**4**	**18**	**6**	**17**	**5**	**4**
	Mt. Salumay	**Mt. Timolan**	**Mt. Timpoong**	**Mt. Ulahingan**	**Panagumayon Forest (Lilingayon, Valencia)**	**Panlamaan Forest (Banlag, Valencia)**	**Marilog Forest Patches**	**Davao Oriental Municipalities (Taghikop and Macambol) La Union**		**Bukidnon Municipalities (Impalutao, Malaybaylay, Namnam, Impasugong)**	
I. Abrodictyum											
1. *Abrodictyum cumingii* C.Presl		+				+	+				
2. *Abrodictyum obscurum* (Blume) Ebihara & K.Iwats.	+			+			+			+	
3. *Abrodictyum obscurum* var. siamense (Christ) K.Iwats.											
4. *Abrodictyum extravagans* (Copel.)											
5. Abrodictyum pluma (Hook.) Ebihara & K.Iwats.											
6. *Abrodictyum* sp. 1											
II. Callistopteris											
7. *Callistopteris apiifolia* (C.Presl) Copel.		+		+	+	+	+				
III. Cephalomanes											
8. *Cephalomanes javanicum* var. *asplenoides* (C.Presl) K.Iwats.		+					+	+			
9. *Cephalomanes javanicum* var. *sumatranum* (Alderw.) K.Iwats.											
10. *Cephalomanes atrovirens* C.Presl								+			
IV. Crepidomanes											
11. *Crepidomanes bipunctatum* (Poir.) Copel.		+					+	+		+	
12. *Crepidomanes minutum* (Blume) K.Iwats.					+	+					
13. *Crepidomanes intermedium* (Bosch) Ebihara & K.Iwats.		+			+		+				
14. *Crepidomanes* sp.											

V. Hymenophyllum									
15. *Hymenophyllum acanthoides* (Bosch) Rosenst.									
16. *Hymenophyllum angulosum* Christ									
17. *Hymenophyllum badium* Hook. & Grev.				+			+		+
18. *Hymenophyllum blandum* Racib.									
19. *Hymenophyllum bontocense* Copel.		+			+				+
20. *Hymenophyllum denticulatum* Sw.		+		+			+		+
21. *Hymenophyllum digitatum* (Sw.) Fosberg									
22. *Hymenophyllum edanoi* (Copel.) C.V.Morton									
23. *Hymenophyllum emarginatum* Sw.				+			+		
24. *Hymenophyllum fimbriatum* J.Sm.									
25. *Hymenophyllum imbricatum* Blume		+					+		
26. *Hymenophyllum javanicum* Spreng.		+		+	+		+		
27. *Hymenophyllum johorense* Holttum									
28. *Hymenophyllum nitidulum* C.Presl									
29. *Hymenophyllum pachydermicum* Ces.				+			+		+
30. *Hymenophyllum pallidum* (Blume) Ebihara & K.Iwats.				+			+		
31. *Hymenophyllum paniculiflorum* C.Presl									
32. *Hymenophyllum penangianum* Matthew & Christ ex Christ									
33. *Hymenophyllum pilosissimum* C.Chr.									
34. *Hymenophyllum polyanthos* (Sw.) Sw.									
35. *Hymenophyllum productum Kunze*				+			+		
36. *Hymenophyllum reinwardtii* Bosch									
37. *Hymenophyllum serrulatum* (C.Presl) C.Chr.									
38. *Hymenophyllum* cf. *serrulatum* (C.Presl) C.Chr.									
39. *Hymenophyllum thuidium* Harr.									
40. *Hymenophyllum* sp. 1									+
VI. Vandenboschia									
41. *Vandenboschia auriculata* (Blume) Copel.						+			
42. *Vandenboschia maxima* (Blume) Copel.		+	+		+		+		
TOTAL	**1**	**10**	**1**	**9**	**6**	**4**	**15**	**3**	**7**

Image 2. Hymenophyllaceae as understory epiphytes: a—*Crepidomanes minutum* | b—*Crepidomanes bipunctatum* | c—*Hymenophyllum angulosum*. © Nietes, A.D.

regions of Mindanao due to human activities, land use changes, and conservation efforts, thus also affecting the current distribution of Hymenophyllaceae species across the island.

Regarding the species richness of Hymenophyllaceae across the different mountain sites in Mindanao, Mt. Kitanglad (30 spp.) recorded the highest number of species, followed by Mt. Apo with 22 species (Table 1). The high species richness of Hymenophyllaceae in these mountain ecosystems is linked to the eco-physiological characteristics of the sites, particularly the altitude range, diverse vegetation, and varied habitats offered by these ecosystems (Amoroso et al. 2009, 2011, 2012). These mountain sites reach an altitude of more than 2,000 m and are comprised of at least three types of vegetation (Amoroso et al. 2011; Azuelo et al. 2020; Coritico et al. 2022) dominated by angiosperms and gymnosperms, therefore offering different types of microhabitats for varying filmy ferns to grow both as epiphytes on trunks and branches and as terrestrial in a limited light environment formed by the forest canopy (Image 2) (Sharpe et al. 2010).

Frequent precipitation together with low evaporation appears to be the key requirement for the successful growth of Hymenophyllaceae (Proctor 2003). These mountain sites have a Type IV climate characterized by a more or less even distribution of rainfall throughout the year (Agpao et al. 1975; Quimpang et al. 2018). The rainforest environment of Mt. Kitanglad and Mt. Apo marked by regular precipitation with foggy conditions allows the successful growth of filmy ferns in these mountain sites. Such environmental condition limits transpiration and, therefore maximize water retention of the filmy ferns.

According to Mehltreter (1995) & Kessler (2010), in terms of elevational distribution, members of Hymenophyllaceae show distinct elevational preferences. Trichomanoid ferns *Abrodictyum*, *Cephalomanes*, *Crepidomanes*, *Callistopteris*, *Vandenboschia*, *Didymoglossum*, and *Polyphlebium* typically occur at low to mid-elevations (Kessler 2010), whereas hymenophylloid (*Hymenophyllum*) ferns are mainly distributed from mid to high elevations (Dubuisson et al. 2023). The specific elevational distribution is primarily determined by the species-specific ecological requirements.

The altitudinal distribution of Mindanao Hymenophyllaceae is shown in Table 2. Only 36 species and three varieties were considered in this table since the other three species were represented by herbarium samples that lacks data on its elevational distribution. Species under the genus *Vandenboschia* were found below 2,000 m. The genus *Callistopteris* is restricted at 1,000–2,500 m and *Cephalomanes* is limited within 500–1,500 m. The genera *Abrodictyum*, *Crepidomanes* and *Hymenophyllum* have a wider altitudinal range, as some species under these genera were found at 500–2,500 m.

Among the filmy ferns recorded, *Crepidomanes minutum* (Blume) K.Iwats. and species of *Abrodictyum*: *A. pluma* Ebihara & K.Iwats. and *A. cumingii* Presl. are the most widely distributed species found at 500–2,500 m. *Crepidomanes minutum* and *A. cumingii* are epiphytes

Table 2. Growth forms and elevational distribution of Hymenophyllaceae in Mindanao.

Species	Growth forms	Micro-habitat	Elevation (m)	Conservation status/ Endemism/ New record
I. *Abrodictyum*				
1. *Abrodictyum cumingii* C.Presl	E	TR	500–2,500	
2. *Abrodictyum obscurum* (Blume) Ebihara & K.Iwats.	T	SO	1,000–2,000	
3. *Abrodictyum obscurum* var. *siamense* (Christ) K.Iwats.	T/L	SO/RS	1,500–2,000	**New Record: South Cotabato (Mt. Matutum)** (previous distribution: China, Thailand, Cambodia, Japan, Peninsular Malaysia, Borneo and Sulawesi)
4. *Abrodictyum extravagans* (Copel.)	T	SO	500–2,000	Endemic
5. *Abrodictyum pluma* (Hook.) Ebihara & K.Iwats.	T/L	SO/RS	500–2,500	
6. *Abrodictyum* sp. 1	T/L	SO/RS	1,500–2,000	
II. *Callistopteris*				
7. *Callistopteris apiifolia* (C.Presl) Copel.	T/E/L	SO/TR/RS	1,000–2,500	
III. *Cephalomanes*				
8. *Cephalomanes javanicum* var. asplenoides (C.Presl) K.Iwats.	T	SO	500–1,500	
9. *Cephalomanes javanicum* var. *sumatranum* (Alderw.) K.Iwats.	T/L/R	SO/TR/WB	500–1,000	**New Record: Zamboanga del Sur (Mt. Kulabog)** (previous distribution: China, Vietnam, Sumatra, Borneo and Java)
10. *Cephalomanes atrovirens* C.Presl	T	SO	500–1,500	
IV. *Crepidomanes*				
11. *Crepidomanes bipunctatum* (Poir.) Copel.	E	TR	500–2,000	
12. *Crepidomanes minutum* (Blume) K.Iwats.	E	TR	500–2,500	
13. *Crepidomanes intermedium* (Bosch) Ebihara & K.Iwats.			100–1,000	
14. *Crepidomanes* sp.	E	TR	2,000–2,500	
V. *Hymenophyllum*				
15. *Hymenophyllum acanthoides* (Bosch) Rosenst.	E	TR	500–1,500	
16. *Hymenophyllum angulosum* Christ	E	TR	1,000–2,000	
17. *Hymenophyllum badium* Hook. & Grev.	E	TR	1,000–2,000	
18. *Hymenophyllum blandum* Racib.*	E	TR	No data in herbarium	
19. *Hymenophyllum bontocense* Copel.	E	TR	1,000–2,500	OWS
20. *Hymenophyllum* cf. *serrulatum* (C.Presl) C.Chr.	E	TR	1,500–2,500	
21. *Hymenophyllum denticulatum* Sw.	E	TR	50–2,000	
22. *Hymenophyllum digitatum* (Sw.) Fosberg *	E	TR	No data in herbarium	
23. *Hymenophyllum edanoi* (Copel.) C.V.Morton	E	TR	1,500–2,500	OWS, Endemic
24. *Hymenophyllum emarginatum* Sw.	E	TR	1,000–2,500	
25. *Hymenophyllum fimbriatum* J.Sm.	E	TR	2,000–2,500	
26. *Hymenophyllum imbricatum* Blume	E	TR	1,000–2,500	
27. *Hymenophyllum nitidulum* C.Presl	T	SO	500–1,500	OWS
28. *Hymenophyllum javanicum* Spreng.	E	TR	50–1,500	
29. *Hymenophyllum johorense* Holttum	E	TR	1,000–1,500	
30. *Hymenophyllum pachydermicum* Ces.	E	TR	1,000–2,000	
31. *Hymenophyllum pallidum* (Blume) Ebihara & K.Iwats.	E	TR	1,000–2,000	
32. *Hymenophyllum paniculiflorum* C.Presl	E	TR	2,000–2,500	
33. *Hymenophyllum pilosissimum* C.Chr.	E	TR	1,500–2,000	
34. *Hymenophyllum polyanthos* (Sw.) Sw.	E	TR	1,500–2,000	
35. *Hymenophyllum productum* Kunze	E	TR	2,000–2,500	
36. *Hymenophyllum reinwardtii* Bosch	E	TR	1,000–2,500	
37. *Hymenophyllum serrulatum* (C.Presl) C.Chr.	E	TR	1,500–2,000	
38. *Hymenophyllum thiudium* Harr.	E	TR	1,000–2,000	

Species	Growth forms	Micro-habitat	Elevation (m)	Conservation status/ Endemism/ New record
39. *Hymenophyllum penangianum* Matthew & Christ ex Christ	E	TR	1,500–2,000	**New Record : South Cotabato (Mt. Matutum)** (previous distribution: Peninsular Malaysia and Borneo)
40. *Hymenophyllum* sp. *	E	TR	No data in herbarium	
VI. *Vandenboschia*		TR		
41. *Vandenboschia auriculata* (Blume) Copel.	E	TR	1,000–2,000	
42. *Vandenboschia maxima* (Blume) Copel.	T/L	SO/RS	500–2,000	

*—lacks data on its elevational distribution | **—new record (Nietes et al. in preparation) | T—terrestrial | E—epiphyte | L—lithophyte | R—rheophyte | TR—tree | SO—soil | RS—rock surfaces | WB—water banks | OWS—other wildlife species.

Image 3. Terrestrial species of Hymenophyllaceae: A—*Vandenboschia maxima* | b—*Abrodictyum obscurum* | c—*Abrodictyum pluma* | d—*Callistopteris apiifolia*. © Nietes, A.D.

Image 4. Epiphytic species of Hymenophyllaceae: A—*Hymenophyllum imbricatum* | b—*Hymenophyllum acanthoides* | c—*Crepidomanes minutum* | d—*Hymenophyllum nitidulum* | e—*Hymenophyllum pallidum* | f—*Hymenophyllum pilossisimum*. © Nietes, A.D.

Image 5. Epiphytic species of Hymenophyllaceae: A—*Abrodictyum cumingii* | b—*Hymenophyllum reinwardtii* | c—*Hymenophyllum emarginatum* | d—*Vandenboschia auriculata* | e—*Hymenophyllum bontocense* | f—*Crepidomanes bipunctatum* | g—*Hymenophyllum badium*. © Nietes, A.D.

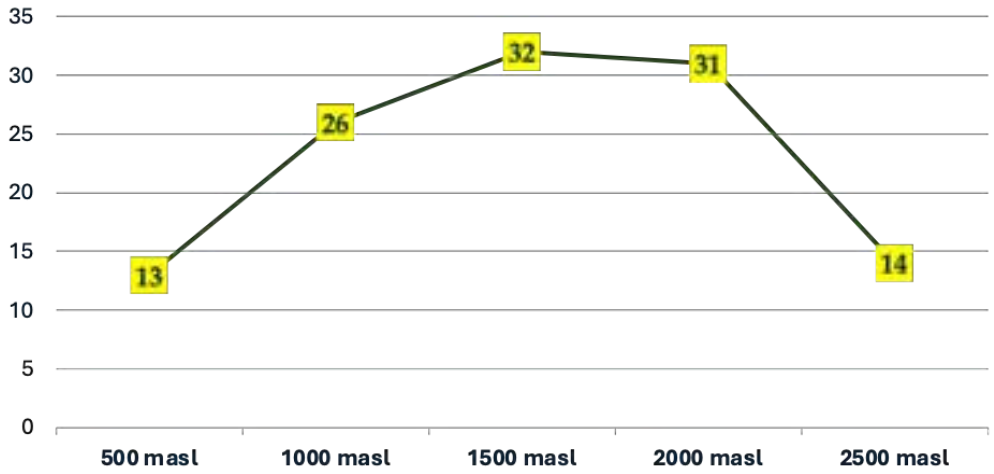

Image 6. Distribution of Hymenophyllaceae species across the elevation gradient.

on branches and trunks of trees, shrubs, and tree ferns. *Crepidomanes minutum* forms a close association with mosses, whereas *A. cumingii* is observed to have a high affinity to tree ferns (Cyatheaceae), and this observation is supported by the work of Ebihara et al. (2006). *Abrodictyum cumingii* relies on the water stored in the adventitious roots in the trunk of tree ferns to sustain its moisture requirements (Iwatsuki & Ebihara 2023). The dependence of this species on tree ferns implies that the removal of tree ferns will also lead to the loss of *A. cumingii* in the forest community (Cano-Mangaoang 2020). The reliance of epiphytes on tree ferns as a substrate could lead to simultaneous extinction if the population of the host is eliminated (Colwell et al. 2012).

Abrodictyum pluma is a terrestrial species, and according to Dubuisson et al. (2023), terrestrial trichomanoid ferns tend to have a wider distribution than epiphytes (Image 3). This observation by Dubuisson et al. (2023) coincides with this study, as the distribution of *Abrodictyum* includes low to high elevations.

The thick monocaulous rhizome of terrestrial species is considered as an adaptation against desiccation caused by limited water supply (Dubuisson et al. 2003). The robust roots attached to this thick rhizome enable terrestrial species to maximize water absorption in the substrate. Whereas epiphytic filmy ferns (Images 4 & 5) are highly restricted by the availability of water. These species have not developed adaptive morphological features to prevent desiccation and/or store water. Thus, these ferns are restricted to very wet places where humid climates and a close canopy are considered the optimal environment for these filmy ferns to diversify (Hennequin et al. 2008).

In general, the distribution of Hymenophyllaceae along the elevation gradient revealed the highest richness at mid-elevations and a lesser number of species at low and high elevations (Image 6). Kessler (2010) stated that this pattern of distribution mostly reflects the maximum humidity of the elevation or the ideal combination of humidity and mild temperatures. Hymenophyllaceae also follows the hump pattern of distribution exhibited by seed plants, by which this seed plant-dominated vegetation served as a conducive microhabitat for both terrestrial and epiphytic filmy ferns (Kessler 2010).

The specific environmental requirement for Hymenophyllaceae makes these ferns vulnerable to ecological and anthropogenic threats. Hence, the reason most of its members are classified as other wildlife species (OWS) in the assessment made by Fernando et al. (2008) but they have an increased tendency to become threatened due to habitat destruction (Fernando et al. 2008; DAO 2017). Habitat destruction through logging, land use/land cover change, environmental pollution, invasive species, and over-exploitation of forest resources are considered to be the main threats to biodiversity (Catibog-Sinha & Heaney 2006), together with climate change (Ibrahim et al. 2013).

And with the alarming rate of forest conversion and degradation occurring in the country, the chances of Hymenophyllaceae being affected by such anthropogenic threats are imminent. If these environmental threats continue to progress, this may lead to the loss of a big portion of Philippine biodiversity. Thus, calls for a more extensive and heightened implementation of biodiversity protection and habitat preservation.

CONCLUSION

Hymenophyllaceae has been less represented in research due to its problematic taxonomy and the difficulty of its identification. In this present study, a total of 42 taxa (39 species and three varieties) of Hymenophyllaceae were recorded in Mindanao, which comprises 69% of the total filmy ferns in the country, including two endemic species— *A. extravagans* and *H. edanoi*.

Out of the 31 Mindanao mountain sites included in this study, the tropical rainforest of Mt. Kitanglad (30 spp.) recorded the highest number of species, followed by Mt. Apo (22 spp.), which provides a suitable ecology for Hymenophyllaceae, particularly the microhabitats, canopy shade and the regular precipitation in these forest ecosystems, which prevents these extremely hygrophilous species from desiccation. The elevational distribution of Hymenophyllaceae shows a hump-pattern of distribution with increasing richness as elevation reaches the montane vegetation and gradually declines towards mossy vegetation. This pattern of distribution mostly reflects the ideal combination of humidity and mild temperatures and the availability of microhabitats for filmy ferns, given that montane vegetation is a seed plant-dominated vegetation serving as a conducive microhabitat for the epiphytic and terrestrial species of Hymenophyllaceae. The results of this study reveal the high richness of Hymenophyllaceae in the island of Mindanao, implying that the island represents a significant floral resource of the country. This research also provided a comprehensive checklist of Hymenophyllaceae in Mindanao, highlighting the importance of conducting an extensive survey on these less-studied fern taxa. Additionally, the findings suggest the extreme dependency of Hymenophyllaceae on forest ecosystems; therefore, to protect these species from extinction or population decline, a more stringent enforcement of policies for the preservation and conservation of forests should be implemented.

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COMMUNICATION

Assessment of genetic variation for conservation implications in the Critically Endangered Bawean Deer *Axis kuhlii* Temminck, 1836 (Mammalia: Artiodactyla: Cervidae)

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Abstract: The Bawean Deer *Axis kuhlii*, endemic to the small Indonesian island of Bawean, is listed as 'Critically Endangered' with fewer than 250 mature individuals remaining in the wild. The first genetic assessment of captive *A. kuhlii* populations using 13 microsatellite markers were conducted. Samples included individuals from Bawean, multiple Indonesian zoos, and a European zoo. The goals were to assess genetic diversity and to test for potential hybridisation with *Rusa unicolor* and *Rusa timorensis*, due to frequent mixed-species housing in Javan facilities. STRUCTURE analysis revealed no evidence of hybridisation and identified three genetic clusters within *A. kuhlii*, likely reflecting drift and kinship effects. Genetic diversity was low across all *A. kuhlii* samples, but slightly higher in the Bawean population. Some alleles present in Java zoo populations were absent from Bawean. These findings suggest that while inbreeding may be a concern, managed translocation between captive and wild populations could enhance genetic diversity without introducing hybridisation risk. Targeted integration of ex-situ individuals and the inclusion of wild-caught stags into the Bawean breeding program are recommended to support genetic rescue efforts and long-term population viability.

Keywords: Captive breeding, conservation genetics, genetic diversity, genetic structure, inbreeding, microsatellites, translocation.

Bahasa Indoesia: Rusa Bawean *Axis kuhlii*, yang endemik di Pulau Bawean, Indonesia, dikategorikan sebagai "Kritis" (Critically Endangered), dengan jumlah individu dewasa yang tersisa di alam diperkirakan kurang dari 250 ekor. Penelitian ini merupakan penilaian genetik pertama terhadap populasi *A. kuhlii* dalam penangkaran dengan menggunakan 13 penanda mikrosatelit. Sampel mencakup individu yang berasal dari Bawean, beberapa kebun binatang di Indonesia, serta satu kebun binatang di Eropa. Penelitian ini bertujuan untuk menilai keragaman genetik dan menguji kemungkinan terjadinya hibridisasi dengan *Rusa unicolor* dan *Rusa timorensis*, mengingat ketiga spesies tersebut sering dipelihara bersama dalam fasilitas penangkaran di Jawa. Analisis STRUCTURE tidak menunjukkan adanya bukti hibridisasi dan mengidentifikasi tiga kelompok genetik dalam *A. kuhlii*, yang kemungkinan mencerminkan pengaruh hanyutan genetik dan hubungan kekerabatan. Keragaman genetik tergolong rendah pada seluruh sampel *A. kuhlii*, namun sedikit lebih tinggi pada populasi Bawean. Beberapa alel yang ditemukan pada populasi kebun binatang di Jawa tidak ditemukan pada populasi Bawean. Hasil ini menunjukkan bahwa meskipun perkawinan sedarah dapat menjadi perhatian, translokasi yang dikelola dengan baik antara populasi penangkaran dan populasi liar berpotensi meningkatkan keragaman genetik tanpa menimbulkan risiko hibridisasi. Integrasi terarah individu dari populasi ex-situ serta pemasukan rusa jantan yang berasal dari populasi liar ke dalam program pengembangbiakan di Bawean direkomendasikan untuk mendukung upaya penyelamatan genetik (genetic rescue) dan keberlanjutan populasi dalam jangka panjang.

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INTRODUCTION

The Bawean Deer is endemic to the small and isolated Indonesian island of Bawean (190 km^2; Image 1) and is listed as 'Critically Endangered' on the IUCN Red List (Semiadi et al. 2015). It is protected under Indonesian law and listed in Appendix I of CITES. Recent camera trap surveys show fewer than 250 mature animals (Ariyanto et al. 2025a). The species is already absent from the eastern part of the island. The threats are traditional hunting with dogs and nets, snares, predation by free roaming dog and poaching (Semiadi et al. 2016; Rahman et al. 2023; Ariyanto et al. 2025b).

Only four to five deer ever left the island and were brought to Surabaya Zoo, Indonesia, in the 1940s. These animals were the founders of all ex-situ populations. Since then, there has been no population management plan. Like most cervids, *A. kuhlii* reproduces well in captivity. Today there are several ex situ populations on Java (e.g., Surabaya Zoo; Maharani Zoo; Taman Safari Bogor/Prigen) and three populations (Zoo Poznan - Poland; Tierpark Berlin - Germany; Edinburgh Zoo - UK) in Europe. In zoos and safari parks on Java, different species of cervids are occasionally kept together, which harbours the risk of hybridisation. An unmanaged captive breeding program has been running on Bawean island since 2010.

Microsatellite loci were used to conduct an initial assessment of genetic diversity in captive *A. kuhlii* populations and to evaluate their suitability for release on Bawean. Specifically, the study aimed to test for evidence of hybridization between *A. kuhlii* and *R. unicolor* and/or *R. timorensis*, particularly in the captive bred *A. kuhlii* from Java. We also aimed to get a first idea of the genetic diversity of the captive *A. kuhlii* populations.

MATERIALS AND METHODS

Ear tissue samples of *A. kuhlii* (n = 15) were collected from the captive population on Bawean. Samples were included from Borgor and Prigen Taman Safari (n = 3), Grati Zoo (n = 4), and Surabaya Zoo (n = 9). Blood samples from two animals from Berlin Zoo, Germany, were included. We also obtained samples of *R. unicolor* (n = 8) from East Kalimantan and *Rusa timorensis* (n = 6) from Sulawesi and Lombok, from museum voucher collections that had been collected between 2004 and 2008 and stored in LIPI (Indonesian Institute of Sciences), which know changes to BRIN (National Research and Innovation Agency).

DNA was extracted using the DNeasy Blood and Tissue Kit (Qiagen), following the manufacturer's instructions and samples were genotyped with 13 microsatellite loci in total. The methods outlined in Frantz et al. (2024) were followed to genotype 11 microsatellites (CSSM14, ETH225, T501, BM1818, CSSM16, OarFCB304, OarFCB5, T156; IDVGA55; TGLA57; TGLA226). Two further microsatellite loci, Ca13 (Gaur et al. 2003) and T26 (Jones et al. 2002) were amplified in PCRs that each contained 1 × GoTaq Master Mix (Promega; Walldorf; Germany) and 0.2 µM of each primer. PCR conditions were as follows: after a 5 min denaturation at 95 °C, the PCR consisted of 35 cycles of denaturation at 95 °C for 30 s, annealing at 56 °C (T26) or 58 °C (Ca13) for 45 s and an extension at 72 °C for 45 s. The PCR was ended with a final extension for 10 min at 68 °C. PCRs were performed using a Mastercycler Nexus cycler (Eppendorf), and products were separated on an ABI 3730XL DNA sequencer (Applied Biosystems).

The *A. kuhlii* samples from Bawean, Java and Tierpark Berlin, Germany, were each a priori defined as a population for deviations from Hardy–Weinberg equilibrium (HWE) using the Markov-Chain method (MCM) in GENEPOP3.4 (Raymond & Rousset 1995), with 1,000 dememorization steps, 500 batches and 1,000 iterations. GENEPOP was also used to test for linkage disequilibria among loci using an exact test based on the MCM. The false discovery rate technique was used to eliminate false assignment of significance by chance (Verhoeven et al. 2005).

Structure 2.3.4 (Pritchard et al. 2000) was used to test *A. kuhlii* for hybridisation with *R. unicolor* and *R. timorensis* as well as to test the intraspecific genetic structure between captive populations. Ten independent runs for K = 1 to K = 5 were carried out with 10^6 Markov-Chain-Monte-Carlo (MCMC) iterations after a burn-in period of 10^5 iterations, using the model with correlated allele frequencies and assuming admixture. A separate alpha was used to represent the degree of admixture between each population and a uniform prior was applied to the parameter. Individual assignments were based on the run with the highest log-likelihood for the given value of K.

Although the genetic analysis indicated the presence of three distinct genetic populations among the *A. kuhlii* samples (see Results), two priori defined populations were considered from Bawean and Java (all ex-situ populations) for the analysis of genetic diversity. The animals from Tierpark Berlin were included in the latter group, which we refer to simply as the 'Java' population for clarity. This approach was adopted because of the small number of samples obtained per enclosure or zoo and given that the clustering observed within *A. kuhlii* was probably due, at least in part, to the presence of related

Image 1. Bawean island in the Java Sea.

individuals in enclosures (see Discussion). The samples from *R. unicolor* and *R. timorensis* were also treated as distinct clusters. We estimated average number of alleles/locus (N_A), observed (H_O) and unbiased expected (H_E) heterozygosity of the four pre-defined populations using GENETIX4.05.2 (Belkhir et al. 2004). Allelic richness (A_r) was calculated using Fstat 2.9.3.2 (Goudet 1995).

RESULTS

Four loci (Ca13; T501; CSSM16; T156) were monomorphic in *A. kuhlii* (but not in *R. unicolor* or *R. timorensis*). After correction for multiple tests, three loci (CSSM14; ETH225; IDVGA55) deviated from the HWE ($P < 0.017$) in the *A. kuhlii* sampled in the enclosure on Bawean, and loci CSSM14 and ETH225 were in linkage disequilibrium ($P < 0.014$). After multiple-test correction, no locus deviated from HWE and no loci were in linkage disequilibrium in the deer sampled from captive populations outside of Bawean. All 13 loci were therefore retained for further analysis.

Structure identified the presence of at least three genetic clusters K = 3 in the dataset (Image 2). Eight of the ten log-likelihood values obtained for K = 3 converged well and all values at K = 3 were higher than the log-likelihood values obtained at K = 2. At K = 3, the algorithm split *A. kuhlii* into two populations (with the second population being formed by individuals from Bawean), but pooled all *R. unicolor* or *R. timorensis* into a single separate population. At K = 4, some log-likelihood values were higher than the values observed for K = 3, but the log-likelihood values of the different K = 4 runs did not converge well. The assignment values of the K = 4 run with the highest log-likelihood split *A. kuhlii* into three clusters — with the new, fourth cluster mainly consisting of animals from Surabaya zoo — while still grouping all *R. unicolor* and *R. timorensis* into a single cluster. No evidence of admixture was found between *A. kuhlii* and *R. unicolor*/*R. timorensis* at any K between K = 2 to K = 4.

All *A. kuhlii* genetic diversity statistics were low, but higher in the deer from Bawean than in those from the Java population (Table 1). However, the estimate of allelic richness was based on two diploid individuals only and the other estimates were not significant different (Wilcoxon signed rank; number of alleles: V=6.0; p=0.317; H_o: V = 30.0; p = 0.407; H_e: V = 25.0; p = 0.362). With two exceptions, all alleles observed in the Java population were also present on Bawean. One allele at locus BM1818 was found in all five ex-situ populations that make up the Javan population but was not observed on Bawean. Another allele at the same locus was detected

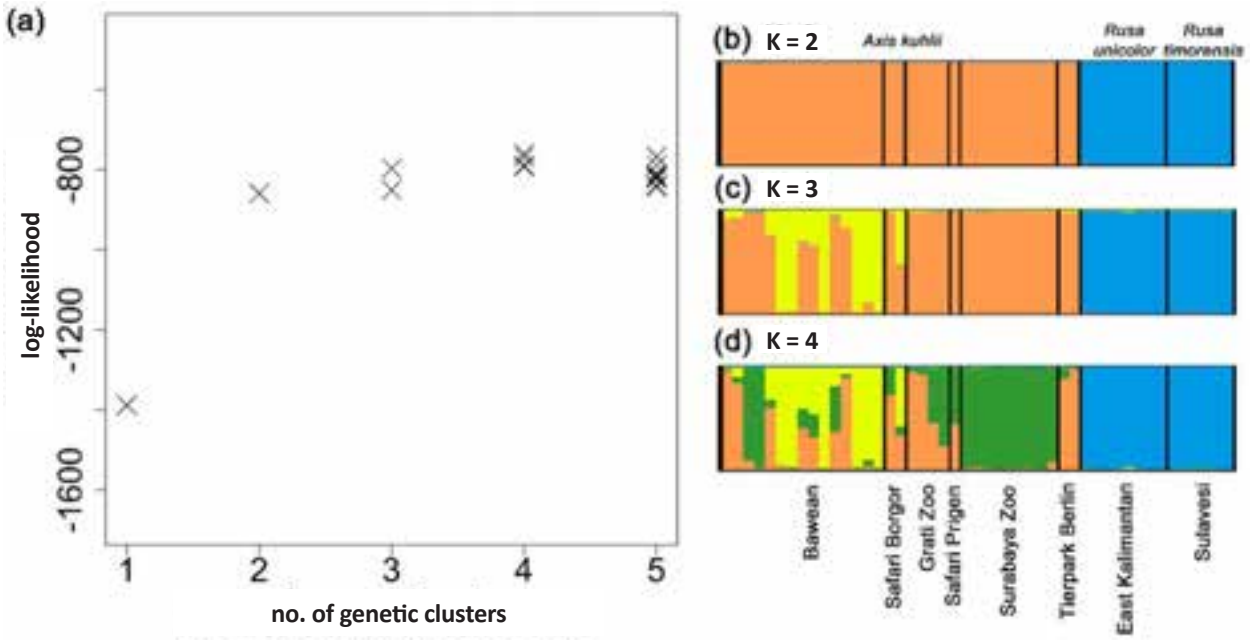

Image 2. Structure plot and log likelihood.

Table 1. Summary of the genetic diversity observed at 13 microsatellite loci in Indonesian cervids. Estimates of allelic richness (A_r) are based on two diploid individuals.

Species/population	n	A	A_r	uH_e	H_o
A. kuhlii wild Bawean	15	2.23	1.59	0.29	0.21
A. kuhlii ex situ Java	18	2.00	1.39	0.20	0.14
R. unicolor	8	4.23	2.55	0.68	0.65
R. timorensis	6	2.92	2.13	0.54	0.41

in a single individual from Grati captive breeding facility only. All diversity statistics were higher in *R. unicolor* and *R. timorensis* than in the two *A. kuhlii* populations (Table 1) and a Kruskal-Wallis test revealed a significant difference between the four groups (χ^2 = 23.49; d.f. = 3; $p < 0.001$).

DISCUSSION

Small island populations are particularly vulnerable to inbreeding depression because of low genetic diversity (Frankham 1998). Apart from increasing the number of individuals, translocation can facilitate genetic rescue, whereby increased heterozygosity and reduced inbreeding improve population fitness (Bell et al. 2019). The low genetic diversity observed in *A. kuhlii* therefore suggests that carefully managed genetic rescue could be beneficial. While genetic rescue has its benefits, it can also have long-term negative effects if the source population is larger than the population to be rescued, as it can introduce recessive deleterious mutations (Hedrick et al. 2019). In addition, a recent study has shown that translocation can lead to counterproductive outcomes when dealing with historically small populations that have had time to eliminate highly deleterious mutations (Kyriazis et al. 2021).

Captive breeding conditions pose a risk of hybridisation with other cervids for ex situ *A. kuhlii* populations on Java. No evidence of hybridisation was found between the Bawean Deer and *R. unicolor* or *R. timorensis*. Nevertheless, due to hybridisation within captive populations, *R. timorensis* and *R. unicolor* formed a single cluster in our STRUCTURE analysis. The three clusters confirmed by STRUCTURE for *A. kuhlii* are probably the result of related individuals and/or genetic drift. In general, genetic diversity (A_r) appears to be very low in *A. kuhlii*. The results suggest that some genetic diversity (i.e. alleles) is present in captive populations on Java that is absent from Bawean. As it was impossible to catch deer born in the wild on Bawean, and as faeces were not useful for sampling due to the tropical conditions, DNA could only be collected from captive-born deer on Bawean. Consequently, the ex situ population on Bawean may not fully represent the island's entire genetic diversity.

There are currently plans to improve and expand the captive breeding programme at Mombul/Bawean, led by the Prigen Conservation Initiative, Malang, Indonesia. As

the in situ population is already restricted to the western part of Bawean, and there is only one record of a female in the north-eastern part of the island (Ariyanto et al. 2025a)— most probably the offspring of a deer released from a captive population — it is recommend to release more deer from the captive breeding programmes (Bawean and Java) in the eastern part of the island. To increase the genetic diversity of the captive breeding program on Bawean, it is recommended to catch one or two stags from the wild population.

The reproduction rate in the wild *A. kuhlii* population is low, with only 17 fawns per 100 does (Ariyanto et al. 2025a). This could be a sign of inbreeding depression due to genetic isolation and a small population size of less than mature 250 individuals. Therefore, it can be concluded that translocation of selected individuals between ex situ populations, as well as between wild and ex situ populations, could be a reliable conservation measure to restore genetic diversity, despite the risk of outbreeding. In the long term, captive breeding programmes only make sense if they are managed to increase genetic diversity and exclude deleterious alleles, and if the offspring are successfully released into the wild.

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COMMUNICATION

First record of interspecific allopreening among *Gyps* vultures in the Aravalli Range, India

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Abstract: We report an observation of interspecific allopreening behaviour among the Indian Vulture *Gyps indicus*, Himalayan Griffon *Gyps himalayensis*, and Eurasian Griffon *Gyps fulvus* in the village of Kailashpuri in the Udaipur District of Rajasthan. A total of 623 seconds of interspecific allopreening behaviour was recorded. In the first instance, a *G. indicus* preened the neck of a *G. himalayensis* for 296 seconds; in another instance, a *G. fulvus* preened the neck of a *G. indicus* for 162 seconds; and further, a *G. fulvus* preened the neck and shoulder of a *G. himalayensis* for 165 seconds. All three species also engaged in self-preening activity during the observation period; *G. indicus* spent the maximum time (376 seconds), followed by *G. fulvus* (300 seconds), and *G. himalayensis* spent the minimum time in self-preening (257 seconds). This is the first documented record of interspecific allopreening behaviour among these vulture species in India. This observation contributes to interspecific interactions that are important for understanding the complex social structures between *G. indicus* and *G. himalayensis* and *G. fulvus* in their natural habitat. Interspecific allopreening is a complex ecological behaviour that contributes to individual health by managing parasites and fostering social tolerance, thereby reducing competition and aggression within the community. Although the functional significance of the behaviour could not be determined from this single observation, interspecific allopreening may have hygienic and social functions similar to those across species boundaries in wild birds.

Keywords: Aggression, behaviour, competition, *Gyps fulvus*, *Gyps himalayensis*, *Gyps indicus*, interaction, natural habitat, self-preening, social structure.

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Author contribution: NLC—observation and data collection, manuscript editing. HG and AKS—manuscript writting and proof reading.

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INTRODUCTION

Preening and scratching are collectively known as grooming behaviours (Carter & Leffer 2015). Grooming and preening behaviours have been recorded in several social animals, including birds and mammals (Baker & Aureli 2000; Lewis et al. 2007; Gill 2012; Carter & Leffer 2015). Among birds, allopreening is defined as the act of one individual preening the neck, shoulders, and feathers of another individual of the same species, in which one individual preens the feathers of another individual, potentially providing hygienic benefits through the removal of ectoparasites and debris, as well as social benefits (Cullen 1963; Brooke 1985; Villa et al. 2016). Additionally, it helps maintain pair bonds between mating partners, mitigates aggression between conspecifics, and facilitates cooperation during parental care (Radford & Du Plessis 2006; Lewis et al. 2007; Takahashi et al. 2017; Gillies et al. 2021). Intraspecific allopreening behaviour has been observed in several animal species, including numerous birds under natural conditions (Barbour & DeGange 1982; Radford & Du Plessis 2006; Choudhary & Chishty 2020, 2021), while interspecific allopreening (allopreening between two different species) is rarely observed in animals, including birds (Mo 2016; Cortes 2017; Zhou & Zhang 2022). These studies document interspecific allopreening behaviour in non-captive environments such as that of the Black Vulture *Coragyps atratus* and Crested Caracara *Caracara plancus* (Ng & Jasperson 1984; Palmeira 2008; Souto et al. 2009; Sanabria 2015), Razorbill *Alca torda* and Common Murres *Uria aalge* (Walsh et al. 2001), Royal Spoonbill *Platalea regia* and Australian White Ibis *Threskiornis molucca* (Mo 2016), Mitred *Psittacara mitratus* and Monk Parakeet *Myiopsitta monachus* (Cortes 2017), and Spot-necked Babbler *Stachyris strialata* and Nonggang Babbler *Stachyris nonggangensis* (Zhou & Zhang 2022).

Prevailing hypotheses regarding the function of allopreening behaviour emphasise its role in parasite removal (Freeland 1976) and its significance in facilitating intra-social interactions (Call et al. 2002; Radford & Du Plessis 2006). According to Souto et al. (2009), the interspecific allopreening observed between Black Vulture and Crested Caracara likely reflects a multifaceted social and ecological interaction. The increased vigilance afforded by mixed-species flocks, the complementary vocal abilities of caracaras that compensate for vultures' morphological limitations, and the opportunistic benefits caracaras gain in locating food all contribute to reinforcing their association.

The underlying mechanism of interspecific allopreening in these species is probably distinct, as they actively pursue preening from other species by engaging in chasing, followed by displays inviting allopreening (Selander & La Rue Jr 1961). In this study, we observed the first interspecific allopreening behaviour among three species of vultures in non-captive environments: Indian Vulture *Gyps indicus*, Himalayan Griffon *Gyps himalayensis*, and Eurasian Griffon *Gyps fulvus*.

Study area

Kailashpuri Village is located at 24.45° N, 73.43° E in the southern Aravalli ranges in Udaipur District of Rajasthan. The site supports several resident and migratory vulture species and serves as an important roosting area. The rock cliff area of the study site is a permanent nesting colony for vultures (Image 3). There are approximately 10 *G. indicus* nests and two Egyptian Vulture *Neophron percnopterus* nests in this region. The vulture nesting colony was approximately 350 m wide. The average elevation of *G. indicus* nests ranged 670–680 m. A cow shelter located near the vulture study site occasionally provides a potential food resource in the form of livestock carcasses. Additionally, the presence of two large water bodies, Indra Sarovar Talab and Bagela Lake, fulfils the demand for water throughout the year. The presence of green patches, rocky cliffs, agricultural landscapes, and these water bodies supports a variety of birds and mammals. Tropical dry deciduous forest occurs in the study area with dominant plant species such as Palash *Butea monosperma*, *Euphorbia* spp., Peepal *Ficus religiosa*, Neem *Azadirachta indica*, Gonda *Cordia dichotoma*, Jamun *Syzygium cumini*, Desi Babool *Vachellia nilotica*, Banyan *Ficus benghalensis*, Mahua *Madhuca indica*, Emli *Tamarindus indica*, and Danda-thor *Euphorbia caducifolious*. Apart from this, mammalian species including Leopard *Panthera pardus*, Jungle Cat *Felis chaus*, Indian Jackal *Canis aureus*, Striped Hyena *Hyaena hyaena*, Hanuman Langur *Semnopithecus entellus*, and Rhesus Macaque *Macaca mulatta* occur.

MATERIAL AND METHODS

Study site selection was based on earlier experience and secondary data gathered from the Forest Department of Rajasthan regarding the presence of vultures in the region. Vultures were observed using Nikon 8 × 42 binoculars. Photographs and video clips of vulture behaviour were recorded using a long-distance zoom camera (Nikon P1000 with 125x zoom). Observations were conducted on a single day (28 January

2025) at 0800–1200 h and 1600–1800 h, and a total of six hours of observation were conducted. Behavioural observations were conducted using the focal sampling method, with particular attention to individuals involved in interspecific allopreening. Interspecific allopreening was defined as the directed manipulation of the feathers of one individual by another individual belonging to a different species. Vulture species were identified using a field manual and identification guide, as prescribed by Ali & Ripley (1987), Kazmierczak (2006), Grimmett et al. (2011), and Vyas (2013).

RESULTS

During the six-hour observation period on a single day, intraspecific and interspecific allopreening behaviour was recorded. *G. indicus* is a resident breeding species of the Aravalli ranges, whereas *G. himalayensis* and *G. fulvus* are winter migrants in this region. During the field survey on 28 January 2025, we found 21 vultures in the village of Kailashpuri. Of these, 12 individuals were *G. indicus*, five were *G. himalayensis*, and the remaining four were *G. fulvus*. The recorded interspecific allopreening behaviour was exhibited by one individual of each of the three species in the study. They were sitting very close to each other and displaying self-preening and interspecific allopreening behaviour. Multiple episodes of self-preening and interspecific allopreening were noted between three vulture species during a six-hour observation period (Tables 1 & 2).

During the six-hour observation period, interspecific allopreening was recorded for a total of 623 s. *G. indicus* preened the neck of *G. himalayensis* for 296 s, *G. fulvus* preened the neck of *G. indicus* for 162 s, and *G. fulvus* preened the neck and shoulder of *G. himalayensis* for 165 s (Table 1; Image 1).

In addition to self-preening and interspecific allopreening behaviour, the three vulture species, namely Indian, Himalayan and Eurasian Griffon, showed various behavioural activities. These activities encompassed walking, resting, wing and neck stretching, flying, soaring, and interspecific territorial fights (Table 2; Images 2 & 6). Tables 1 & 2 provide a comprehensive account of these behavioural episodes, illustrating the complexity and diversity of vulture activity patterns. A review of the literature revealed no previous record of interspecific allopreening behaviour by *G. indicus*, *G. himalayensis*, and *G. fulvus* in this region. To the best of our knowledge, this represents the first documented observation of interspecific allopreening among three vulture species in the Aravalli region of Rajasthan, India, as we found no previously published record.

DISCUSSION

Allopreening is associated with a "preening invitation" or "head-down" display (David & Jasperson 1984). Interspecific allopreening behaviour is more complex when it occurs between different animal species and is rarely observed in wild or non-captive environments. Interspecific allopreening has been documented in Black Vultures and Crested Caracaras (David & Jasperson 1984). Black Vultures showed allopreening behaviour, in which one vulture nibbled the feathers of the lower neck of the other individual, and the latter that individual responded by nibbling the neck feathers of the first (Haverschmidt 1977). Intraspecific allopreening has also been reported for vultures in wild environments (Haverschmidt 1977), similar to the "head-down" display described by Selander & La Rue (1961). During this one-day observation, it was observed that *G. indicus* preened the neck of the *G. himalayensis*, whereas *G. fulvus* preened the shoulder of the *G. himalayensis*, and *G. fulvus* preened the neck of the *G. indicus.* Vultures may spend considerable time sunbathing or wing-spreading in extended postures, as a thermoregulatory behaviour (Manigandan et al. 2021). Self-preening is an important component of plumage maintenance and may contribute to the removal of ectoparasites, debris, and other materials from their feathers. Thermoregulatory or sunbathing time varies according to the climatic conditions or seasons in a particular area. For instance, *G. indicus* spends more time on thermoregulation during the winter months than during the summer months (Chishty & Choudhary 2020). In this manner, intra- and interspecific allopreening behaviour is a complex social interaction that goes beyond mere grooming and may contribute to social tolerance and maintenance of affiliative interactions among individuals. Through allopreening, individuals not only enhance hygiene by removing ectoparasites and debris but also strengthen social bonds that are essential for group stability. This observation was based on a single day of field observation and therefore does not allow inference about the frequency, seasonality, or generality of interspecific allopreening among these species. Repeated observations across seasons and sites would be necessary to determine whether the behaviour represents a regular component of interspecific social interactions or an occasional association.

Table 1. Duration of interspecific allopreening behaviour among three species of vulture: Indian Vulture (IV), Eurasian Griffon (EG), and Himalayan Griffon (HG), during six hours.

Study hours (in h)	Time duration (in h)	Species interaction	Direction/ interaction	Time duration of interspecific allopreening (in s)
0800–0900	0811–0820	EG-HG	EG→HG	40
0901–1000	0900–0910	IV-HG	IV→HG	38
	0921–0930	IV-HG	IV→HG	42
	0931–0940	IV-HG	IV→HG	10
	0941–0950	IV-HG	IV→HG	27
		EG-HG	EG→HG	44
1000–1100	1000–1010	EG-HG	EG→HG	40
	1031–1040	IV-HG	IV→HG	40
	1041–1050	IV-HG	IV→HG	68
		EG-IV	EG→IV	58
	1051–1100	EG-IV	EG→IV	40
1100–1200	1100–1110	EG-HG	EG→HG	25
	1111–1120	IV-HG	IV→HG	40
	1121–1130	EG-HG	EG→HG	16
	1131–1140	IV-HG	IV→HG	31
	1141–1150	EG-IV	EG→IV	29
	1151–1200	EG-IV	EG→IV	35
1600–1700	1600–1700	Interspecific allopreening behaviour was not performed during this duration.		
1700–1800	1700-1800	Interspecific allopreening behaviour was not performed during this duration.		
Total observation time	06 h	Three types of interspecific interaction were observed: EG-HG; IV-HG; EG-IV.	Direction of interspecific allopreening: EG→HG; IV→HG; EG→IV.	Total time duration of interspecific allopreening: 623 s (EG→HG =165 s; IV→HG = 296 s; EG→IV = 162 s).

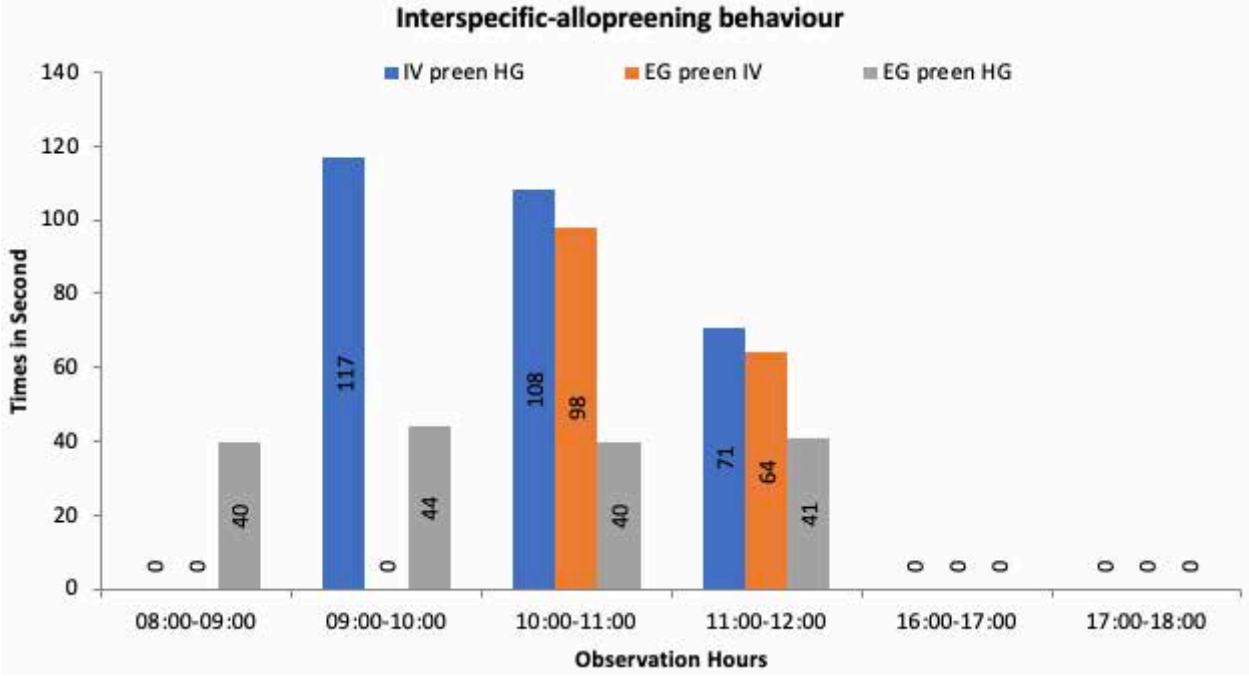

Image 1. Time duration of interspecific allopreening behaviour performed by three species of vultures (in seconds): HG—Himalayan Griffon | IV—Indian Vulture | EG—Eurasian Griffon.

Table 2. Ethogram of three species of vultures: IV—Indian Vulture | EG—Eurasian Griffon | HG—Himalayan Griffon during the observation period. Activity: +—activity was performed | -—activity was not performed.

Time duration (in h)	Behaviour	Species of vulture			Time spent in Interspecific allopreening behaviour in a particular hours.
		IV	EG	HG	
0800–0900	Self-preening	+ (153 s)	+ (79 s)	+ (105 s)	EG preens neck of HG (40 s)
	Body movement	+	+	+	
0900–1000	Self-preening	+ (60 s)	+ (104 s)	+ (46 s)	IV preens neck and body of HG (117 s); EG preens neck of HG (44 s)
	Thermoregulation	-	+	+	
1000–1100	Self-preening	+ (97 s)	+ (43 s)	+ (38 s)	IV preens neck of HG (108 s); EG preens neck of IV (98 s); EG preens neck of HG (40 s)
	Walking on rock	-	+	+	
1100–1200	Self-preening	+ (49 s)	+ (36 s)	+ (49 s)	IV preens neck of HG (71 s); EG preens neck of IV (64 s); EG preens neck of HG (41 s)
	Wing stretching and thermoregulation	+	-	+	
	Walking on rock	-	+	-	
1600–1700	Self-preening		+ (38 s)	+ (19 s)	
	Resting	+	+	+	
	Wing stretching and thermoregulation	+	+	+	
	Flying / soaring	+	-	+	
1700–1800	Self-preening	+ (17 s)	-	-	-
	Walking on rock	+	-	-	
	Flying / soaring	-	+	+	
	Resting	+	+	+	

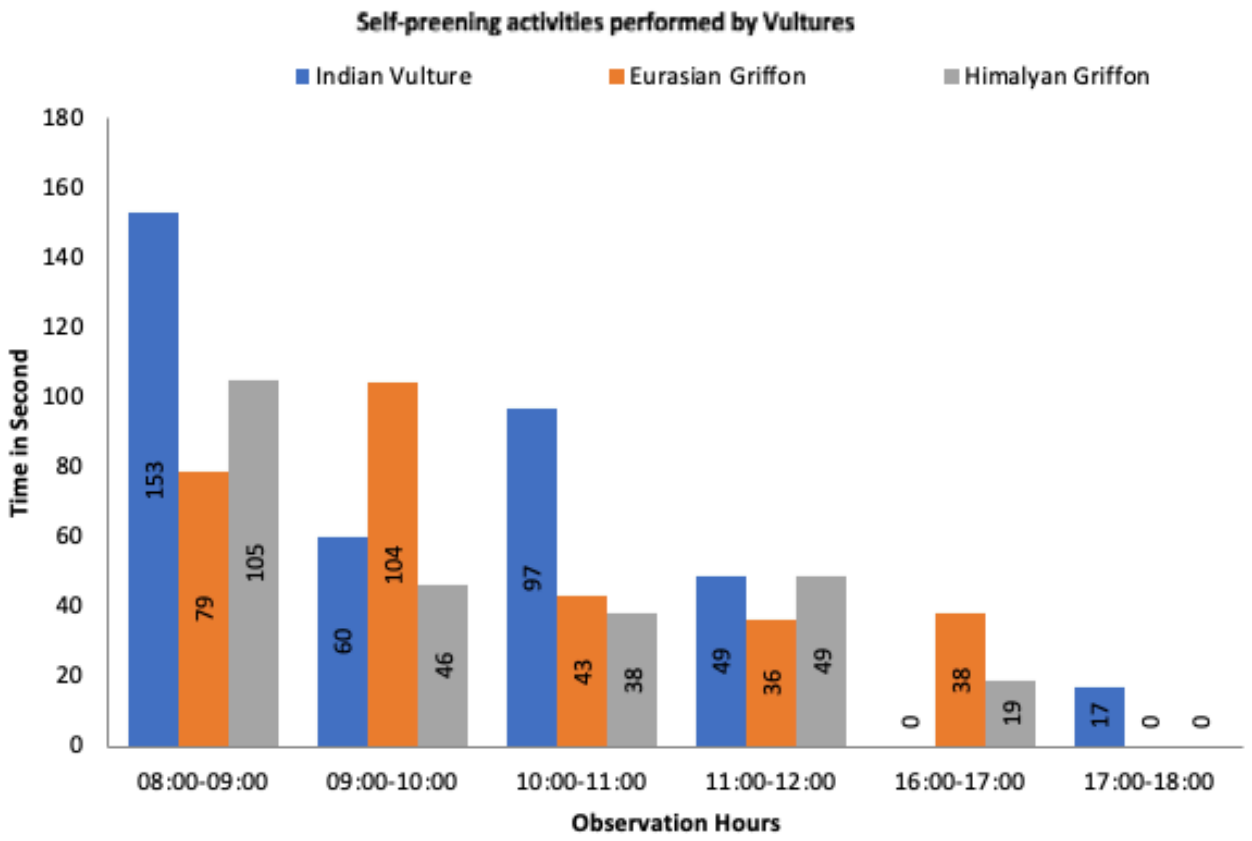

Image 2. Duration of self-preening behaviour performed by three species of vultures (in seconds), based on six hours of observation on 28.i.2025.

Image 3. A—Study site | B—Eurasian Griffon, Himalayan Griffon, and Indian Vulture at the roosting site. © Narayan Lal Choudhary.

Image 4. A—Interspecific allopreening: Indian Vulture preens the neck of the Himalayan Griffon | B & C—Interspecific allopreening: Eurasian Griffon preens the shoulder of the Himalayan Griffon | D—Interspecific allopreening: Eurasian Griffon preens the neck of the Indian Vulture. © Narayan Lal Choudhary.

Image 5. Self-preening behaviour: A—Self-preening behaviour performed by Eurasian Griffon and Indian Vulture | B—Self-preening behaviour performed by Eurasian Griffon | C—Self-preening behaviour performed by all three species of vultures | D—Eurasian Griffon and Himalayan Griffon in resting position. © Narayan Lal Choudhary.

Image 6. Different behavioural activities performed by three vulture species at the study site during the study period: A—Thermoregulation by Indian Vulture | B—Resting behaviour performed by Eurasian Griffon and Indian Vulture | C—Roosting behaviour performed by Eurasian Griffon | D—Resting behaviour performed by Eurasian Griffon and Himalayan Griffon after the interspecific allopreening | E—Wing stretching and self-preening behaviour performed by Indian Vulture | F—Sitting behaviour performed by Indian Vulture. © Narayan Lal Choudhary.

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COMMUNICATION

DNA Barcode based species delineation within Freshwater Garfish *Xenentodon cancila* (Hamilton, 1822) (Beloniformes: Belonidae) reveals the existence of multiple lineages under single nominal taxon

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Abstract: The present correspondence provides the first DNA barcode-based evidence of multiple evolutionary lineages within the freshwater garfish *Xenentodon cancila* across South Asia. Taxonomically validated specimens from the Ujani Reservoir, Maharashtra, India, were analyzed with 77 publicly available mt COI sequences. Phylogenetic and species delimitation analyses revealed seven distinct clades within *Xenentodon*, substantially exceeding the currently recognized two species. The Ujani population formed a strongly supported monophyletic cluster with sequences from India, Bangladesh, and Korea, corresponding closely to the nominal *X. cancila*. Other geographically structured lineages from southern, northeastern, and central India, exhibit deep genetic divergence, indicating potential undescribed taxa. These findings highlight persistent taxonomic gaps within *Xenentodon* and emphasize the need for integrative revision combining molecular and morphological datasets.

Keywords: Cryptic diversity, freshwater biodiversity, garfish, integrative taxonomy, morphological datasets, phylogeny, polyphyletic, Ujani Reservoir.

सदर संशोधन हे दक्षिण आशियातील गोड्या पाण्यातील कुत्रा किंवा टोकली मासा म्हणून ओळखल्या जाणाऱ्या माशामध्ये असलेल्या अनेक उत्क्रांतीवादी वंशांचा पहिला डीएनए बारकोड-आधारित पुरावा सादर करते. महाराष्ट्रातील उजनी जलाशयातून गोळा केलेल्या आणि वर्गीकरणदृष्ट्या प्रमाणित केलेल्या नमुन्यांचे, सार्वजनिकरित्या उपलब्ध असलेल्या ७७ मायटोकॉन्ड्रियल COI जनुकिय क्रमांसोबत विश्लेषण करण्यात आले. वंशवृक्षीय आणि प्रजाती सीमांकन विश्लेषणातून या माशामध्ये मध्ये सात स्वतंत्र वंशसमूह आढळून आले, जे सध्या दोन मान्यताप्राप्त प्रजातींमध्ये विभागले गेले आहेत. उजनी जलाशयातील प्रजाती ही भारत, बांगलादेश आणि कोरिया येथील प्रजातीशी एक वंशीय समूह तयार करते, जी मुळ प्रजातीशी संबंधित आहे. दक्षिण, ईशान्य आणि मध्य भारतातील इतर भौगोलिकदृष्ट्या संरचित अंश गटामध्ये खोल अनुवंशिक भिन्नता दिसून येते, जे संभाव्य नव्या अज्ञात प्रजाती असल्याचे संकेत देते. कुत्रा/टोकली माशांच्या प्रजातीमधील हे संशोधन वर्गीकरणविषयक उणिवांवर प्रकाश टाकते आणि जातिवृत्तविज्ञान तसेच आकारशास्त्रीय माहितीसंच एकत्रित करून सर्वसमावेशक पुनरावलोकनाची गरज अधोरेखित करते.

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Author contributions: RM and JS designed the experiment. RM conducted the practical work. AS and KPD collected and analyzed the molecular data. RM, AS, and KPD contributed to manuscript writing. All authors have read and approved the final manuscript.

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INTRODUCTION

DNA barcoding is a widely used molecular tool, enabling rapid species identification and discovery of cryptic diversity in fishes (Hajibabaei et al. 2007; Stein et al. 2014; Rahman et al. 2019). Although extensive DNA barcode datasets are available through global repositories such as BOLD (Ratnasingham & Hebert 2007) and GenBank, significant geographic gaps persist across Asia, resulting in taxonomic uncertainties in many Indian fish species.

The family Belonidae (order Beloniformes) comprises 47 species in 10 genera (Fricke et al. 2018). Among them, the southern and southeastern Asia endemic genus *Xenentodon* includes two recognized species, *Xenentodon cancila* (Hamilton, 1822) and *X. canciloides* (Bleeker, 1854). *X. cancila*, originally described from the Ganga River, India, is widely distributed in India, Bangladesh, Cambodia, Malaysia, Nepal, Sri Lanka, Bhutan, Laos, Myanmar, Pakistan, Vietnam, Hawaii, Hong Kong, Indonesia, and Thailand (Hossain et al. 2013), while *X. canciloides* is restricted to Cambodia, Indonesia, Laos, Thailand, and Vietnam (Froese and Pauly 2026).

The freshwater garfish *X. cancila* is an economically important fish in southern Asia and is widely traded in regional fisheries (Islam & Dutta 2018). Despite its broad distribution range and commercial significance, molecular studies have been limited and geographically fragmented (Thapliyal et al. 2013; Khedkar et al. 2014; Patil et al. 2018), resulting in its poorly resolved genetic identity. Against this backdrop, the present study examines the genetic identity of morphologically verified *X. cancila* specimens from Ujani Reservoir, Maharashtra, India, using mitochondrial Cytochrome C Oxidase subunit 1 (mt COI) barcodes to assess species monophyly of *X. cancila* through single-gene-based phylogenetic analysis. The phylogenetic pattern recovered are discussed and ascertained through ASAP species-delimitation analysis to delineate the potential existence of cryptic species within *Xenentodon*.

MATERIALS AND METHODS

Specimens were collected and studied from the Ujani Reservoir, Maharashtra, India, during 2018–2021. The Identity of the specimens as *Xenentodon cancila* was confirmed by a taxonomic expert at the Zoological Survey of India. The studied specimens were deposited in the Zoology Museum, Modern College, Pune, and the Arts, Science and Commerce College, Indapur (ICASC/ZOO/105–106/2021–22). Fresh specimens were photographed (Image 1) before DNA-barcoding studies.

Genomic DNA was extracted from white muscle or fin clips using the DNeasy Blood & Tissue Kit (Qiagen), following the manufacturer's protocol. DNA quality was assessed using a Qubit 2.0 fluorometer, and samples above 50 ng were amplified with universal mitochondrial Cytochrome C Oxidase subunit 1 (mt COI) primers. PCR was performed in a 25 µL reaction volume under the following thermal-cycling conditions: 95 ^{o}C for three min; 35 cycles of 95 ^{o}C for 30 s, 50 ^{o}C for 30 s, 72 ^{o}C for 45 s; final extension at 72 ^{o}C for three min (Patil et al. 2018). Amplified ~700 bp COI fragments were bidirectionally sequenced at Barcode Biosciences, Bengaluru, India.

Raw sequence files were manually checked for quality to be used for further analysis. Additionally, 77 sequences of Belonidae were downloaded from GenBank, cleaned, and aligned in MEGA X (Kumar et al. 2018). Maximum--Likelihood (ML) analysis was performed with 83 sequences (Table 1) in the IQ-TREE v1.6.12 web server (Trifinopoulos et al. 2016), with 1,000 ultrafast

Image 1. Lateral view of *Xenentodon cancila* from Ujani River, Maharashtra, India. © Ranjit More.

bootstraps under the GTR+F+I+G4 model selected by Bayesian information criterion (BIC). The obtained tree was visualized in FigTree v1.4. The same dataset was subjected to species-delimitation analysis using the Assemble Species by Automatic Partitioning (ASAP) method (Puillandre et al. 2021). Sequences from this study were submitted to GenBank under accessions OM865416–OM865419.

RESULTS AND DISCUSSION

The mt COI phylogenetic analysis of Belonidae revealed multiple lineages within *Xenentodon*, although with low bootstrap support indicating polyphyly of the genus (Image 2). However, *X. cancila* sequence from the Ujani Reservoir formed monophyletic clade with sequences from India, Bangladesh, and Korea. Overall,

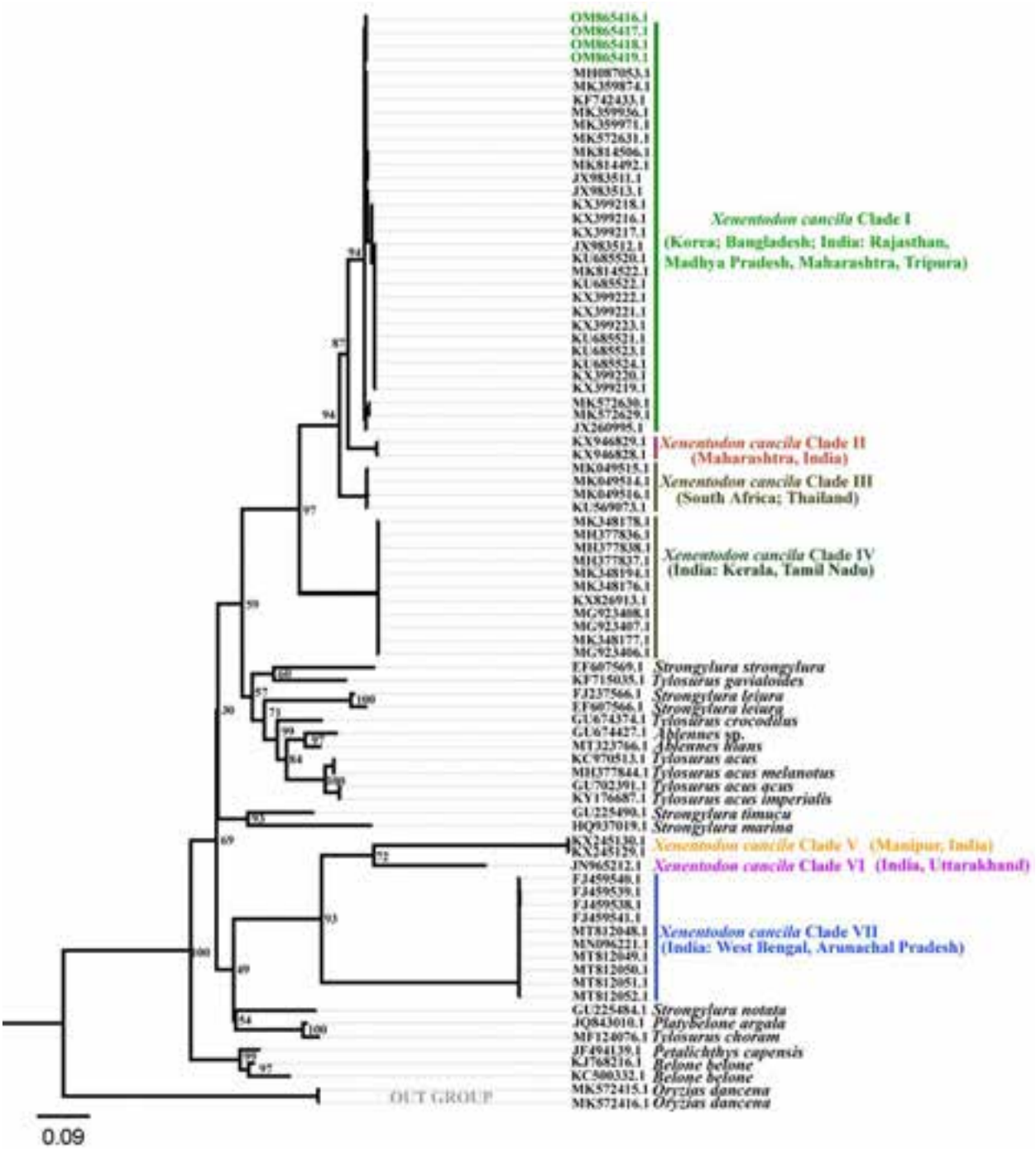

Image 2. Maximum likelihood analysis of Belonidae using 600 bps partial fragment of mitochondrial COI gene data.

Table 1. Sequences details of 600 bps fragment of mt COI gene data used in maximum likelihood IQ tree construction.

	Accessions	Name in GenBank	Locality as per GenBank	References
1	OM865416.1	*Xenentodon cancila*	Ujani reservoir, Maharashtra, India	This study
2	OM865417.1	*X. cancila*	Ujani reservoir, Maharashtra, India	This study
3	OM865418.1	*X. cancila*	Ujani reservoir, Maharashtra, India	This study
4	OM865419.1	*X. cancila*	Ujani reservoir, Maharashtra, India	This study
5	MH087053.1	*X. cancila*	Bangladesh	Unpublished
6	MK359874.1	*X. cancila*	Korea	Unpublished
7	KF742433.1	*X. cancila*	Maharashtra, India	Unpublished
8	MK359936.1	*X. cancila*	Korea	Unpublished
9	MK359971.1	*X. cancila*	Korea	Unpublished
10	MK572631.1	*X. cancila*	Moulvibazar, Sylhet, Bangladesh	Rahman et al. 2019
11	MK814506.1	*X. cancila*	Rajasthan, India	Unpublished
12	MK814492.1	*X. cancila*	Rajasthan, India	Unpublished
13	JX983511.1	*X. cancila*	Narmada river, Dindori, MP, India	Khedkar et al. 2014
14	JX983513.1	*X. cancila*	Narmada river, Dindori, MP, India	Khedkar et al. 2014
15	KX399218.1	*X. cancila*	Tripura, India	Unpublished
16	KX399217.1	*X. cancila*	Tripura, India	Unpublished
17	KX399216.1	*X. cancila*	Tripura, India	Unpublished
18	JX983512.1	*X. cancila*	Narmada river, Dindori, MP, India	Khedkar et al. 2014
19	KU685520.1	*X. cancila*	Tripura, India	Unpublished
20	MK814522.1	*X. cancila*	Rajasthan, India	Unpublished
21	KX399222.1	*X. cancila*	Tripura, India	Unpublished
22	KU685522.1	*X. cancila*	Tripura, India	Unpublished
23	KX399223.1	*X. cancila*	Tripura, India	Unpublished
24	KX399221.1	*X. cancila*	Tripura, India	Unpublished
25	KU685524.1	*X. cancila*	Tripura, India	Unpublished
26	KX399220.1	*X. cancila*	Tripura, India	Unpublished
27	KX399219.1	*X. cancila*	Tripura, India	Unpublished
28	KU685521.1	*X. cancila*	Tripura, India	Unpublished
29	KU685523.1	*X. cancila*	Tripura, India	Unpublished
30	JX260995.1	*X. cancila*	Maharashtra, India	Unpublished
31	MK572630.1	*X. cancila*	Bangladesh	Rahman et al. 2019
32	MK572629.1	*X. cancila*	Bangladesh	Rahman et al. 2019
33	KX946829.1	*X. cancila*	Maharashtra, India	Patil et al. 2018
34	KX946828.1	*X. cancila*	Maharashtra, India	Patil et al. 2018
35	MK049515.1	*X. cancila*	Thailand	Panprommin et al. 2019
36	MK049514.1	*X. cancila*	Thailand	Panprommin et al. 2019
37	MK049516.1	*X. cancila*	Thailand	Panprommin et al. 2019
38	KU569073.1	*Xenentodon sp.*	South Africa	Unpublished
39	MK348178.1	*X. cancila*	Ashtamudi lake, Kerala, India	Unpublished
40	MH377838.1	*X. cancila*	Kerala, India	Unpublished
41	MH377837.1	*X. cancila*	Kerala, India	Unpublished
42	MH377836.1	*X. cancila*	Kerala, India	Unpublished
43	MK348194.1	*X. cancila*	Ashtamudi lake, Kerala, India	Unpublished
44	MK348176.1	*X. cancila*	Ashtamudi lake, Kerala, India	Unpublished
45	KX826913.1	*X. cancila*	Tamil Nadu, India	Unpublished
46	MG923408.1	*X. cancila*	Vembanad Lake, Kerala, India	Unpublished
47	MG923407.1	*X. cancila*	Vembanad Lake, Kerala, India	Unpublished
48	MK348177.1	*X. cancila*	Ashtamudi lake, Kerala, India	Unpublished
49	MG923406.1	*X. cancila*	Vembanad Lake, Kerala, India	Unpublished
50	EF607569.1	*S. strongylura*	China	Unpublished
51	KF715035.1	*Tylosurus gavialoides*	Philippines	Unpublished
52	EF607566.1	*Strongylura leiura*	China	Zhang 2011
53	FJ237566.1	*Strongylura leiura*	India	Lakra et al. 2011
54	GU674374.1	*Tylosurus crocodilus*	Indonesia	Unpublished
55	GU674427.1	*Ablennes sp.*	Indonesia	Unpublished
56	MT323766.1	*Ablennes hians*	Gulf of Mexico	Unpublished
57	KC970513.1	*Tylosurus acus*	Philippines	Unpublished
58	MH377844.1	*Tylosurus acus melanotus*	India	Unpublished
59	GU702391.1	*Tylosurus acus acus*	Brazil	Unpublished
60	KY176687.1	*Tylosurus acus imperialis*	Turkey	Unpublished
61	GU225490.1	*Strongylura timucu*	Mexico	Unpublished
62	HQ937019.1	*Strongylura marina*	USA	April et al. 2011
63	KX245130.1	*X. cancila*	India	Unpublished
64	KX245129.1	*X. cancila*	India	Unpublished
65	JN965212.1	*X. cancila*	Dehradun, India	Thapliyal et al. 2013
66	FJ459540.1	*X. cancila*	India	Unpublished
67	FJ459539.1	*X. cancila*	India	Unpublished
68	FJ459538.1	*X. cancila*	India	Unpublished
69	FJ459541.1	*X. cancila*	India	Unpublished
70	MT812048.1	*X. cancila*	Arunachal Pradesh, India	Unpublished
71	MN096221.1	*X. cancila*	West Bengal, India	Unpublished

	Accessions	Name in GenBank	Locality as per GenBank	References
72	MT812049.1	*X. cancila*	Arunachal Pradesh, India	Unpublished
73	MT812050.1	*X. cancila*	Arunachal Pradesh, India	Unpublished
74	MT812052.1	*X. cancila*	Arunachal Pradesh, India	Unpublished
75	MT812051.1	*X. cancila*	Arunachal Pradesh, India	Unpublished
76	GU225484.1	*Strongylura notata*	Mexico	Unpublished
77	JQ843010.1	*Platybelone argala*	Trinidad and Tobago	Weigt et al. 2012
78	MF124076.1	*Tylosurus choram*	Israel	Unpublished
79	JF494139.1	*Petalichthys capensis*	South Africa	Unpublished
80	KJ768216.1	*Belone belone*	Portugal	Landi et al. 2011
81	KC500332.1	*Belone belone*	Turkey	Keskin & Atar 2014
82	MK572415.1	*Oryzias dancena*	Bangladesh	Rahman et al. 2019
83	MK572416.1	*Oryzias dancena*	Bangladesh	Rahman et al. 2019

seven distinct clades were recovered, far beyond the two currently recognized *Xenentodon* species. Species delimitation using ASAP (Image 3) corroborated the phylogenetic pattern, supporting the existence of multiple independently evolving lineages.

Although mt COI inference has limited utility for resolving deeper phylogenetic relationships, it remains valuable marker for detecting lineage diversity and identifying taxonomic hypotheses for further taxonomic revisions (Kalawate et al. 2022). Notably, most publicly available *Xenentodon* sequences are from India but lack associated voucher-specimen data, limiting taxonomic assignment with confidence.

Type locality of *X. cancila* is the Ganga River, India (Hamilton 1822), whereas that of *X. canciloides* is the Kapuas River, Indonesia (Bleeker 1854) (Image 4). Considering the proximity of sequences origin location and respective type localities tentatively Clade I can be assigned to *X. cancila* (sequences from

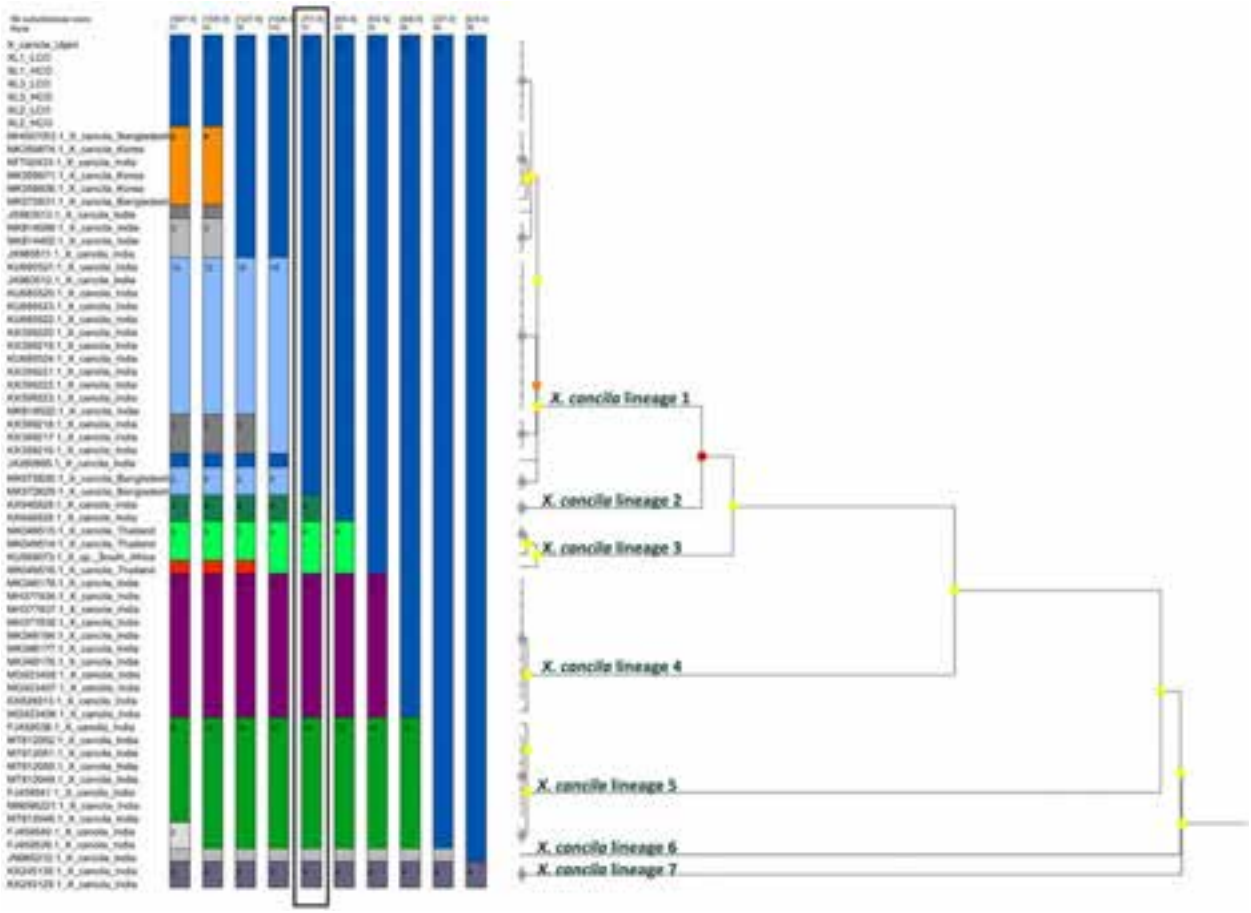

Image 3. Species delimitation analysis of *Xenentodon cancila* sequences using ASAP method with best partition marked in black (Number of subsets: 7, ASAP score 1).

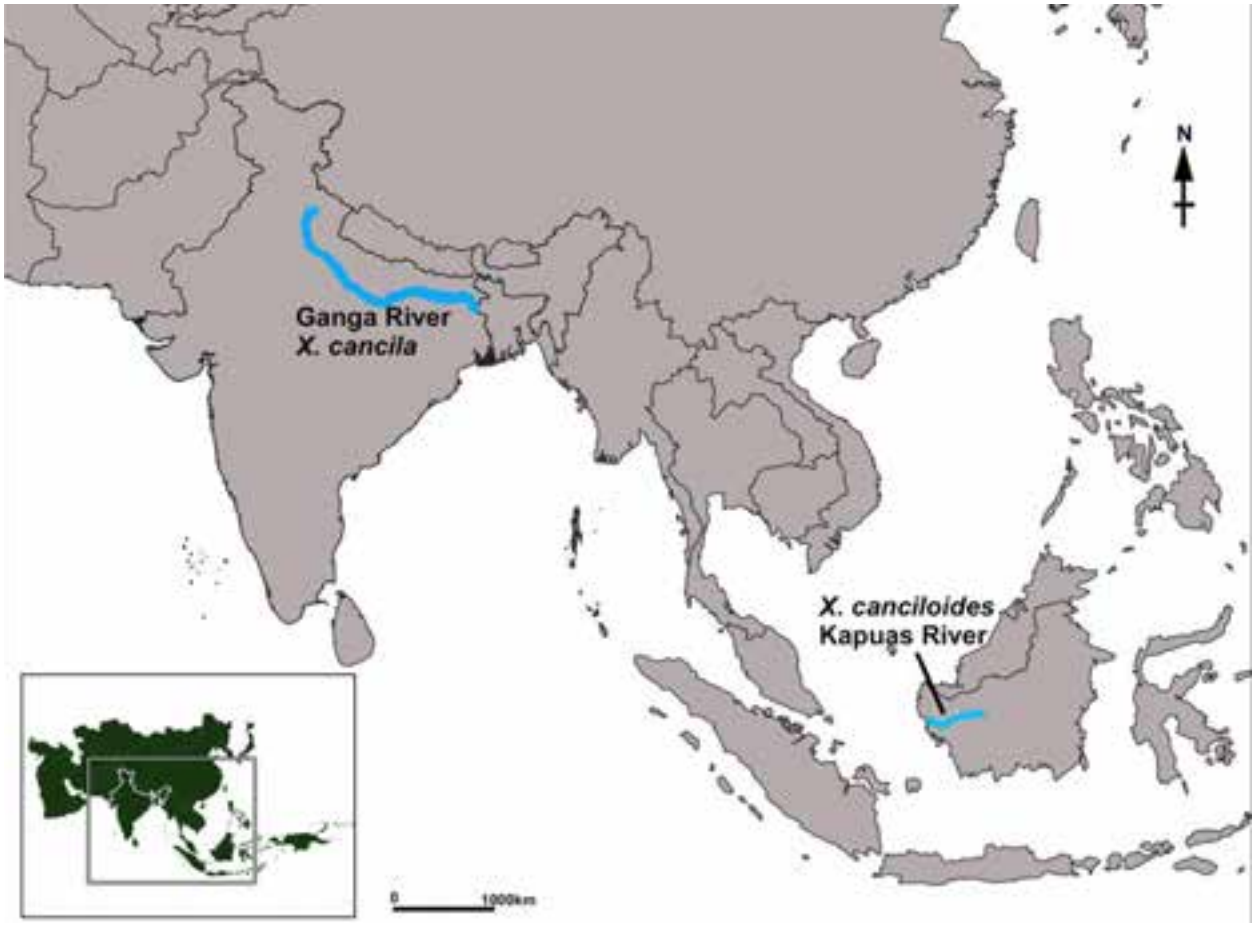

Image 4. Type locality map for the two species of *Xenentodon* in India and Thailand to their closest region based on available original description.

India and Bangladesh) (Images 2 & 3) and Clade III to *X. canciloides* (sequences from Thailand) tentatively (Images 2 & 3). The Remaining lineages corresponding to Clade II (from Maharashtra, India), Clade IV (from Kerala and Tamil Nadu, India), Clade V (from Manipur, India), Clade VI (from Uttarakhand, India), and Clade VII (from Arunachal Pradesh, West Bengal, India) (Images 2 & 3) likely represent undescribed species, warranting 'Integrative Taxonomic Studies' with broader sampling from respective localities and taxonomic revision of the group.

CONCLUSION

The genetic heterogeneity among populations suggests that current knowledge of species distribution and diversity is far from complete. This brings into attention multiple lineages and the need to revisit and re-evaluate riverine and watershed-based biogeographic patterns of *Xenentodon* species across southern Asia, primarily in India and Bangladesh, to better understand the diversity, distribution, evolutionary relationships, and ecology.

Data availability statement

All relevant data supporting the findings of this study are included within the manuscript. No additional datasets were generated or analyzed during the current study.

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Characterization of *Aphelenchoides confusus* Thorne & Malek, 1968 (Nematoda: Rhabditida: Aphelenchoididae) occurring in a marine habitat of eastern India

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Abstract: *Aphelenchoides confusus* Thorne & Malek, 1968, was isolated and described during a survey on the east coast mangroves from Odisha, India. The females characterized by a short body (596.6 ± 20.1 µm), a short stylet (9.7 ± 0.3 µm) with small basal knobs, a vulva at 64.7–69.6% of body length with an unmodified lip, a well-developed post-uterine sac, and a conoid, rounded tail without a mucro. Morphometrics closely agree with the original description and other populations. Principal component analysis explained 91.67% of total variation and clustered the present population with previously reported populations, indicating morphometric congruence. This record extends the known host association of the species to mangrove plants.

Keywords: *Avicennia marina*, mangroves, morphotaxonomy, parasitic, PCA, pneumatophores.

Abbreviations: MBL—Median bulb length | MBW—Median bulb width | PCA—Principal component analysis | PUS—Post-uterine sac | SD—Standard deviation.

The genus *Aphelenchoides* Fischer, 1894 (Aphelenchoididae) includes nematodes exhibiting diverse feeding habits, ranging from mycophagy to phytophagy (Handoo et al. 2020). Members of this genus are distinguished by vermiform females possessing a functional anus and rectum, a relatively short stylet with basal swellings, a well-developed median bulb, a posteriorly positioned vulva, heat relaxed males assume a walking-stick shape with the tail region curled ventrally, and bursa absent (Chanu et al. 2015). Globally, more than 200 species of *Aphelenchoides* have been described, with 54 species reported from India to date (Chanu & Mohilal 2023). Several species, including *A. besseyi*, *A. fragariae*, and *A. ritzemabosi* are recognised as economically important plant parasites that cause severe damage to agricultural and horticultural crops worldwide (Sanchez-Monge et al. 2015). Detection of foliar and root-associated *Aphelenchoides* species is often challenging, as external disease symptoms may not become apparent for extended periods (Jagdale & Grewal 2006).

Aphelenchoides confusus was first described by Thorne & Malek (1968) and was later recorded from *Morus alba* in Manipur, India, by Chanu et al. (2015). However, there have been no prior records of *Aphelenchoides* species associated with mangrove plants. The present study documents the occurrence of *A. confusus* in pneumatophores of *Avicennia marina*, representing the first evidence of an *Aphelenchoides* species in a mangrove habitat.

Materials and Methods

Necrotic and damaged pneumatophores of *Avicennia marina* (Image 1) were collected on 22.vii.2025 from

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Image 1. The pneumatophore of *Avicennia marina*.

from Talsari Beach, Odisha, India (21.6019° N, 87.4546° E). The roots were cut into small pieces, thoroughly washed with running tap water, and ground with a domestic mixer grinder. Nematodes were extracted by modified Baermann funnel technique (Whitehead & Hemming 1965). Finally, we hand-picked individual specimens under a stereomicroscope (MS Z-TR, Magnus) using a fine hairbrush. Specimens were heat-killed in hot triethanolamine–formalin fixative (TAF), and processed in Seinhorst's solutions for morphological analysis (Ravichandra 2014). After fixation, specimens were permanently mounted in anhydrous glycerin on clean glass slides for morphological and morphometric analyses. All morphological and morphometric measurements, along with the photomicrographs, were obtained using a Dewinter Ultima phase-contrast microscope equipped with a camera integrated with DIGI-4K software.

Results

Aphelenchoides confusus Thorne & Malek, 1968 (Images 2 & 3, Tables 1 & 3)

Measurements: All the morphometric measurements and de Man's ratio values are listed in Table 1.

Description: Females: Body short in length (571.4–616.4 µm), ventrally curved after fixation. Cuticle finely annulated. Lateral field with four incisures occupying approximately one-eighth of body width. Lip region slightly offset, 1.9–2.4 µm high and 4.1–5.4 µm wide. Stylet short (9.2–10.2 µm) with small basal knobs. Median bulb well-developed, oval to spheroid shaped (10.3–18.2 µm long and 7.3–15.8 µm wide), occupying about three-fourth of body width, with a centrally located refringent valve plate. Nerve ring located anterior to the median bulb. Excretory pore situated 62.4–68.1 µm from the anterior and situated posterior to the median bulb. Esophageal gland lobe aphelenchoid in form, extending dorsally over the intestine and provided with a short, arm-like ventral projection near the pharyngo-intestinal junction, extending 35–48 µm posterior to the base of the median bulb. Reproductive system monodelphic, anteriorly outstretched, occupying 35.9–39.8 % of body length, occasionally reaching median bulb. Vagina slightly anteriorly directed, uterus well developed, vulva a transverse slit located at 64.7–69.6 % of body length, with slightly elevated labial part. Post-uterine sac well

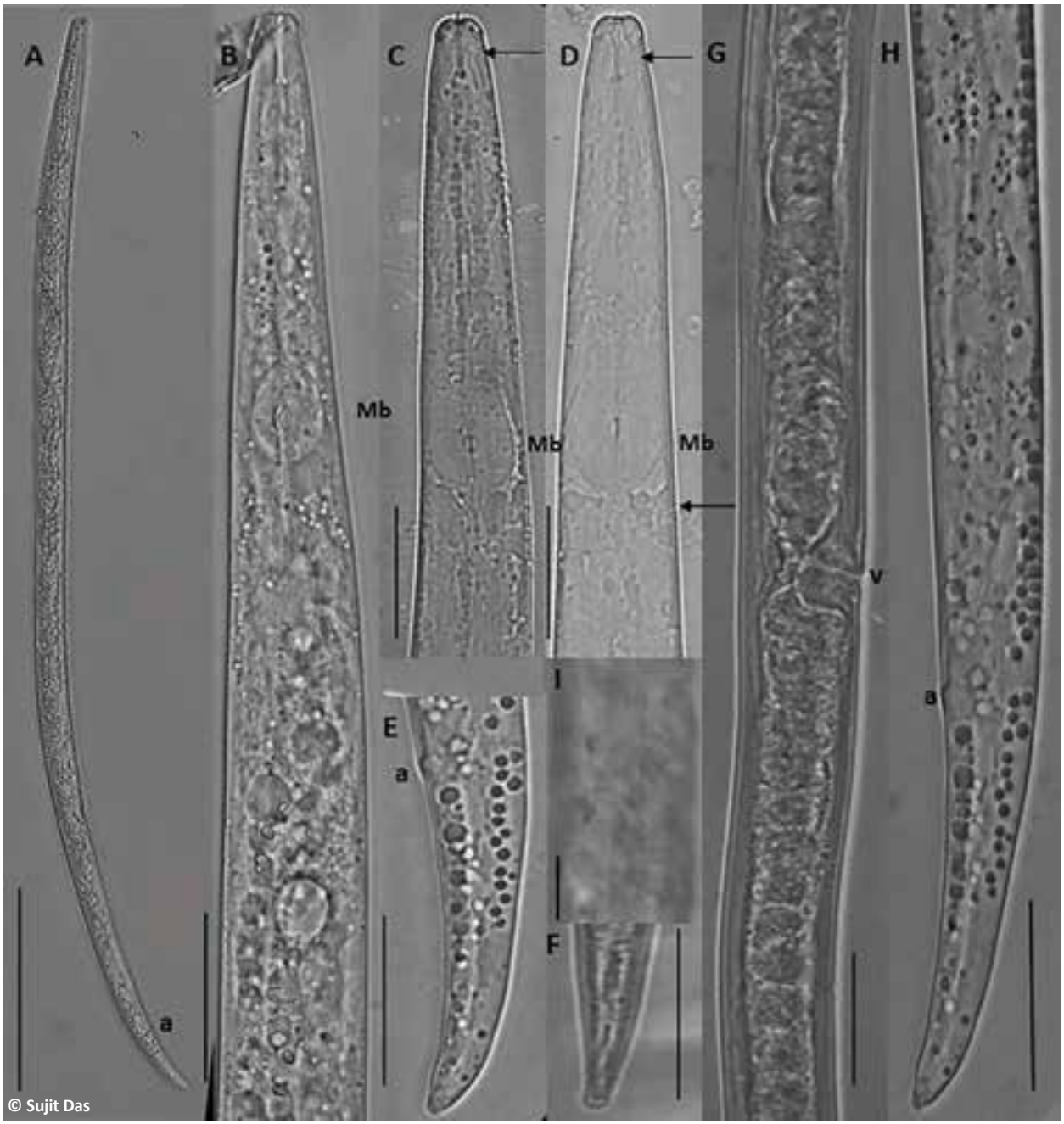

Image 2. Light photomicrographs of *Aphelenchoides confusus*: A—Entire female body | B—Anterior region with intestinal junction | C, D—Anterior region with secretory excretory pore (arrow) | E, F—Tail region | G—Female gonad and vulva with pus | H—Posterior region | I—Lateral line. (mb—median bulb | v—vulva | a—anus). Scale bars: A—100 µm | B–I_20 µm.

developed, extending posterior towards anus. Tail conoid, rounded, 39.3–43.7 µm long, without mucro.

Male: Not observed.

Host and locality: Collected on 22.vii.2025 from pneumatophores of the white mangrove *Avicennia marina* at Talsari Beach, Odisha, India (21.6019° N, 87.4546° E).

Relationship

Based on the present morphological and morphometric observations, the studied population was identified as *Aphelenchoides confusus* Thorne & Malek, 1968. Comparative analysis showed close agreement with the original description in the principal diagnostic characters, including body length, a ratio, stylet length, and conoid tail shape. Minor differences were observed

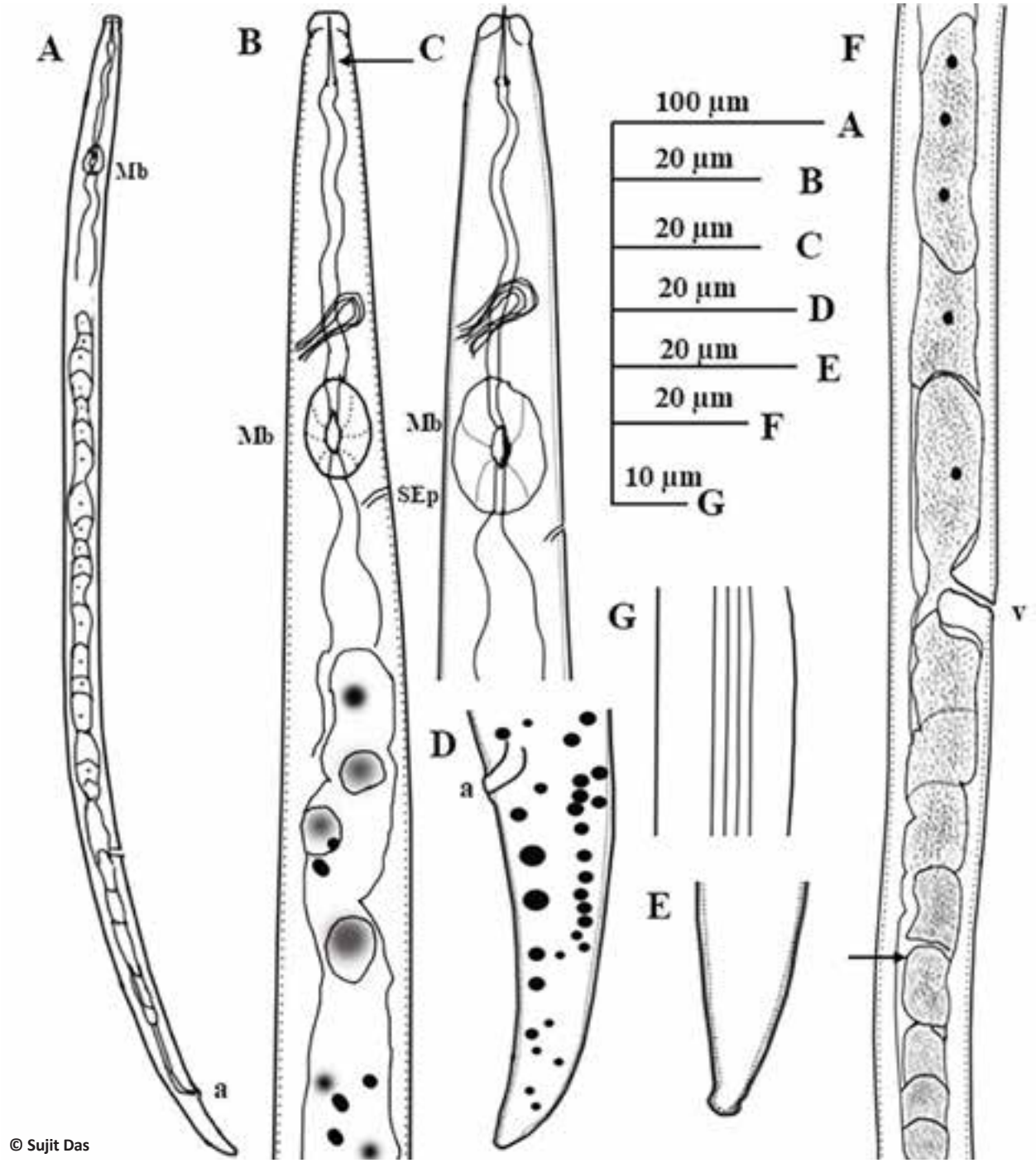

Image 3. Line drawings of *Aphelenchoides confusus*: A—Entire female body | B, C—Anterior region with secretory excretory pore | D, E—Tail with rounded tail terminus | F—Female gonad with vulva | G—Lateral line. (Mb—median bulb | Sep—secretory-excretory pore | v—vulva | a—anus).

in the de Man indices, with higher b (12.4–14.9 vs. 7.8–9.4) and c' (4.8–5.5 vs. 2.5–3.2) values, and a lower c value (9.4–9.9 vs. 17.5–19.0). These differences most likely reflect geographical or intraspecific variation (Table 2). *Aphelenchoides confusus* is visually similar to *A. obtusus* Thorne & Malek, 1968, and *A. avenae* Kumari, 2012. However, *A. confusus* differs from *A. obtusus* with respect to larger body size (571.4–616.4 µm in *A. confusus* vs. 401–550 µm in *A. obtusus*), nerve ring location (Anterior to median bulb in *A. confusus* vs. posterior to median bulb in *A. obtusus*), phasmid presence at the base of the tail, higher a value (32.8–

Table 1. Morphometric parameters of *Aphelenchoides confusus*. All values are in micrometers (µm), and in the form of mean ± SD (range).

Morphometric characters	Females (n = 14)
	Mean ± SD (Range)
L	596.6 ± 20.1 (571.4–616.4)
a	33.6 ± 1.1 (32.8–35.9)
b	13.6 ± 1 (12.4–14.9)
c	9.8 ± 0.3 (9.4–9.9)
c′	5.2 ± 0.3 (4.8–5.5)
Lip height	2.25 ± 0.2 (1.9–2.4)
Lip width	4.7 ± 0.5 (4.1–5.4)
Body diameter	17.1 ± 1.1 (15.9–18.7)
V%	67.5 ± 1.6 (64.7–69.6)
Stylet	9.7 ± 0.3 (9.2–10.2)
MBL	15.3 ± 2.2 (10.3–18.2)
MBW	13 ± 2.4 (7.3–15.8)
MBL/MBW	1.1 ± 0.1 (1.1–1.4)
Anterior to median bulb	61.3 ± 2.4 (57.6–65.2)
Anterior to excretory pore distance	64.6 ± 2.2 (62.4–68.1)
Distance of nerve ring from anterior	40.7 ± 4.1 (38.2–46.9)
Vulva to anus distance	194.2 ± 5.3 (185.2–201.4)
Length of female gonad	208.6 ± 26 (186.2–245.7)
Post uterine sac length (PUS)	98.4 ± 11.6 (81.3–110.5)
PUS/maximum body width	5.5 ± 0.2 (5.1–5.9)
Tail length	42.2 ± 2 (39.3–43.7)

35.9 µm in *A. confusus* vs. 25–31 µm in *A. obtusus*), higher b value (12.4–14.9 µm in *A. confusus* vs. 7.3–9.6 µm in *A. obtusus*), smaller stylet (9.2–10.2 vs. 11–12); from *A. avenae* with respect to shorter body length (571.4–616.4 µm in *A. confusus* vs. 710–910 µm in *A. avenae*), number of the lateral line (Four in *A. confusus* vs. 10–14 in *A. avenae*), higher b value (12.4–14.9 µm in *A. confusus* vs. 6.2–7.5 µm in *A. avenae*), lower c value (9.4–9.9 µm in *A. confusus* vs. 26.5–45.4 µm in *A. avenae*), and position of the vulva (Table 3).

Statistical analysis

The first two principal components explained 91.67% of the total variation in female morphometrics, PC1 explained 68.11% of the variance, while PC2 explained 23.56%. PC1 represents the principal axis explaining the largest proportion of total variance and is predominantly influenced by b (r = −0.426), tail length (r = −0.420), c′ (r = −0.412), c (r = 0.408), and V% (r = 0.408). These loadings indicate that variation in tail and body proportions accounts for most of the observed population differentiation, with moderate contributions from body length (r = 0.256) and a (r = 0.225). PC2 explains the second-largest proportion of variance and is mainly driven by a (r = 0.563) and stylet length (r = −0.684), followed by body length (r = 0.326) (Table 5). Principal component analysis (PCA) of morphometric characters from the present and previously reported populations of *Aphelenchoides confusus* revealed evident intraspecific variation (Table 4). The present population formed a distinct cluster, primarily associated with tail length and the *b* and *c′* ratios, whereas the population of Chanu et al. (2015) was characterized by greater body length and higher *a* and *c* values. The populations reported by Cheri et al. (2016) and Thrace occupied separate positions, with the latter showing a close association with stylet length. These differences likely represent geographical variation in morphometric traits rather than species-level divergence (Image 4).

Table 2. Morphometric differentiation of *Aphelenchoides confusus* (India) with previously reported species. All values are in µm and in the form of mean ± SD (range).

	Present study	Thrace	Chanu et al. 2015	Cheri et al. 2016
n	14	4	10	7
L	596.6 ± 20.1 (571.4–616.4)	610 ± 26 (590–650)	620 ± 99.3 (480–790)	640 ± 76 (580–770)
a	33.6 ± 1.1 (32.8–35.9)	32.4 ± 1.8 (30–34.6)	36.5 ± 5.8 (28.6–46.6)	30.1 ± 1.2 (29–32)
b	13.6 ± 1 (12.4–14.9)	4.8 ± 0.2 (3.91–5)	3.5 ± 0.6 (2.5–4.4)	8.4 ± 0.5 (7.8–9.4)
c	9.8 ± 0.3 (9.4–9.9)	24.1 ± 2.2 (21.2–26.4)	30.4 ± 4.8 (23.8–38.8)	18.2 ± 0.5 (17.5–19)
c′	5.2 ± 0.3 (4.8–5.5)	2.0 ± 0.1 (1.9–2.3)	2.2 ± 0.2 (2–2.4)	2.9 ± 0.2 (2.5–3.2)
Stylet	9.7 ± 0.3 (9.2–10.2)	18.2 ± 1.8 (16.2–20.4)	15 ± 2.2 (10.2–17)	12.4 ± 0.7 (11–13)
Tail	42.2 ± 2 (39.2–43.7)	24.8 ± 0.1 (24.7–24.9)	9.3 ± 0.8 (20.4–25.5)	31.7 ± 2.1 (29–35)
V%	67.5 ± 1.6 (64.7–69.6)	75.3 ± 0.47 (75–76)	77.7 ± 0.7 (74–78)	71.4 ± 1.6 (68.4–73.6)

Overall, PCA revealed clear intraspecific morphometric variation among populations, likely reflecting geographic and environmental influences.

Remarks

The present study contributes to the existing knowledge of *Aphelenchoides* taxonomy by providing updated polyphasic data for *A. confusus* found in a mangrove-associated habitat in eastern India. This record expands current knowledge of *Aphelenchoides* and provides a framework for future studies on its adaptation, host associations, and ecological distribution.

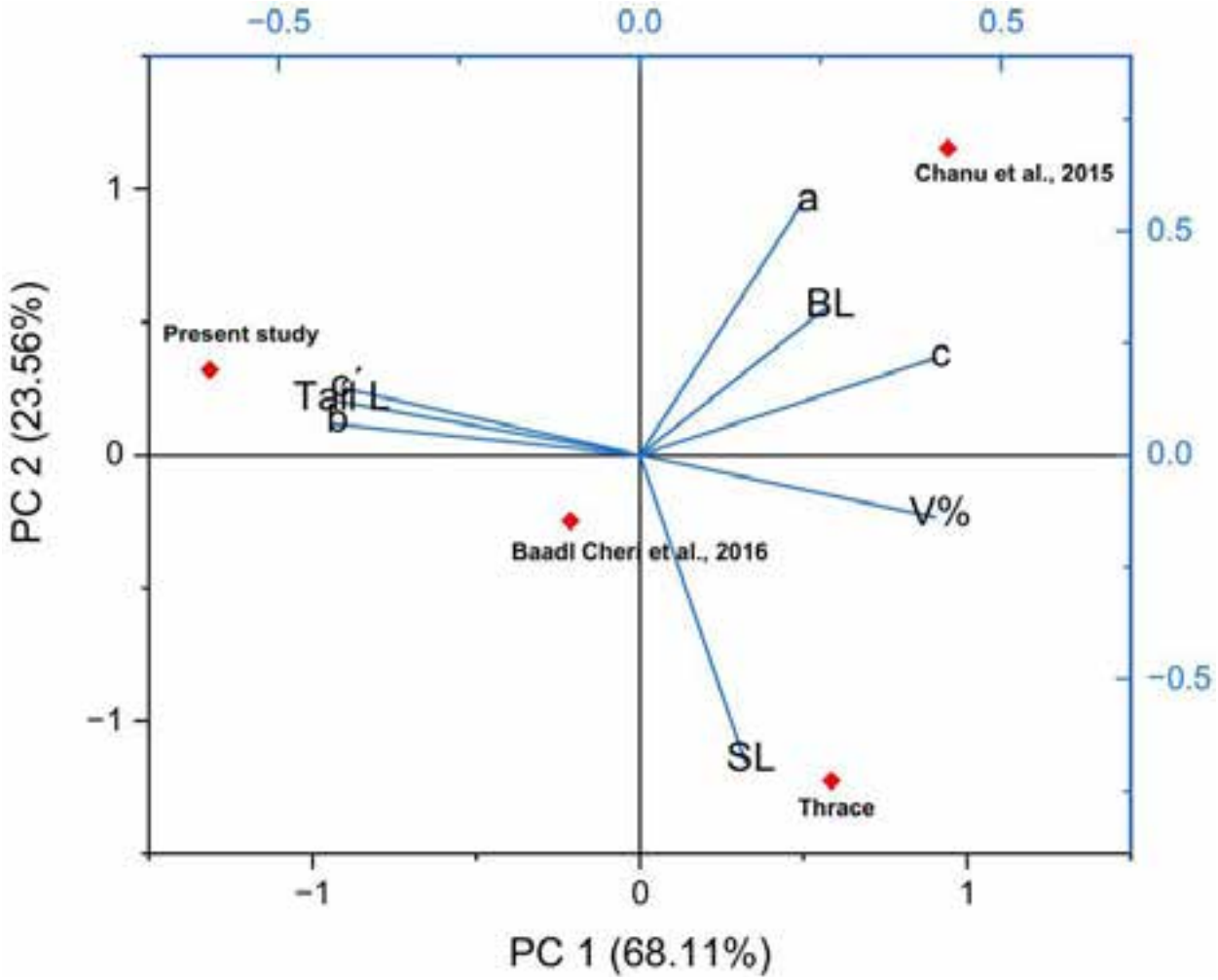

Image 4. PCA biplot of standardized morphometric characters of *Aphelenchoides confusus* populations. PC1 and PC2 explained 68.11% and 23.56% of the total variance, respectively.

Table 3. Comparative morphometric data of *Aphelenchoides confusus* from closely related species.

Characters	*A. confusus* (Present study)	*A. confusus* (Thorne & Malek, 1968 / Chanu et al., 2015)	*A. obtusus* Thorne & Malek, 1968	*A. avenae* Kumari, 2012
Body length (µm)	571.4–616.4	Comparable	401–550	710–910
Body posture	Straight to slightly curved	Similar	Similar	Similar
Lateral field	4 incisures	4 incisures	4 incisures	10–14 incisures
Stylet length	Short	Short	Longer	Longer
Nerve ring position	Anterior to median bulb	Anterior to median bulb	Posterior to median bulb	Anterior
Vulva position (V%)	64.7–69.6	Similar	Different	Different
Phasmids	Present near tail base	Present	Absent or indistinct	Present
Tail shape	Conoid, rounded	Conoid	Conoid	Conoid
Tail length (µm)	39.3–43.7	Similar	Shorter	Variable
a (µm)	32.8–35.9	Similar	25–31	Lower
b (µm)	12.4–14.9	7.8–9.4	7.3–9.6	6.2–7.5
c (µm)	9.4–9.9	17.5–19.0	Higher	26.5–45.4
c' (µm)	4.8–5.5	2.5–3.2	Lower	Lower

Table 4. Factor scores of the variable of the different populations of *Aphelenchoides confusus*.

Observation	PC1	PC2
Present study	-1.314	0.320
Thrace	0.584	-1.226
Chanu et al. 2015	0.941	1.154
Cheri et al. 2016	-0.211	-0.248

Table 5. Factor scores of the different morphometric features for different populations of *Aphelenchoides confusus*.

Characters	PC1	PC2
BL	0.256	0.326
a	0.225	0.563
b	-0.426	0.069
c	0.408	0.215
c´	-0.412	0.149
SL	0.145	-0.684
V%	0.408	-0.138
Tail L	-0.420	0.120

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COMMUNICATION

Geo-ecological dynamics of Bhairabkunda Grasslands: flood origins, florican dependence, and conservation need

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Abstract: This study investigated the dynamics of land cover change in the Bhairabkunda region of Assam, with a focus on the emergence of grasslands resulting from flood-driven river course changes. The objective was to assess how flooding events and subsequent ecological succession influenced grassland formation and their role in supporting the 'Critically Endangered' Bengal Florican *Houbaropsis bengalensis*. Multi-temporal satellite imagery from Landsat 5, 7, 8, and 9 (1987–2024) with 30 m spatial resolution was analyzed using supervised classification in QGIS to quantify land cover transitions. Ground surveys were conducted in 2024 to validate florican presence and vegetation composition. The results revealed that significant grassland patches emerged after the 1988–1989 floods, which altered the river's course and deposited sandbars, leading to 9.64 km² of grassland by 1991. However, between 2015 and 2024, rapid woodland expansion reduced grassland to 6.29 km², threatening grassland-dependent species. Bengal Florican sightings during field surveys confirmed the ecological significance of these newly formed habitats. Future projections for 2034, based on the MOLUSCE artificial neural network model, indicated further grassland decline to 4.72 km² and woodland expansion to 9.87 km². These findings demonstrated the dynamic nature of floodplain ecosystems, the influence of hydrological changes on vegetation succession, and the vulnerability of specialized species to habitat contraction. The study concluded that continued monitoring and targeted habitat management are urgently required to conserve grassland ecosystems and ensure the survival of the Bengal Florican in the sub-Himalayan landscape.

Keywords: Bengal Florican, emerging grassland, flood dynamics, habitat management, hydrological changes, land cover change, long-term monitoring, sub-Himalayan grassland, vegetation succession.

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Author contribution: Jonmani Kalita contributed to scientific analysis and manuscript writing. Karishma Sharma Chamlagain and Koushik Rajbongshi contributed to data collection. Dhritiman Das critically analyzed all findings.

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INTRODUCTION

Grassland and savanna biomes cover 40% of the Earth's land surface (Dixon et al. 2014; Wilsey 2018) and approximately 20% of the area in tropical latitudes (Parr et al. 2014; Bond 2016). The sub-Himalayan grasslands are among the most threatened ecosystems on the Indian subcontinent; they comprise a unique mix of alluvial grassland, savanna, and forest ecosystems, extending in a narrow belt from east to west at the base of the Himalaya (Semwal 2005; Banerjee et al. 2023; Douglas et al. 2023; Rahmani et al. 2016). A tropical to subtropical climate, with over 1,200 mm of annual rainfall, supports high productivity resulting in dense woodlands, extensive grasslands and savannas with varying tree cover (Banerjee et al. 2023). Although famously important for high-profile, 'flagship' species, this grassland also supports a range of lesser-known threatened and endemic species, including the Pygmy Hog *Porcula salvinia*, Bengal Florican *Houbaropsis bengalensis*, Hispid Hare *Caprolagus hispidus*, Hog Deer *Axis porcinus*, and Swamp Francolin *Ortygornis gularis* (Bell & Oliver 1992; Narayan & Deka 2008; Rahamani et al. 2016; Thakur et al. 2024). Their ecological importance makes them a key focus of conservation efforts in this region, particularly as they support these species, which are highly sensitive to habitat changes and serve as an indicator of grassland ecosystem health. This ecosystem experiences seasonal monsoonal flooding due to its geographic position, and the frequency and intensity of floods varies substantially, often changing the course of rivers in the region (Magilligan 1992; Bayley 1995; Lehmkuhl et al. 2006). Studies have also noted that shifts in river course affect the extent and duration of flooding at specific sites. For example, Miller et al. (1995) demonstrated that alterations in river channel patterns led to increased flood frequency and changes in sediment deposition in floodplain ecosystems. Similarly, Biswas (2010) linked changes in river course within the eastern Terai to the loss of grasslands and forests due to altered hydrological regimes and land use patterns. These changes play a role in shaping the distribution, persistence, and succession of forests and grasslands (Walsh & Townsend 1995; Michener & Houhoulis 1997). In addition to flooding, sub-Himalayan grassland habitats experience woody encroachment and anthropogenic disturbance, which impact the structure and function of these ecosystems (Kumar 2000; Bijlmakers 2020). Much of the sub-Himalayan grassland has been converted to agriculture and settlements over the past three decades (Douglas et al. 2023). For instance, the total extent of grasslands declined by 34.4% from 1,417 km² (28% of the total area) in 1988–1989 to 923 km² in 2018–2019, while woodland area increased by 8.7%, expanding from 3,235 km² to 3,516 km² (Johnsingh 2006; Banerjee et al. 2023). Multiple factors drive grassland loss globally, including conversion to croplands (Bullock et al. 2021; Douglas et al. 2023), spread of invasive species (Gornish & Santos 2016), climate change (Sankaran 2019), livestock grazing (Kariuki et al. 2021; Douglas et al. 2023), altered fire regimes (Simpson et al. 2022), bio-resource exploitation (Ryan et al. 2016), tree planting in grassland (Douglas et al. 2023), and woody encroachment (Devine et al. 2017; Buisson et al. 2019; Bardgett et al. 2021). At the same time, grassland formation has also been documented, particularly in riverine systems, where flooding and channel shifts have led to the development of new grass-dominated areas (Biswas 2010).

This study aims to examine the formation of new grasslands in the Bhairabkunda area, a dynamic sub-Himalayan landscape located along the Assam–Bhutan foothills, where recent hydrological disturbances and land-use changes have led to rapid vegetation turnover. The area represents a transitional zone between grassland and woodland ecosystems, making it a suitable model system for understanding the environmental drivers and ecological processes governing grassland emergence and grassland–woodland shifts in the eastern Himalayan foothills. During field visits, the grasslands in this region appeared relatively young and recently formed—a pattern not commonly observed in other sub-Himalayan sites. Indeed, a 1989 extensive survey by Narayan (1992) did not document this grassland, and no Bengal Florican sightings were recorded at that time. This prompted a focused investigation using land-use and land-cover analysis to better understand the drivers and implications of these emerging grassland habitats as well as for the florican. By linking florican occurrence with multi-temporal satellite imagery, the study offers insights into habitat suitability and grassland conservation potential in riverine landscapes of the eastern sub-Himalaya.

METHODS

Study site

The study area, Bhairabkunda (26.89°–26.85° N, 92.11°–92.17° E), is located in the Udalguri District of Assam near the borders of Assam, Arunachal Pradesh, and Bhutan (Image 1). The landscape is dominated by seasonally inundated alluvial grasslands composed

mainly of tall grasses such as *Saccharum spontaneum*, and *Imperata cylindrica*, with grass heights ranging ~1.5–2 m, which experience extensive flooding during the monsoon and remain relatively dry in winter, while being subject to periodic human use including seasonal grazing, and uncontrolled burning. However, invasive species like *Chromolaena odorata* and *Mikania micrantha*, as well as common riverine tree like *Bombax ceiba*, were also present. Additionally, prominent woody species such as Sisoo *Dalbergia sissoo* and Khair *Senegalia catechu* were observed, likely due to plantation efforts. The area features several water channels that deposit sandy sediments, with soil primarily of sandy and loamy texture. Positioned approximately 22 km north of the district headquarters of Udalguri and adjacent to the Bhutanese town of Daifam, Bhairabkunda serves as a transit point for the eastern province of Bhutan, the area is characterized by the confluence of the Jampani and Bhairabi rivers, forming the Jia Dhansiri River, a significant tributary of the Brahmaputra. The study area covers 15.08 km² at an average elevation of 703 m. Bhairabkunda (Reserve Forest) RF also features a man-made forest managed by the Joint Forest Management Committee (JFMC) established through collaboration between local villagers and the forest department.

Research Design, Materials and Data Sources

The study followed a landscape-scale ecological design integrating remote sensing, GIS-based land cover classification, predictive modeling, and field validation. Multi-decadal satellite imagery was analyzed to detect historical and current land cover changes, followed by projection modeling for future scenarios (Rawat & Kumar 2015). Field surveys were incorporated to validate remote sensing outputs and assess species-habitat associations.

Open-source Landsat satellite images were obtained from the United States Geological Survey (USGS) Earth Explorer. Landsat 5 (1987, 1988, 1989, 1990, 1991), Landsat 7 (1999, 2007), Landsat 8 (2015), and Landsat 9 (2024) datasets were used, each with a spatial resolution of 30 × 30 m, for regional-scale land cover change analysis.

The imagery was processed in QGIS v3.34.13 using a supervised maximum likelihood classification (MLC) approach (Foody 2002; Lu & Weng 2007). Four land

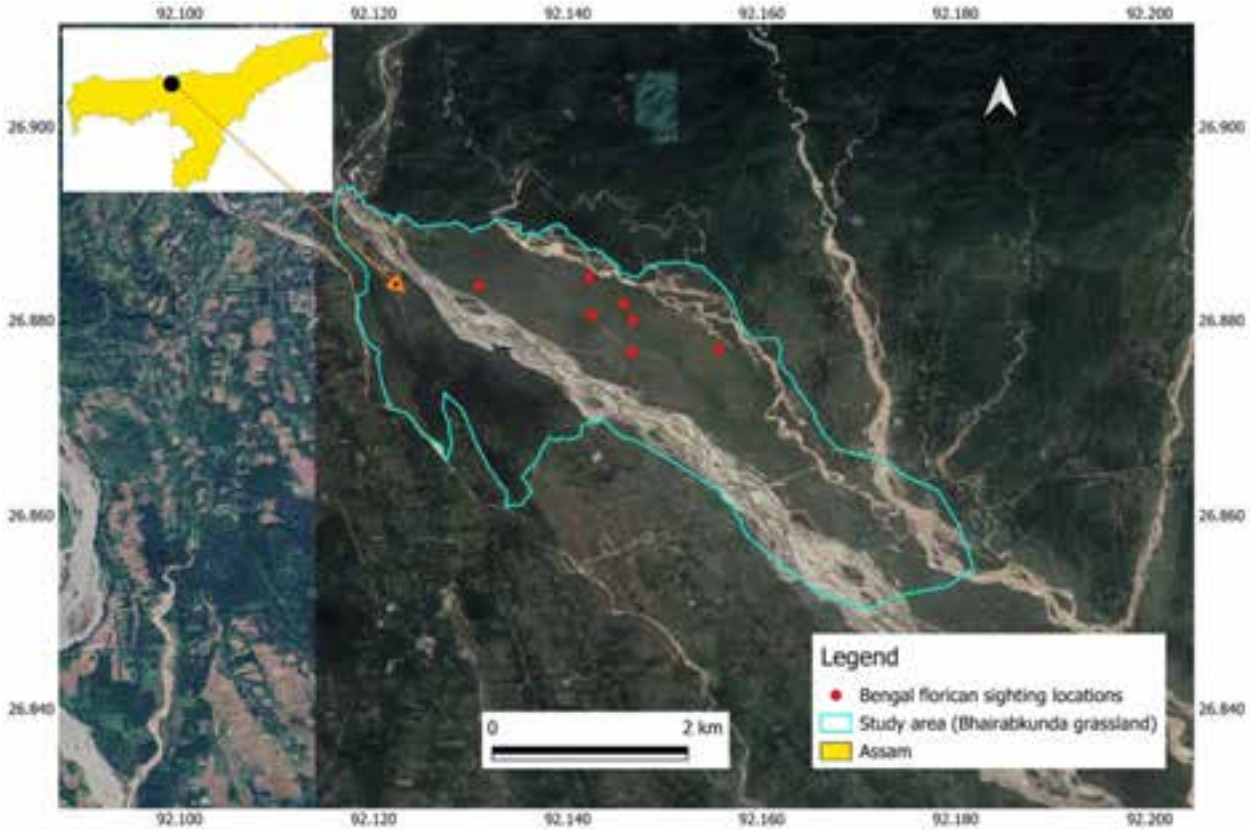

Image 1. Map of the Bhairabkunda grassland study area in Udalguri District, Assam, near the Assam–Bhutan border. The base image is from Google Earth satellite view (Google 2024).

cover classes were delineated: woodland, grassland, waterbody, and sandbar. Post-classification change detection was applied to assess transitions between classes across the study period.

Land cover predictions for 2034 were generated using the MOLUSCE plugin in QGIS, employing an artificial neural network (ANN) model trained on observed land-cover transitions and change trajectories derived from multi-temporal classified maps from 1987–2024 (Bugday & Bugday 2019; El-Tantawi et al. 2019; QGIS 2024). Transition probabilities between land-cover classes were estimated from historical change patterns, while digital elevation and road network data were used as explanatory variables.

From March to June 2024, systematic field surveys were conducted to document Bengal Florican sightings and associated vegetation characteristics within the study area. Surveys were carried out on 32 survey days (n = 32), at bi-weekly intervals, depending on field accessibility, during the early morning (0600–0930 h) and late evening (1500–1800 h) when florican activity is highest. Observations were made on foot along pre-defined transects, following established grassland survey routes. Each survey involved three trained observers, and all detections were recorded as visual sightings. Locations of birds were geo-referenced using handheld GPS units.

Vegetation characteristics were recorded at florican sighting locations and at representative points along transects using 5 × 5 m quadrat sampling (Narayan 1992; Thakur et al. 2024). Measurements of dominant grass species, grass height, vegetation structure, and the presence of woody or invasive elements were recorded, and these field data were subsequently compared with classified satellite imagery to validate grassland emergence and habitat suitability inferred from remote sensing analyses.

RESULTS

Land use land cover change

Land use and land cover analysis indicated temporal changes in landscape composition between 1987 and 2024 (Table 1; Images 2&3). In the late 1980s, frequent transitions among woodland, waterbody, and sandbar classes were observed, reflecting active fluvial processes. During this period, woodland cover declined, while waterbody and sandbar areas increased, followed by the appearance of grassland. Grassland expansion was evident in the early 1990s, with grassland becoming the dominant land-cover class by 1991. This phase was accompanied by a reduction in woodland and waterbody cover, indicating a shift from sandbar and woody habitats to grassland. By the late 1990s and mid-2000s, land-cover classes were more evenly distributed, suggesting relative stability. By 2015, woodland cover increased, consistent with successional processes and grassland extent decreased. By 2024, grassland again became the dominant land-cover class, followed by woodland, while waterbody and sandbar occupied smaller areas. Overall, the observed patterns indicate recurrent cycles of grassland formation and succession associated with fluvial processes and vegetation change in the Bhairabkunda landscape.

Table 1. Temporal changes in land-cover area (km²) in Bhairabkunda (L5: 1987, 1988, 1989, 1990, 1991; L7: 1999, 2007; L8: 2015; L9: 2024 and predicted LULC map of 2034).

Year ↓ / Habitat →	Grassland	Woodland	Waterbody	Sandbar
1987	0.56	10.04	4.3	0.18
1988	1.97	3.85	7.11	2.16
1989	1.93	2.35	5.05	5.76
1990	6.17	1.93	1.93	5.05
1991	9.64	0.83	1.6	3.01
1999	6.7	4.51	1.53	2.35
2007	5.58	3.3	2.22	3.99
2015	4.97	7.42	0.58	2.11
2024	6.49	6.29	0.47	1.83
2034	4.72	9.87	0.22	0.28

Based on the MOLUSCE model, land-cover projections for 2034 indicate further changes in Bhairabkunda region (Table 1). Woodland is projected to become the dominant land-cover class, reflecting continued expansion since 2015. Grassland extent is projected to decline relative to 2024, while sandbar and waterbody areas are expected to decrease further. Overall, the projections suggest continued land-cover transitions characterized by woodland expansion, contraction of grassland, and reduced waterbody and sandbar features. These predicted patterns reflect ongoing changes in vegetation distribution and fluvial processes influencing the landscape.

Bengal Florican sightings and vegetation composition

Ground surveys revealed the presence of *Houbaropsis bengalensis* across seven survey sites (Images 1&4), although detections were not made on every visit at each site. A total of five individual floricans were recorded

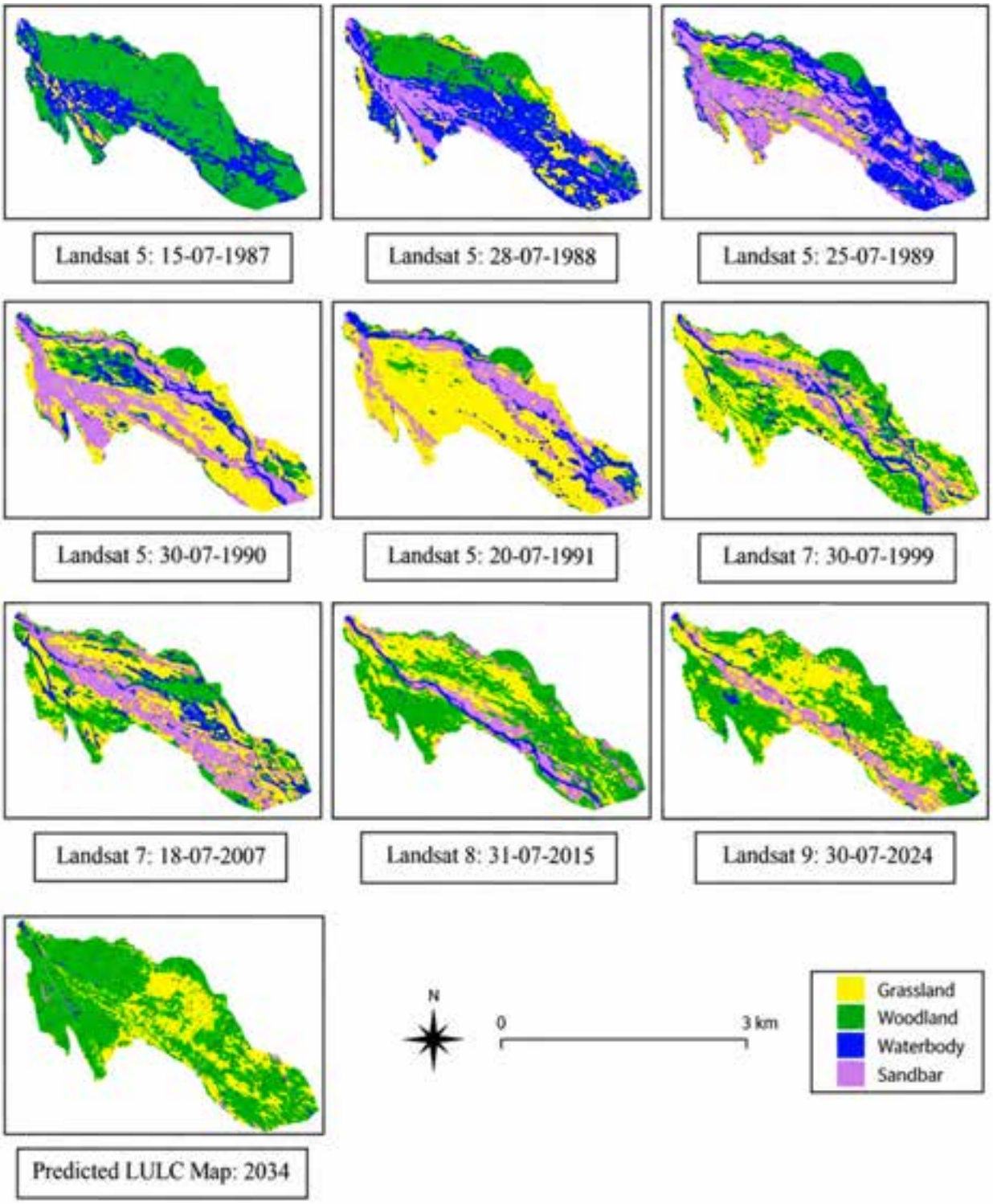

Image 2. Land cover classification map of the study area for nine time points, Landsat 5 (1987, 1988, 1989, 1990, 1991), Landsat 7 (1999, 2007), Landsat 8 (2015), Landsat 9 (2024), and predicted LULC Map (2034).

during the survey period, comprising four males detected in flight display and one female observed on the ground within grassland vegetation. These observations indicate that the newly formed grasslands are being used by floricans, while not implying uniform or continuous occupancy across all surveyed sites.

And most of the Bengal Florican habitats where they are recorded in the grassland have short grass *Imperata*

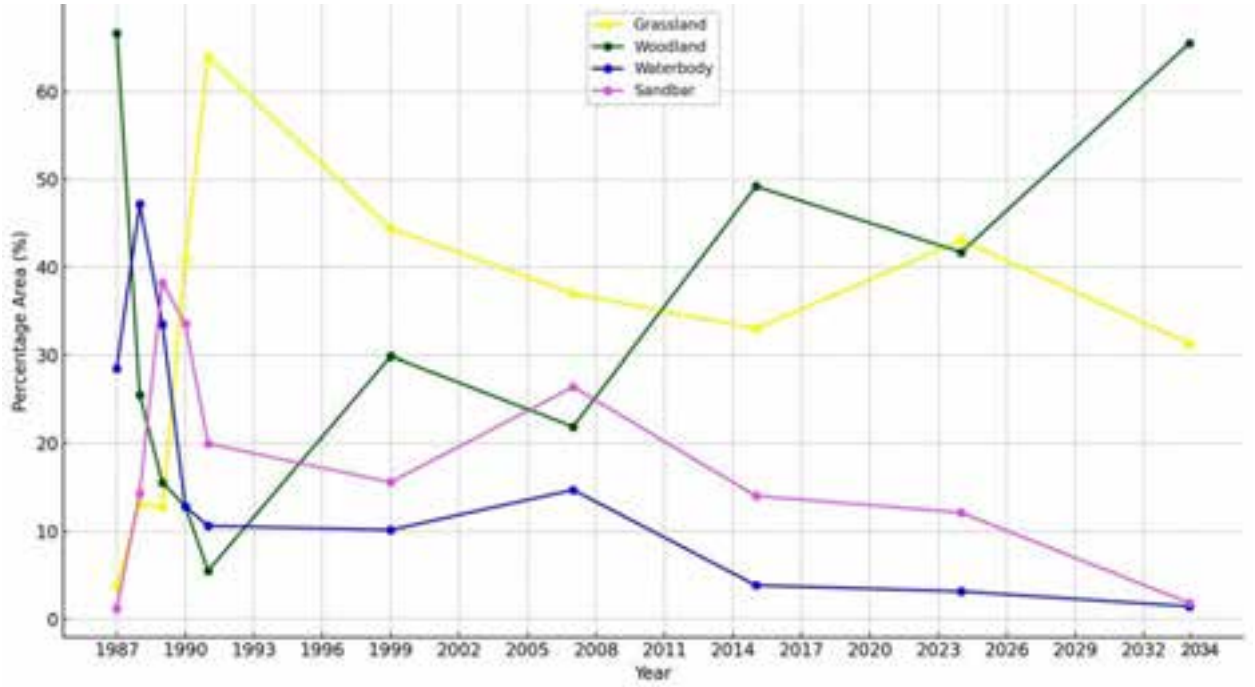

Image 3. Scatter plot showing the habitat transitions of the study area for nine-time points (1987, 1988, 1989, 1990, 1991, 1999, 2007, 2015, 2024).

Image 4. Male Bengal Florican in flight. © Jonmani Kalita.

cylindrica and moderately tall and dense grasses like *Saccharum spontaneum* followed by some other shrub species *Leea* spp. and *Grewia sapida.*

DISCUSSION

The results of our study highlight the dynamic nature of land cover changes in the Bhairabkunda region, emphasizing the emergence of new grassland patches and significant shifts in vegetation distribution over the years. A pronounced phase of grassland formation was observed by 1991, when grassland expanded to 9.64 km². This expansion followed extensive sandbar deposition in 1989 and widespread inundation during the major flood events of 1988–1989, indicating that flooding and subsequent sediment deposition played a key role in facilitating grassland development. These floods altered the course of the river from the north-west to the north-east, leading to significant sand deposition, which contributed to grassland formation. Similar observations were made by Biswas (2010), who reported that flooding and changes in the river course during the 1968 flood in Jaldapara National Park led to considerable alterations in the grassland distribution within the park. In line with this, research suggests that the frequency and duration of floods play critical roles in shaping the spatial distribution

of plant communities within floodplains (Bayley 1995; Miller et al. 1995). Any shift in the flooding regime is likely to modify the vegetation patterns. As flood frequency and duration decrease, moist grasslands may gradually transition to savanna, woodland, or forest (Walsh & Townsend 1995; Michener & Houhoulis 1997), while increased flooding could reverse this process, reinstating grassland areas. Between 2015 and 2024, woodlands expanded to 7.42 km², leading to a reduction in grassland areas to 6.29 km². Projections for 2034 indicate that woodland is expected to dominate, occupying 9.87 km² (65.48%), while grassland is projected to decline to 4.72 km² (31.29%). These trends are extrapolated from observed historical land-cover transitions, suggesting that vegetation succession and reduced flooding influence continue to shape the regional landscape.

The Bengal Florican, listed as 'Critically Endangered' by the IUCN Red List and protected under Schedule I of the Wild Life (Protection) Act, 1972 (as amended by the Wild Life (Protection) Amendment Act, 2022), is a flagship grassland-dependent species (Collar et al. 2017; Baral et al. 2020; BirdLife International 2024). This highlights the ecological importance of grassland habitats, where the emergence of specific conditions allows threatened species like the Bengal Florican to naturally return to their habitat. Narayan's 1989 survey indicated no extensive grassland patches in the study area (Narayan 1992). To investigate this further, land cover classification was performed, confirming the recent formation of suitable grassland habitats. These findings underscore the need for adaptive, site-specific management of floodplain grasslands that explicitly accounts for seasonal hydrological variability and successional change. In dynamic systems such as Bhairabkunda, grassland conservation should prioritize the maintenance of early successional stages through regulated disturbance regimes, including controlled burning, selective removal of woody encroachment, and the prevention of plantation activities within grassland patches. For the Bengal Florican, management should focus on retaining large, contiguous tracts of short and tall grassland dominated by *Imperata* and *Saccharum*, while minimizing habitat fragmentation and human disturbance during the breeding season (Rahmani et al. 2016; Jha et al. 2018). Long-term scientific monitoring and repeat land-cover assessments are essential to understand inter-annual variability, evaluate management effectiveness, and ensure the persistence of suitable florican habitat under changing flood and land-use regimes.

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VIEWPOINT

Schedule III of the Wild Life (Protection) Amendment Act, 2022: a new legal shield for India's threatened plant species

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Abstract: India's Wild Life (Protection) Amendment Act, 2022 marks a pivotal step in plant conservation by introducing Schedule III for specified plant species. This schedule regulates the cultivation, possession, trade, and transport of threatened and high-value plants through a permit-based system, aligning domestic law with CITES obligations. It shifts focus from outright collection bans to a balanced approach that encourages sustainable cultivation while preventing illegal wild extraction. The amendment enhances biodiversity conservation, supports livelihoods, and strengthens global compliance. Effective implementation can achieve long-term conservation outcomes with streamlined permits, better awareness, scientific support, and community participation.

Keywords: Biodiversity conservation, CITES, community participation, illegal trade, IUCN, legislation, livelihood, permit, rare flora, sustainable cultivation.

India is one of the world's richest countries in terms of plant biodiversity, hosting thousands of endemic, medicinal, ornamental, economically and ecologically significant plant species. The Wild Life (Protection) Act, 1972 serves as India's primary legislation for safeguarding wild animals, birds, plants, and their habitats. Initially, it categorized protection levels into six Schedules (I–VI), each offering varying degrees of legal protection and penalties. The plants listed in Schedule VI of this Act are rare and threatened, and the act prohibits cultivation, possession, and trade without permission aiming to conserve rare flora. However, increasing commercial demand, illegal trade, habitat loss, and unregulated cultivation have placed many valuable plant species under serious threat.

Recognizing these challenges, the Government of India enacted the Wild Life (Protection) Amendment Act, 2022, which updates and strengthens the original law rather than replacing it. The 2022 Amendment modernizes it to tackle wildlife trafficking, invasive species, global trade, and current conservation challenges. It was passed by Parliament in 2022, signed by the President on 19 December 2022, and came into force on 1 April 2023.

The 2022 Amendment Act has four (I to IV) Schedules, introducing a new Schedule III dedicated exclusively for protection of specified plant species. The species of plants listed under the Schedule III are defined as 'specified plants' under Section 2(27) of the Wildlife (P) Act, 1972 as amended.

This landmark amendment marks a significant shift in India's conservation framework by extending regulatory protection beyond animals to include high-value and threatened plants, thereby aligning national legislation

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with international conservation commitments such as CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora).

Schedule III of the Wild Life (Protection) Act, as amended in 2022, lists specified plant species whose: cultivation, possession, sale, purchase, transport, and trade (domestic and international) are now regulated through a permit-based system. While earlier provisions focused primarily on bans on collection from the wild, Schedule III introduces a balanced regulatory approach, allowing controlled cultivation and trade while preventing illegal extraction from the wild.

A separate Chapter IIIA under the heading 'Protection of Specified Plants' have been included under the Act and regulatory provisions in respect of the Schedule III specified plants have been mentioned under Sections 17A to 17H in the Act highlighting various legislative guidelines under the following headings:

Section 17A: Prohibition of picking, uprooting etc. of specified plants.

Section 17B: Grants of permit for special purpose.

Section 17C: Cultivation of specified plants without license prohibited.

Section 17D: Dealing in specified plants without license prohibited.

Section 17E: Declaration of stock.

Section 17F: Possession etc. of plants by licensee.

Section 17G: Purchase etc. of specified plants.

Section 17H: Plants to be Government property.

Plant Species Included in Schedule III

The schedule includes several ecologically, medicinally, and culturally significant plant species, as listed below:

1. *Strobilanthes kunthiana* (Nees) T.Anderson ex Benth. ['Neela-kurinji' – a mass-flowering endemic plant of the Western Ghats; Vulnerable VU A2c (Bachan & Devika 2024 as per IUCN Red list of Threatened Species, ver. 3.1)].

2. *Coptis teeta* Wall. ['Gold threat', 'Mishmi teeta' – extensively used as medicinal plant; Endangered EN A2cd (Saha et al. 2015a as per IUCN Red list of Threatened Species, ver. 3.1)].

3. *Coscinium fenestratum* (Gaertn.) Colebr. ['Tree Turmeric' – roots are traded under the name 'Mirmanjal', used in various systems of medicine, such as Ayurveda, folk, Tibetan and Siddha; Data Deficient DD (Ved et al. 2015a as per IUCN Red list of Threatened Species, ver. 3.1)].

4. *Taxus wallichiana* Zucc. [Common 'Yew' or 'East Himalayan Yew'– extensively used in preparing furniture, cabinet work, candlestick, the alkaloid compounds (taxanes) of the bark are a source for the anti-cancer drug paclitaxel (Taxol); Endangered EN A2acd (Thomas & Farjon 2011 as per IUCN Red list of Threatened Species, ver. 3.1)].

5. *Vanda coerulea* Griff. ex Lindl. ['Blue Vanda Orchid' – highly prized ornamental orchids for long-lasting, spectacular blooms, preferred for hybridization and also used in traditional medicine, cosmetic and skincare].

6. *Nepenthes khasiana* Hook.f. ['Pitcher Plant'– India's only native carnivorous plant, endemic to Meghalaya; Endangered EN B2ab(iii) (Ved et al. 2015b as per IUCN Red list of Threatened Species, ver. 3.1)].

7. *Renanthera imschootiana* Rolfe ['Red Vanda Orchid' – highly ornamental, long-lasting, vibrant orange-red flowered orchid with long branching spikes, also used in traditional medicine].

8. *Cycas* spp.

9. *Ceropegias* spp.

10. *Aenhenrya rotundifolia* (Blatt.) C.S.Kumar & F.N.Rasm. ['Jewel Orchid' – highly attractive for beautiful, reticulated leaves; endemic to southern Western Ghats of India; (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

11. *Odontochilus grandiflorus* (Lindl.) Benth. ex Hook.f. ['Jewel Orchid' – threatened, very attractive for its unique flowers with spotty petals and green leaves; earlier endemic to India, but now also found in Myanmar and Vietnam (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

12. *Odontochilus tetrapterus* (Hook.f.) Av.Bhattacharjee & H.J.Chowdhery ['Jewel Orchid' – unique in having four lobed, cruciform epichile and dark velvety green leaves; endemic to Manipur, India; (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

13. *Rhomboda pulchra* (King & Pantl.) Ormerod & Av.Bhattacharjee [syn. *Zeuxine pulchra* King & Pantl.; 'Jewel Orchid' – leaves adaxially blackish or purplish-brownish; endemic to northeastern India (Arunachal Pradesh, Meghalaya, Sikkim); (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

14. *Vrydagzynea viridiflora* Hook.f. ['Jewel Orchid' – with white-green flowers and green leaves; (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

15. *Zeuxine andamanica* King & Pantl. ['Jewel Orchid' – with white flowers having yellow blotch on labellum and 5 to many veined leaves; Endemic to India (Andaman Island); (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

16. *Ipsea malabarica* (Rchb.f.) Hook.f. ['Malabar Daffodill Orchid' – a threatened and beautiful yellow flowered ground orchid; endemic to India (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

17. *Habenaria barnesii* Summerh. ex C.E.C.Fisch. ['Barnes Habenaria' – a rare ground orchid of Nilgiris and other parts of the Western Ghats; endemic to southern Western Ghats of India (assessment not yet done as per IUCN Red list Criteria, ver. 3.1)].

18. *Podophyllum hexandrum* Royle ['Himalayan Mayapple', 'Indian Mayapple', 'Papra' – perennial rhizomatous herb found in alpine region, distributed in the entire range of Himalayas from Ladakh to Sikkim, extensively used in traditional systems of medicine; Endangered (EN) A2bd+3cd+4cd (Chauhan 2024 as per IUCN Red list of Threatened Species, ver. 3.1)].

19. *Dolomiaea costus* (Falc.) Kasana & A.K.Pandey [= *Saussurea lappa* (Decne.) Sch.Bip., *Saussurea costus* (Falc.) Lipsch, 'Kuth' – an important medicinal plant used in Ayurveda and Tibetan medicine; Critically Endangered CR A2cd (as *Saussurea costus*) (Saha et al. 2015b as per IUCN Red list of Threatened Species, ver. 3.1)].

Renanthera imschootiana, *Nepenthes khasiana*, *Dolomiaea costus* (as *Saussurea costus*) and *Cycas beddomei* are listed under Appendix I of CITES, while rest of the *Cycas* spp., *Taxus wallichiana*, *Podophyllum hexandrum* and rest of the above mentioned orchids are listed in Appendix II of CITES. These species have long been vulnerable to over-exploitation and illegal trade, both domestically and internationally, however, only five of these were earlier listed and provided protection under Schedule VI of the Wild Life (Protection) Act, 1972. Although several species have been added to Schedule III, ladies slipper orchids (*Paphiopedilum* spp.), listed in Appendix I of CITES and earlier included in Schedule VI of the Wild Life (Protection) Act, 1972 are missing from the Schedule III.

A comparative list between Schedule VI of Wild Life (Protection) Act, 1972, and Schedule III of Wild Life (Protection) Amendment Act, 2022 is given below.

	Plants listed in Schedule VI of Wild Life (Protection) Act, 1972	Plants listed in Schedule III of Wild Life (Protection) Amendment Act, 2022
1	Beddomes' cycad (*Cycas beddomei*)	*Strobilanthes kunthiana*
2	Blue Vanda (*Vanda soerulec*) [*Vanda coerulea*]	*Coptis teeta*
3	Kuth (*Saussurea lappa*) [= *Dolomiaea costus*]	*Coscinium fenestratum*
4	Ladies slipper orchids (*Paphiopedilum* spp.)	*Taxus wallichiana*
5	Pitcher plant (*Nepenthes khasiana*)	*Vanda coerulea*
6	Red Vanda (*Renanthera imschootiana*)	*Nepenthes khasiana*
7	---	*Renanthera imschootiana*
8	---	*Cycas* spp.
9	---	*Ceropegia* spp.
10	---	*Aenhenrya rotundifolia*
11	---	*Odontochilus grandiflorus*
12	---	*Odontochilus tetrapterus*
13	---	*Rhomboda pulchra*
14	---	*Vrydagzynea viridiflora*
15	---	*Zeuxine andamanica*
16	---	*Ipsea malabarica*
17	---	*Habenaria barnesii*
18	---	*Podophyllum hexandrum*
19	---	*Dolomiaea costus*

Linkages of Schedule III species with the Foreign Trade Policy of Govt. of India and exclusion of *Paphiopedilum spp*. from Schedule III

The Government of India, through the Ministry of Environment, Forest and Climate Change (MoEF&CC), issued the Wild Life (Protection) International Trade of Specimens Rules, 2023 via Notification No. S.O. 5408(E) dated 21 December, 2023. These rules were framed under the authority of Section 63 of the Wild Life (Protection) Act, 1972 to operationalize the provisions of Section 49H. Their primary objective is to regulate the international movement of wildlife specimens, including their import, export, and re-export, while ensuring compliance with the requirements of the CITES and the applicable policies of the Directorate General of Foreign Trade (DGFT). There is a total ban on export of wild orchids from India under the Foreign Trade Policy of Government of India since long. So, although the *Paphiopedilum spp.* are left out of the purview of Schedule III during 2022 amendments to the Wildlife (P) Act, 1972, the export of the genus of orchids of wild origin remains prohibited from India.

In Schedule III of the amended Act, *Cycas* L. and *Ceropegia* L. are just vaguely listed as 'Cycas spp.' and 'Ceropegia spp.'. However, 18 taxa of *Cycas* (Devi et al. 2025) and 72 taxa of *Ceropegia* (Ranjan et al. 2024; Chiranjeevi et al. 2026) are found in India. Here, 'spp.' may be interpreted as multiple species within the genus *Cycas* and genus *Ceropegia* and that all the species within the genus *Cycas* and genus *Ceropegia* found in India are deemed to be included under the Schedule III of the Wildlife (P) Act, 1972 as amended. However, an annotation explaining the above facts or a proper

Image 1. A—*Strobilanthes kunthiana*. © P.S. Kushwaha | B—*Coptis teeta* | C–C1—*Coscinium fenestratum*. © C.R. Chitra | D–D1—*Taxus wallichiana*. © R. Layola M.R. | E—*Vanda coerulea* | F—*Nepenthes khasiana* | G—*Renanthera imschootiana* | H—*Cycas beddomei*. © K. Prasad | I—*Ceropegia candelabrum*. © P.S. Kushwaha. © B,E,F,G—Avishek Bhattacharjee

clarification (with list) needs to be provided to include all the species and infraspecific taxa of these two genera (*Cycas* and *Ceropegia*) in order to provide protection to each taxa against exploitation.

Under the amended Act, permits are required for the cultivation, possession, sale, transport, and trade of specified plants. The state forest departments are appointed as the authorities responsible for issuing these permits. Traceability systems are implemented to differentiate legally cultivated plants from those collected in the wild. Violations, such as unauthorized trade or transport, are subject to penalties and legal action. This framework promotes conservation while allowing sustainable use, benefiting both biodiversity and legitimate growers.

Alignment with CITES and Global Conservation Standards

Many species listed under Schedule III are already included in Appendices of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which regulate international trade. A separate Schedule IV has been incorporated during 2022 amendments to the Wildlife (P) Act, 1972 which includes all animal and plant species listed under the various Appendices to the CITES. Therefore, some of the species/genera are listed both under the Schedule III and Schedule IV of the Wildlife (P) Act, 1972 as amended. Hence, both the provisions under the CITES and Chapter IIIA of the Wildlife (P) Act, 1972 will be applicable during international trade in these CITES listed species. A separate Chapter VB is included under the heading 'Regulation of International Trade in Endangered Species of Wild Fauna and Flora as per CITES' and Sections 49D to 49R describe the various provisions/definitions/ regulatory guidelines for implementation of CITES. Since Schedule III includes several CITES listed species/genus, the traders/growers need to understand inter alia both the provisions under the Chapter IIIA and VB. For proper implementation of the provisions under the Act in relation to Schedule III and IV, coordination among State Forest Departments, Customs and CITES Management Authority is imperative. Stakeholders' awareness regarding 2022 amendments needs to be promoted.

By incorporating these Schedule III plants into domestic law, India strengthens enforcement against illegal export, reduces loopholes exploited by wildlife traffickers and enhances compliance with international conservation obligations. This harmonization improves India's credibility in global biodiversity governance.

Conservation and Socio-Economic Significance

The introduction of Schedule III has multiple benefits, biodiversity conservation by protecting rare and endemic plant species from extinction, providing sustainable livelihoods by encouraging regulated cultivation by farmers, nurseries, and tribal communities, promoting scientific research by facilitating lawful access for research and conservation breeding, and awareness and accountability by bringing plants into mainstream wildlife protection discourse. Importantly, it recognizes that like animals, plants also require legal safeguards due to their ecological and economic value.

Challenges

With proper execution, Schedule III can become a model for plant conservation in biodiversity-rich countries. Despite its progressive intent, the introduction of Schedule III for specified plant species has several limitations and practical challenges that may affect its effective implementation.

For legal trade/dealing/possession of any Schedule III species, the growers or traders must obtain a license from the concerned chief wildlife warden of the state/ union territories and declare their stock of such specified plants (Schedule III). Also, there is a need for proper identification of the species and their parts/ products and derivatives during trade/transit which is a major challenge for the law enforcement agencies. The MoEF&CC, Government of India, notified a list of 23 designated Scientific Authorities under the CITES recently and for identification/scientific advice/ Non-detriment Finding study report, necessary guidance/assistance may be taken from the concerned/appropriate scientific authority designated for the purpose.

The requirement of permits for cultivation, possession, sale, and transport may lead to delays in approvals, increased paperwork and administrative bottlenecks. This can discourage genuine cultivators, researchers, and small-scale nurseries from engaging in legal plant trade. Many farmers, traders, nursery owners, and even local forest officials are unaware of Schedule III provisions and don't have a clear understanding about permit procedures and compliance requirements. This knowledge gap may result in unintentional violations of the law.

Distinguishing legally cultivated plants from illegally collected specimens from wild remains difficult. Forest departments often face shortage of trained manpower, lack of botanical expertise for species identification, limited infrastructure for monitoring cultivation and trade.

Image 2. A—*Aenhenrya rotundifolia*. © U.C. Pradhan | B—*Odontochilus grandifloras* | C—*Zeuxine andamanica*. © S. Mishra | D—*Vrydagzynea viridiflora* © fide Gogoi, 2016 | E—*Habenaria barnesii*. © C. Sathishkumar | F—*Ipsea malabarica*. © S. Suresh, through C. Sathishkumar | G. *Rhomboda pulchra* | H—*Podophyllum hexandrum* | I—*Dolomiaea costus*. © B,G,H,I—Avishek Bhattacharjee

Image 3. A—*Podophyllum hexandrum* (dry fruits) | B—*Dolomiaea costus* (dried roots)| C—*Dolomiaea costus* (dried flowers). © Avishek Bhattacharjee

Schedule III mainly regulates trade and possession, but does not directly address survival problems arising due to habitat loss, climate change, or invasive species, and thus, may not fully protect species whose survival depends on ecosystem-level conservation. Local communities and indigenous groups who traditionally use or cultivate these plants may face legal hurdles, reduced access, lack of clear exemptions or simplified procedures. This could negatively affect livelihoods and traditional knowledge systems. Furthermore, Schedule III overlaps with forest laws, Biodiversity Act, 2002, state-specific regulations. Such overlaps may cause confusion, duplication of permissions, and legal complexity.

Future Scope and Way Forward for Schedule III of the Wild Life (Protection) Amendment Act, 2022

The introduction of Schedule III marks an important milestone in India's plant conservation regime. However, its long-term success depends on adaptive governance, scientific support, and stakeholder participation. The following measures outline the future scope and strategic way forward.

1. Expansion and periodic revision of Schedule III: i) additional threatened, endemic, and high-value plant species should be scientifically assessed and included based on IUCN status (ver3.1) and trade pressure; ii) regular revision of the Schedule will ensure responsiveness to emerging conservation threats.

2. Development of clear cultivation and certification protocols: i) standardized species-specific cultivation guidelines should be issued in consultation with botanical institutions; ii) a certification and tagging system (QR codes / barcoding) can help distinguish cultivated stock from wild-collected plants, improving traceability.

3. Simplification and digitization of permit systems: i) introduction of a single-window, online permit platform for cultivation, transport, and trade; ii) time-bound approvals of permits/ certificates will reduce processing delays and encourage legal compliance.

4. Strengthening institutional and technical capacity: i) training programs for forest officials in plant taxonomy, trade monitoring, and CITES procedures; ii) engagement of institutions like Botanical Survey of India (BSI), universities, and herbaria for scientific validation and advisory support.

5. Community and farmer participation: i) promote community-based cultivation models involving local farmers, self-help groups, and indigenous communities; ii) provide incentives such as subsidies, technical assistance, and assured buy-back mechanisms for legally cultivated plants.

6. Integration with biodiversity and climate policies: i) harmonize Schedule III implementation with the Biological Diversity Act, 2002, National Biodiversity Action Plan, and climate adaptation strategies; ii) focus on ex situ conservation, seed banks, micropropagation, and assisted regeneration programs.

7. Strengthening research and monitoring: i) encourage research on propagation techniques, population dynamics, and sustainable harvest limits; ii) establish national-level databases for tracking trade volumes and conservation status.

8. Public awareness and outreach: i) awareness campaigns targeting traders, nurseries, enforcement agencies, and the public; ii) inclusion of Schedule III species in educational curricula and conservation outreach programs.

9. International cooperation and CITES compliance: i) strengthen coordination with CITES authorities for monitoring cross-border trade; ii) promote India as a leader in plant conservation governance at global biodiversity forums.

Conclusion

The introduction of Schedule III under the Wild Life (Protection) Amendment Act, 2022 represents a historic step in India's conservation journey. By legally regulating the cultivation and trade of threatened plant species, the amendment strikes a crucial balance between protection and sustainable use. It reinforces India's commitment to conserving its unique botanical heritage while aligning national law with global environmental standards.

Protecting plants today is essential for securing ecosystems, livelihoods, and biodiversity for future generations. The future of Schedule III lies in transforming it from a regulatory instrument into a science-driven, participatory conservation framework. With improved implementation, technological support, and community engagement, Schedule III can ensure the long-term conservation of India's threatened plant species while supporting sustainable livelihoods and legal trade.

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SHORT COMMUNICATION

A century-long hiatus: rediscovery of Cadorna's Pipistrelle *Hypsugo cadornae* (Chiroptera: Vespertilionidae) from India

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Abstract: Cadorna's Pipistrelle is a lesser-known vespertilionid bat, described from Darjeeling in the year 1916. Since its discovery, there has been no further record of this species from India. Based on two recently collected specimens from Mizoram State, the species has been reported from India after a gap of more than a century. A detailed description and morphometric measurements of the newly collected specimens are provided.

Keywords: Indo-Burma biodiversity hotspot, Mizoram, morphometrics, northeastern India, vespertilionid bat.

Based on a male specimen collected during the Mammal Survey of India organized by the Bombay Natural History Society, British zoologist Oldfield Thomas described Cadorna's Pipistrelle *Pipistrellus cadornae* (Thomas, 1916). The type specimen was collected on 19 July 1915 by the veteran collector N.A. Baptista from Pashok, a village in the present Darjeeling District of West Bengal, India, at an elevation of 1,060 m. Since its original description more than a century ago, the species had not been recorded from India, resulting in considerable uncertainty regarding its current status in the country. During systematic surveys of bat fauna in the state of Mizoram, northeastern India, two male specimens of *Hypsugo* (as identified by their overall size, ear, and tragus shape) were collected; the present report documents their craniodental and bacular characteristics.

Materials and Methods

As part of a systematic assessment of the bat fauna of Mizoram State, field surveys were carried out at Sairep (22.9800° N, 92.7491° E, 1,450 m) in Lunglei District and Reiek (23.6922° N, 92.6063° E, 1,260 m) in Mamit District during October 2023 and March 2025, respectively. A two-bank harp trap (Austbat, Australia) and monofilament mist nets were employed for bat sampling. Both individuals were caught in the harp trap, euthanized, preserved in ethanol, and deposited in to the collection of Zoological Survey of India, Shillong under the registration nos. V/M/ERS/742 (Sairep specimen) and V/M/ERS/788 (Reiek specimen). The cranium and baculum of the specimens were extracted

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and prepared following established protocols (Topál 1958). Craniodental measurements of the vouchers were obtained with a digital calliper (Sylvac, Switzerland) accurate to the nearest 0.01 mm following standard methods. Unfortunately, due to possible issues with preservation, no genetic material could be extracted from any of the specimens.

The acronyms for measurements are: Tail length (TL); Ear length (E); Tragus length (TR); Hindfoot length excluding claw (HF); Forearm length (FA); Tibia length (TB); 3rd Metacarpal length (3MT); 4th Metacarpal length (4MT); 5th Metacarpal length (5MT); Greatest length of skull including incisors (GTLi); Condylocanine length (CCL); Maxillary toothrow length (CM^3); Width across third molars (M^3-M^3); Width across canines (C^1-C^1); Zygomatic breadth (ZW); Postorbital constriction (PoC); Breadth of braincase (BW); Mastoid breadth (MAB); Skull height (SKH); Length of mandible including incisors (MLi); Mandibular toothrow length (CM_3); Height of coronoid process (COH).

For comparison, the following museum specimens were examined. Museum acronyms are as follows – CBC: Center for Biodiversity Conservation, Phnom Penh, Cambodia; CDZTU: Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal; HNHM: Hungarian Natural History Museum, Budapest, Hungary; HZM: Harrison Institute (formerly Harrison Zoological Museum), Sevenoaks, UK; IEBR: Institute of Biology (formerly Institute of Ecological and Biological Resources), Hanoi, Vietnam; NHMUK: The Natural History Museum (formerly British Museum (Natural History)), London, UK; ROM: Royal Ontario Museum, Canada;

H. cadornae: CAMBODIA: CBC IS.010310.2; INDIA: NHMUK 16.3.25.6 (holotype); LAOS: ROM 106385; 110471, 110479, 118267, 118288, 118306, 118327, 118328; MYANMAR: NHMUK 1997.375, 50.466, 50.467, 50.480, 76.1266; NEPAL: CDZTU (no number); VIETNAM: HNHM 2014.3.2; HZM 1.30538, 2.32164, 3.32165, 4.32166; IEBR 2556, 3266, 3269, PM05; ROM 106200, 106201, 106202, 107650, 107653.

Results

Descriptions of the specimens: The forearm length of the newly recorded specimens are 35.0 and 35.7 mm. The dorsal fur is chocolate brown with a slight glossy

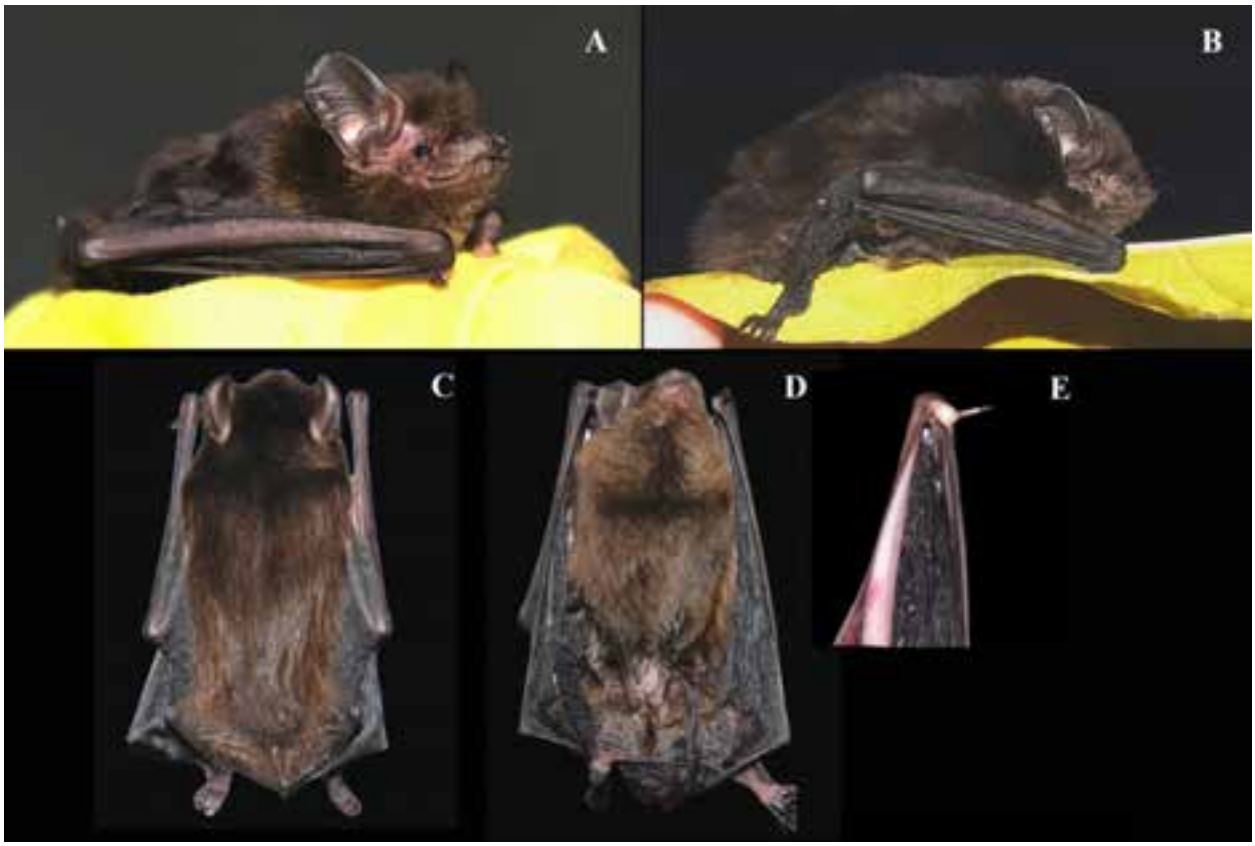

Image 1. Habitus of *Hypsugo cadornae* specimens from: A—Sairep V/M/ERS/742 | B—Reiek V/M/ERS/788 | C—dorsal | D—ventral aspects of fur | E—thumb callosity of the V/M/ERS/742 specimens (not to scale). © Uttam Saikia.

sheen, while the ventral fur is a lighter brown (Image 1). The bases of both dorsal and ventral hairs are dark brown. The wing and tail membranes are dark brown. The muzzle bears scattered hairs and swollen glands. The ears are broad; the distal margin is straight and rises to form a broadly rounded tip, whereas the proximal margin descends straight for approximately two-thirds of its length before curving inward to join the ear base. Five horizontal ridges are present across the distal half of the pinna. The tragus is short, wide, and curves inward.

Among the wing elements, the third metacarpal is the longest, followed by the fourth and fifth metacarpals (Table 1). The thumb bears a prominent oval callosity. The wing membrane attaches at the base of the toes. The calcar runs for around two thirds along the edge of the interfemoral membrane and has a longish lobe. The interfemoral membrane attaches to the feet at the tibio-metatarsal joint (the origin point of calcar). The tail is enclosed within the interfemoral membrane except for the terminal tip. The testes of the Sairep specimen collected in October 2023 were swollen. In both individuals, the penis is thick, hirsute, and lacks any distinct modifications.

The cranium, in lateral view, exhibits an almost straight dorsal profile, except for a slightly elevated midsection (Image 2). The sagittal and lambdoid crests are moderately developed. In dorsal view, the braincase appears globose, the zygomatic arches are slightly flared outward, and the narial emargination is V-shaped. The first upper incisor is bicuspid and approximately equal in height to the second incisor. A distinct diastema is present between the second incisor and the canine. The canine is robust, unicuspid, and approximately twice the height of the second premolar. In the upper toothrow the first premolar is minute and completely displaced from the toothrow, resulting in direct contact between the canine and second premolar; the first and second molars possess nearly equal crown areas. The third molar is reduced, parastyle, and protocone are absent. The lower canine is weak, and the first lower incisor reaches about two thirds the height of the canine. Second lower premolar is higher than the first but does not attain the

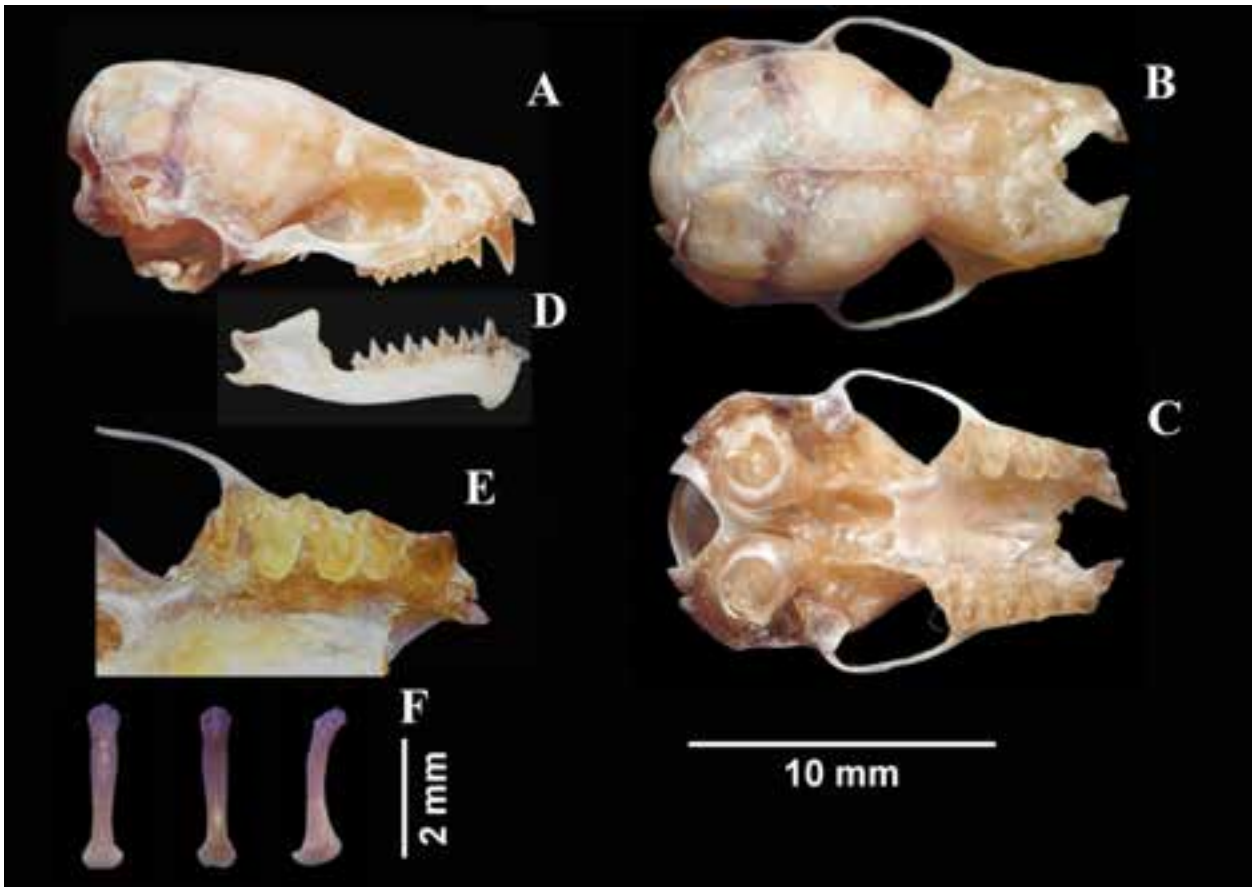

Image 2. *Hypsugo cadornae* Reiek specimen (V/M/ERS/788): A—lateral view of cranium| B—dorsal view of cranium| C—ventral view of cranium| D—lateral view of mandible | E—close-up occlusal view of the right maxillary dentition | F—dorsal, ventral & lateral view of baculum. © Uttam Saikia.

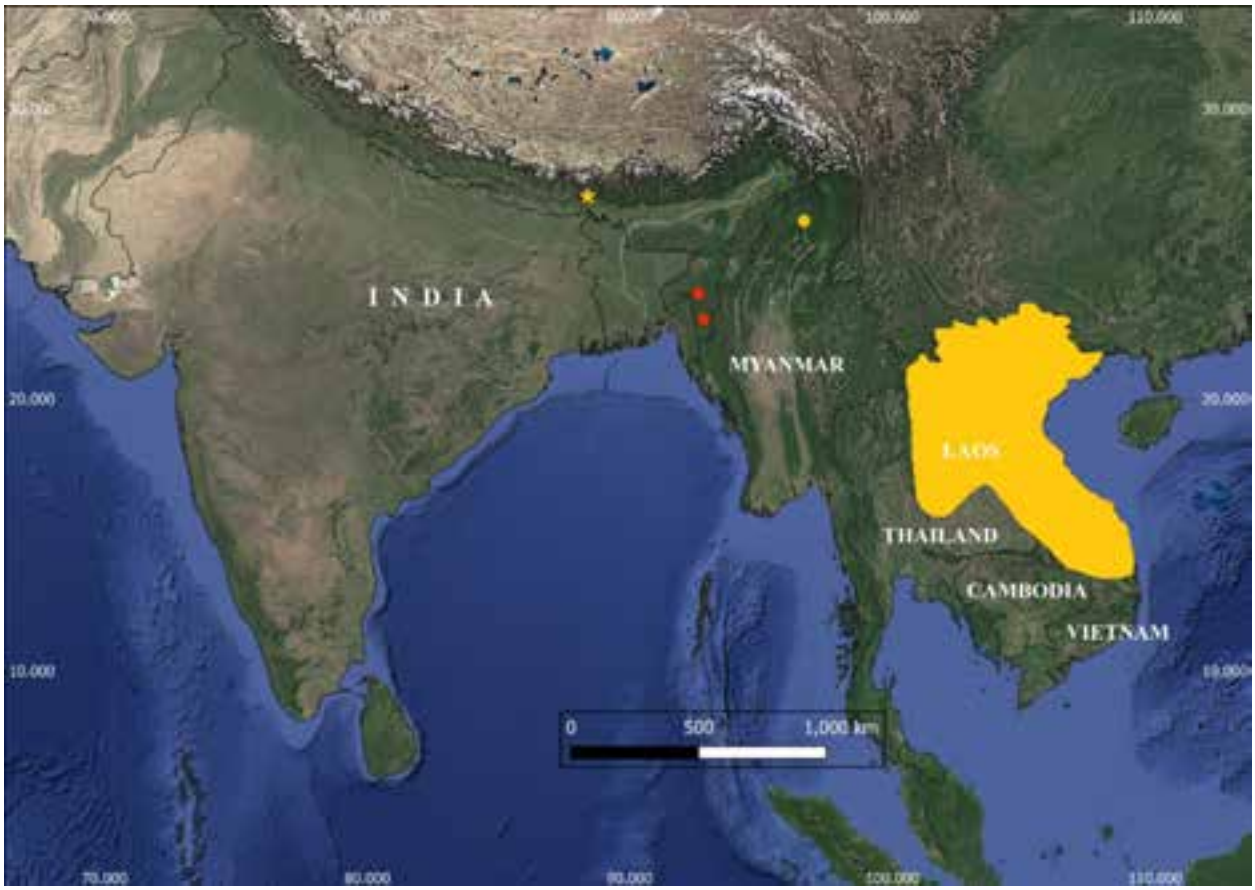

Image 3. Distribution of *Hypsugo cadornae*. The yellow colour indicates the distribution after Bates et al. (2019) with the type locality denoted by an asterisk; current records are marked by red dots.

height of the lower canine. The first two lower molars possess a myotodont cusp structure. The third molar is slightly reduced than the first two in surface area.

The baculum measures 2.35 mm in both specimens. In dorsal view, the baculum has a bulbous base, from which the shaft gradually widens to reach its maximum width at approximately two-thirds of its total length. Distal to this point, the shaft tapers slightly and terminates in a broad, rounded tip; in lateral view, the shaft curves anteriorly (Image 2F). It possesses a deep ventral groove.

The overall size, ear and tragus shape, combined with the bacular traits and myotodont dental characteristics, undoubtedly identify the two specimens as *Hypsugo*; within the genus, as defined by the FA length (below 37 mm), and the minute, labially fully intruded P2, they evidently represent *H. cadornae*.

Ecological notes: At Sairep Village, the individual was caught in the harp trap set across a forest trail. The sampling area was situated at a hilltop surrounded by tropical evergreen forest and bamboo clumps. At Reiek, the specimen was caught in the harp trap set across a dry stream bed surrounded by tropical semi evergreen forest. Both the locations are in the vicinity of human habitations indicating its adaptation to human proximity. Although all the Indian records (Image 3) thus far are from mid elevation ranges (1,060–1,450 m), in other parts of the range, it was recorded from lowland forests and near human periphery (Bates et al. 2005; Xie et al. 2021) indicating broad ecological adaptations. Presence of distinct thumb pads in the specimens may also indicate roosting habits in smooth surfaces like bamboo internodes etc. Although no echolocation calls could be recorded, the reported maximum echolocation call frequency of 65.60 ± 4.89 kHz in China is suitable for hunting hard bodied insects like beetles or bugs (Xie et al. 2021).

Discussion

Hypsugo cadornae is a widely distributed vespertilionid bat in southeastern Asia but confirmed locality records across the region remain sporadic (Bates et al. 2019). Interestingly, apart from its type locality, the species has not been documented elsewhere in

Table 1. Comparative morphometric details (in mm) of *Hypsugo cadornae* from Mizoram, India and from other parts of its distribution range including the type specimen (refer to comparative materials).

Parameter	Sairep V/M/ERS/742	Reiek V/M/ERS/788	Holotype	Specimens from SE Asia
Wt (g)	6.0	7.0	-	-
TL	38.0		-	-
E	12.0	13.9	-	-
TR	4.8	5.8	-	-
FA	35,0	35.7	-	35.4 ± 1.20 33.2–37.0 (19)
TB	15.7	15.8	-	15.2 ± 0.97 13.1–16.4 (13)
HF	5.8	6.7	-	6.1 ± 0.42 5.2–6.9 (17)
3MT	34.6		-	-
4MT	32.5		-	-
5MT	31.2		-	-
GTLi	13.70	14.56	-	13.71 ± 0.28 13.40–14.11 (23)
CCL	12.70	13.53	12.80	12.85 ± 0.23 12.44–13.32 (25)
ZB	8.73	9.73		8.73 ± 0.23 8.49–9.10 (17)
BW	6.47	7.21	7.09	6.80 ± 0.16 6.50–7.11 (23)
MAW	7.00	7.92	7.74	7.68 ± 0.22 7.09–8.01 (23)
POC	3.80		3.97	3.69 ± 0.13 3.45–3.93 (26)
SKH	5.40		5.11	4.90 ± 0.16 4.52–5.15 (24)
C^1C^1	4.55	4.88	4.76	4.61 ± 0.15 4.30–4.86 (26)
M^3M^3	6.14	6.38	6.28	5.91 ± 0.19 5.61–6.28 (25)
CM^3	4.52	4.94	4.91	4.70 ± 0.10 4.56–4.88 (26)
MLi	9.90		9.75	9.71 ± 0.19 9.42–10.13 (26)
CM_3	4.93	5.53	-	5.03 ± 0.11 4.84–5.16 (26)
COH	3.07		2.81	2.71 ± 0.09 2.53–2.87 (25)
Baculum length	2.35	2.35	-	-

India. This apparent rarity is likely attributable to the lack of extensive field surveys and rigorous taxonomic investigations, a pattern that broadly characterizes bat research in India. However, recent records from two localities in Mizoram suggest its continued presence in suitable habitats of northeastern India. Although classified as 'Least Concern' on the IUCN Red List (Bates et al. 2019), the species remains poorly studied, and the absence of population data highlights the need for further surveys and conservation-focused research across its range.

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SHORT COMMUNICATION

Photographic record of the Painted Bat (Chiroptera: Vespertilionidae: *Kerivoula picta* (Pallas, 1767)) from the Terai Region of Uttar Pradesh, India

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Abstract: The Painted Bat *Kerivoula picta* is a distinctive foliage-roosting vespertilionid, widely distributed across southern and southeastern Asia. This study reports the photographic records of *Kerivoula picta* from the Terai region of Uttar Pradesh, northern India, based on three independent observations between 2017 and 2025. Records were obtained from Dudhwa National Park (January 2017), Kishanpur Wildlife Sanctuary (October 2024), and Pilibhit Tiger Reserve (October 2025). The morphological features of all individuals were bright orange pelage, contrasting black wing membranes, orange-pigmented metacarpals, large funnel-shaped ears, and elongated tragi. These observations represent a significant northward range extension into the Terai Arc Landscape and emphasize the value of opportunistic photographic documentation. The findings also highlight the urgent need for systematic chiropteran surveys combining acoustic monitoring, and roost searches to comprehensively assess bat diversity and inform conservation planning in the Terai forests of northern India.

Keywords: Chiroptera, first record, photographic documentation, Terai Arc Landscape, Uttar Pradesh, Vespertilionidae.

Chiropterans represent the second most speciose mammalian order globally, yet remain among the most poorly studied vertebrate groups in tropical Asia. It contributes substantially to mammalian diversity and provides ecosystem services, such as arthropod suppression, pollination, and seed dispersal (Kunz et al. 2011). In India, approximately 139 bat species have been documented, representing 46 genera and nine families (Srinivasulu et al. 2026). Despite their ecological significance, distributional knowledge on bat species remains comparatively limited in several northern lowland landscapes of India, including the Terai region, where systematic surveys of chiropteran diversity remain relatively limited. The Painted Bat *Kerivoula picta* (Pallas, 1767) is a small insectivorous vespertilionid distinguished by its striking coloration bright orange to reddish-orange fur contrasting sharply with uniformly black wing membranes. This species is widely distributed across southern and southeastern

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Asia, and has been documented from India, Myanmar, Thailand, Cambodia, Vietnam, Malaysia, and Indonesia (Huang et al. 2020). In India, the Painted Bat has been documented from several states Assam, Manipur, Andhra Pradesh, Goa, Karnataka, Kerala, Tamil Nadu, Maharashtra, Odisha, Rajasthan, Gujrat, Sikkim, West Bengal (Madhavan et al. 2014; Patel et al. 2017; Saikia et al. 2020; Huang et al. 2020; Lagade et al. 2023). However, no confirmed records, whether specimen-based or photographic, have been published from Uttar Pradesh, particularly from the ecologically distinct Terai region. Despite supporting diverse mammalian assemblages, chiropteran diversity in the Indian Terai remains inadequately documented, with survey efforts primarily focused on charismatic megafauna. This knowledge gap impedes effective conservation planning and may result in underestimation of regional biodiversity. This study presents the photographic documentation of *Kerivoula picta* from three protected areas in the Terai region of Uttar Pradesh, extending the known distribution of this species northward and emphasizing the need for intensified bat survey efforts in this under-studied landscape.

Materials and Methods

Study Area

Field observations were conducted across three protected areas in the Terai region of Uttar Pradesh, northern India: Dudhwa National Park (28.52° N, 80.90° E; 490.3 km²), Kishanpur Wildlife Sanctuary (28.38° N, 80.52° E; 227 km²), and Pilibhit Tiger Reserve (28.70° N, 80.08° E; 730 km²) (Image 1). The Terai Arc Landscape spans approximately 49,500 km² across India and Nepal, forming a globally significant conservation corridor characterized by exceptional habitat heterogeneity and faunal diversity (Chanchani et al. 2014). The vegetation is predominantly moist deciduous forest dominated by *Shorea robusta* (Sal), interspersed with riverine forests along the Suheli, Mohana, and Sharda rivers, extensive grasslands composed of *Saccharum spontaneum*, *Imperata cylindrica*, and *Phragmites karka*, and forest-grassland ecotones providing structural heterogeneity (Champion & Seth 1968). Abandoned forest infrastructure, including disused guard posts (chowkis), creates potential roosting microhabitats for crevice- and foliage-roosting bat species. The region experiences a tropical monsoonal climate characterized by three distinct seasons: hot summer (March–June,

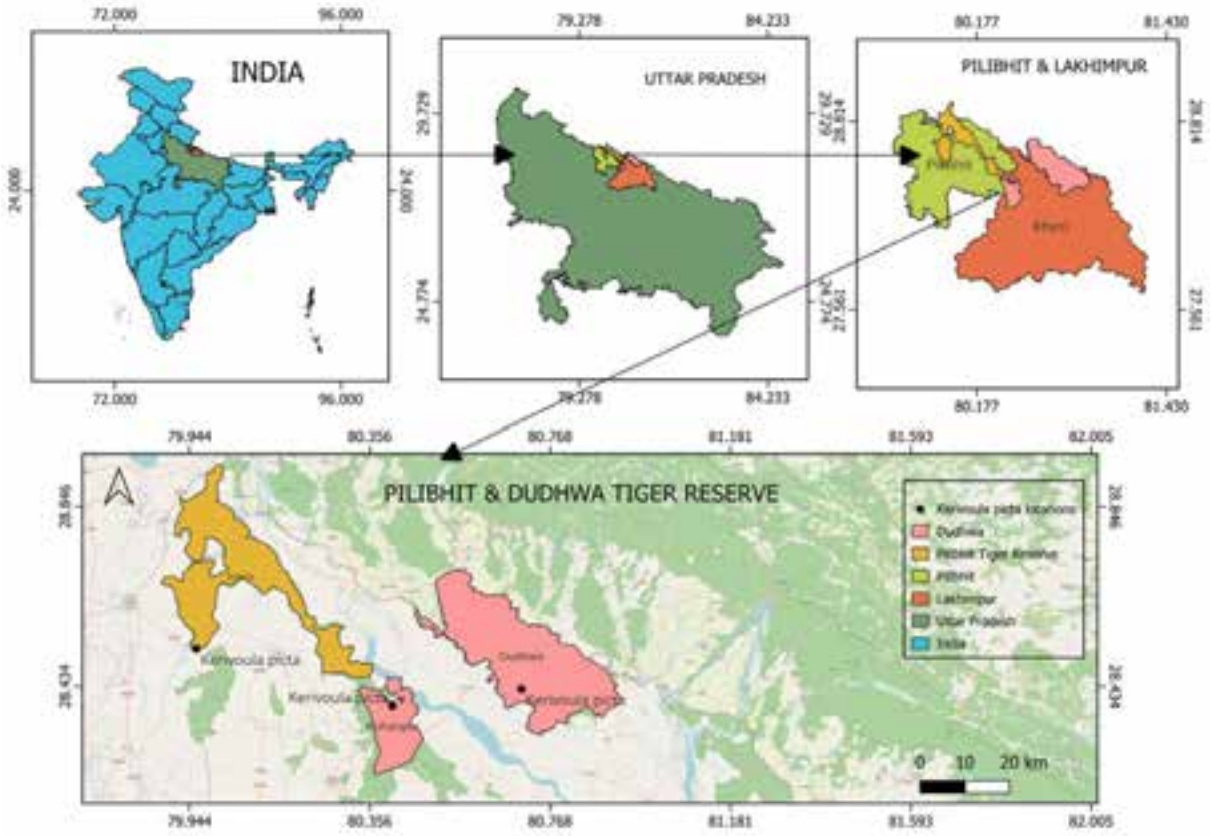

Image 1. Location map of *Kerivoula picta* sighting in Pilibhit & Dudhwa Tiger Reserve, Uttar Pradesh, India. (Source: QGIS Desktop 3.44.3)

temperatures 35–42°C), monsoon (July–September, annual precipitation 1,400–1,800 mm), and cool winter (October–February, temperatures 5–15°C).

Field Observations and Documentation

All observations were obtained opportunistically during routine field activities and wildlife monitoring programs conducted between January 2017 and October 2025. No systematic bat surveys were undertaken; rather, records represent incidental encounters during other conservation work. Individuals were observed without handling or capturing them, and efforts were made to minimize disturbance during documentation. Two individuals were photographed during direct observations through Canon EOS 200D Mark II digital camera equipped with an EF-S 18–55 mm lens, while the third individual was observed in a Cuddeback C1 camera trap with white flash, deployed at ground level (approximately, 30 cm height) along a forest trail for large mammal monitoring. Geographic coordinates of all the three observation sites were recorded using a Garmin eTrex 30x handheld GPS (accuracy ±3 m). Species identification was based on diagnostic morphological characters visible in the photographs and comparison with published taxonomic literature and identification guides (Bates & Harrison 1998; Francis 2019).

Results

All observed individuals were identified as *Kerivoula picta,* recorded from three protected areas (Dudhwa National Park, Kishanpur Wildlife Sanctuary, and Pilibhit Tiger Reserve) in Uttar Pradesh, representing the photographic evidence of this species from the Terai landscape of Uttar Pradesh (Image 1). The first observation was recorded from Dudhwa National Park in January 2017 (28.42771° N, 80.70275° E), where a single individual was encountered roosting inside an abandoned forest chowki in the Dudhwa Range during a routine patrol (Image 2a). The individual was photographed at the roost without being handled. The bat remained undisturbed during the observation.

The second observation was recorded from Kishanpur Wildlife Sanctuary in October 2024 (28.38861° N, 80.40821° E) (Image 2b), where a single individual of *K. picta* was observed roosting during daylight hours inside an abandoned forest chowki. The site was located within a riverine forest tract characterized by mixed deciduous vegetation. Multiple photographs were obtained, documenting the characteristic orange pelage, black wing membranes, orange pigmentation on the metacarpals, ear shape, tragus morphology, and overall body form. The individual was not handled, and no apparent disturbance was observed during photographic documentation.

The third record was recorded from Pilibhit Tiger Reserve in October 2025 through an incidental camera-trap photograph (28.520208° N, 79.960553° E) (Image 2c). The most striking feature was the bright orange to reddish-orange pelage covering both dorsal and ventral body surfaces. This vivid coloration was uniformly distributed across the head, neck, torso, and limbs, creating a highly distinctive appearance. The fur texture was notably long, soft, and woolly, imparting a fluffy appearance characteristic of foliage-roosting *Kerivoula* species. Wing membranes (patagia) were uniformly jet-black, providing stark contrast against the brilliant orange body fur. This colour demarcation was sharply defined along the membrane attachment line. Significantly, the orange pigmentation extended along the metacarpals and proximal portions of the wing membranes, forming distinct linear orange streaks visible both in roosting position and when wings were extended. This metacarpal pigmentation pattern represents a key diagnostic trait distinguishing *Kerivoula picta* from sympatric vespertilionids. Ears were proportionally large, distinctly funnel-shaped, and semi-translucent with visible blood vessels. The tragus was narrow, elongated, and sharply pointed, comprising approximately half the ear length. Overall body structure was small and delicate, with a fragile appearance typical of foliage-roosting species.

The combination of bright orange pelage, contrasting black wing membranes, orange metacarpal streaks, large funnel-shaped ears, elongated tragus, and delicate body structure collectively provided a definitive identification. No other bat species occurring in northern India exhibits this distinctive colour pattern and morphology. Given the species' highly diagnostic appearance, photographic documentation alone can be considered sufficient for reliable identification, as established in previous photographic records from other regions (Madhavan et al. 2014; Patel et al. 2017; Saikia et al. 2020).

Discussion

The records presented here significantly expand the documented distribution of *Kerivoula picta* in Terai Arc Landscape of northern India. The absence of records from Uttar Pradesh, particularly the Terai region, represented a conspicuous distributional gap given the species' presence in adjacent regions. Our observations bridge this geographic gap and suggest ecological continuity between the Terai Arc Landscape and other foliage-rich habitats occupied by *Kerivoula picta* elsewhere in India.

Image 2. *Kerivoula picta*: a—in Dudhwa National Park | b—in Kishanpur Wildlife Sanctuary | c—in Pilibhit Tiger Reserve. © Vipin Kapoor Sainy & Rohit Ravi.

The northward range extension documented here raises questions about potential distributional continuity across the Indo-Gangetic Plain and connectivity with populations in the Himalayan foothills. Further surveys in intervening areas, particularly in western Uttar Pradesh, Uttarakhand, and neighbouring Nepal, may reveal additional populations and clarify the species' distribution pattern in northern India.

The apparent scarcity of *K. picta* records from Uttar Pradesh likely reflects survey bias rather than genuine rarity. Foliage-roosting bats are notoriously difficult to detect using conventional survey methods (Meyer 2015). In the Terai region, conservation and monitoring efforts in protected areas have largely focused on large mammals such as Tiger, Asian Elephant, Greater One-horned Rhinoceros, and Swamp Deer, with comparatively limited attention to bat diversity. The three records presented here all resulted from incidental encounters during other activities, not from targeted bat surveys, suggesting that systematic efforts would yield substantially more records.

The habitat contexts of our three records provide insights into the roosting ecology of this species in the Terai region. The species has previously been recorded from a variety of habitats, including dry deciduous forests, dry dipterocarp forests, small woodland patches, floodplains, and agricultural landscapes such as paddy fields, mainly in dried banana leaves, dry grass, and sugarcane, as well as occasionally in green leaves of banana and broadleaf trees, orchards, and mixed plantations (Madhavan et al. 2014; Funakoshi et al. 2015; Hawkeswood & Sommung 2017; Patel et al. 2017). All three records in the present study were obtained from dry deciduous forest habitats. Two individuals were found roosting inside abandoned forest chowkis, while the third individual was recorded along a forest trail. The

occurrence of all three records in dry deciduous forest is consistent with previously reported habitat associations of *K. picta*. The two roosting records also indicate that the species may use abandoned man-made structures as roosting sites. However, further systematic studies are required to determine its roosting-site preferences and habitat requirements in the Terai region. The three records were obtained in January and October, indicating that *K. picta* occurs in the study area during both winter and post-monsoon periods. However, the limited number of observations does not allow conclusions about seasonal movements or residency. Further systematic surveys across seasons are needed to determine the seasonal occurrence, roosting ecology, and habitat use of the species in the Terai region.

Conclusion and Recommendations

This study documents three photographic records of *Kerivoula picta* from Dudhwa National Park, Kishanpur Wildlife Sanctuary, and Pilibhit Tiger Reserve in the Terai region of Uttar Pradesh. These observations provide additional distributional evidence for the species and emphasize the value of opportunistic photographic and camera-trap records in documenting bats in the region. Further future studies should be focus on systematic methods, including acoustic monitoring, mist-netting, and roost searches, to document bat diversity and habitat use across different seasons and habitats. Strengthen awareness and capacity of forest department staff and local researchers in bat survey techniques, acoustic analysis, and non-invasive monitoring methods to support long-term monitoring efforts and conservation of bats in the Terai landscape.

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SHORT COMMUNICATION

New record of the Indian Roofed Turtle *Pangshura tecta* (Gray, 1831) (Reptilia: Testudines: Geoemydidae) from Jaisamand Lake, Rajasthan, India

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Abstract: The Indian Roofed Turtle *Pangshura tecta* (Gray, 1831) is a vulnerable freshwater geoemydid with a fragmented and poorly documented distribution in Rajasthan, India. Here, a recent observation of a *P. tecta* is reported from near Jaisamand Lake, Udaipur District, based on diagnostic morphological characters and colouration patterns. This record represents a significant and possibly new confirmed contemporary occurrence of *P. tecta* from southern Rajasthan in over three decades. The finding suggests the continued persistence of *P. tecta* in the region and highlights the urgent need for targeted surveys to assess its distribution, habitat use, and conservation status in southern Rajasthan.

Keywords: Biodiversity monitoring, citizen science, conservation monitoring, conservation status, freshwater chelonians, freshwater geoemydid, range extension, range record, re-sighting, wetland biodiversity.

The Indian Roofed Turtle *Pangshura tecta* (Gray, 1831) is a small freshwater turtle of the family Geoemydidae, characterized by a distinctly elevated, roof-shaped carapace bearing a prominent median keel on the vertebral scutes, a pointed snout, and conspicuous colouration patterns on the head and neck (Hanfee 1999). The species is native to the major lowland river systems of southern Asia and is distributed across India, Pakistan, Bangladesh, and Nepal (Ahmed et al. 2021). It inhabits rivers, oxbow lakes, floodplain wetlands, and associated lentic habitats within the Ganges, Brahmaputra, Indus, Mahanadi, and their tributaries, with confirmed records from sites such as Koshi Tappu Wildlife Reserve, Nepal (Das 1991; Iverson 1992; Ahmed et al. 2021). The species is currently assessed as 'Vulnerable' on the IUCN Red List of Threatened Species, primarily due to population declines resulting from exploitation for food, illegal trade for the pet market, and the use of dried plastron in traditional Chinese medicine (Choudhury & Bhupathy 1993; Ahmed et al. 2021). In India, *P. tecta* is afforded the highest level of legal protection under Schedule I of the Wildlife (Protection) Act, 1972**,** prohibiting its capture, trade, and exploitation.

Records of the Indian Roofed Turtle from Rajasthan are extremely scarce (Bhupathy & Mathur 2013). Over the past three decades, the only confirmed record from the state is from Keoladeo National Park, Bharatpur (Hanfee 1999; Bhupathy & Mathur 2013). Subsequently, Johnson et al. (2021) reported a single individual between the Kota barrage and the Jawahar Sagar dam. Historical accounts further suggest that the species was once abundant in the lakes (i.e., Fatehsagar and

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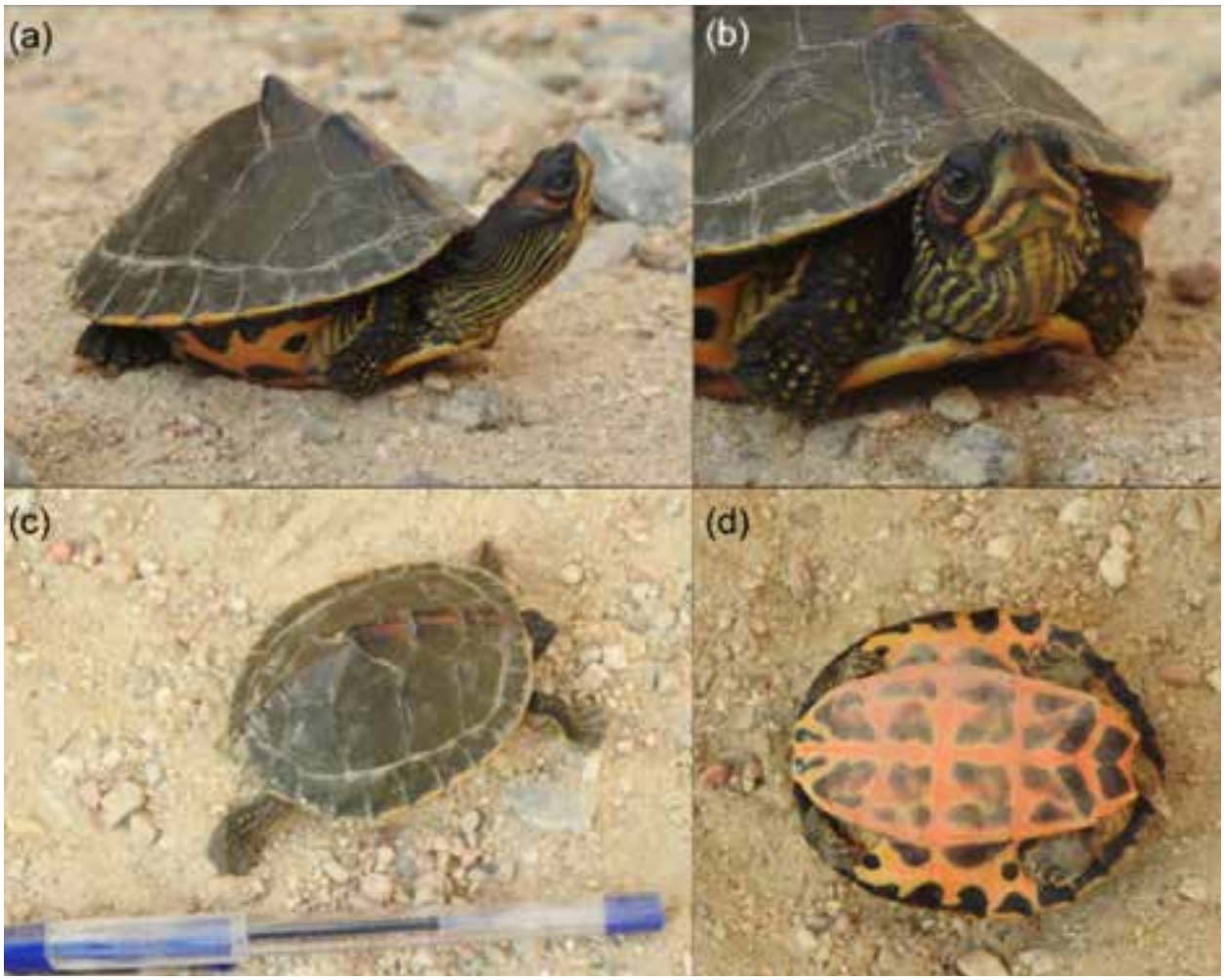

Image 1. A—side | B—front | C—dorsal | D—ventral views of the Indian Roofed Turtle *Pangshura tecta* (Gray, 1831) sighted in Jaisamand Lake, Udaipur District, Rajasthan, India. © Vijay Kumar Koli.

Pichola lakes) of Udaipur city prior to 1992 (S.K. Sharma pers. comm. 29 December 2025; Sharma 2014). More recently, the species was reported from Pichola Lake in 2025, located approximately 45 km north (aerial distance) of the present observation site. In the southern direction, Ahmedabad (Gujarat State) represents the nearest available distribution record, approximately 196 km away (aerial distance) (iNaturalist 2026; India Biodiversity Portal 2026). Additional recent observations from several localities within Rajasthan have also been uploaded through citizen-science platforms during the last few years (iNaturalist 2026). Here, we report a new sighting of *Pangshura tecta* based on a turtle sighted in Udaipur, Rajasthan.

Observation

On 28 December 2025, at approximately 0700 h, a slow-moving juvenile turtle (Image 1) was sighted along the roadside near the edge of Jaisamand Lake (24.269° N, 73.955° E; elevation 305 m; Image 2) in Udaipur District, Rajasthan.

The individual exhibited a dark olive to blackish head with bright yellow to orange longitudinal stripes extending from the snout along the sides of the head and neck (Images 1A&B). A conspicuous crescent-shaped orange post-orbital blotch was present behind each eye. The carapace was olive to olive-brown with a distinct and well-developed median keel (Images 1B&C), while the plastron was yellow to orange with irregular dark brown blotches (Fig. 1d). Morphometric measurements recorded were: straight carapace length = 6.7 cm, straight carapace width = 5.4 cm, plastron length = 6.2 cm, and plastron width = 3.2 cm.

Discussion

Based on diagnostic morphological characters and

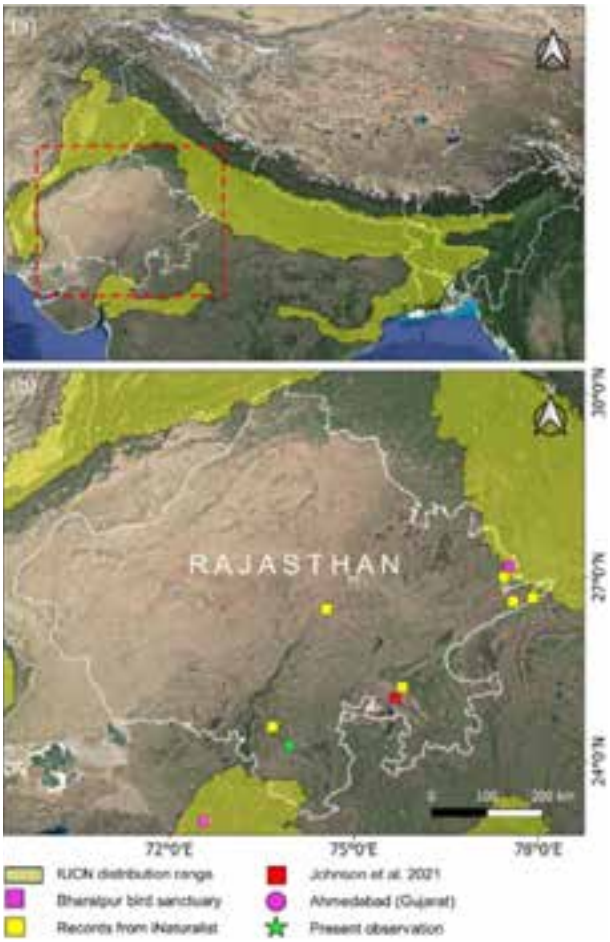

Image 2. A—The distribution range of The Indian Roofed Turtle *Pangshura tecta* (Gray, 1831) | B—its presence records in the state of Rajasthan, India and closest record in Gujarat State (i.e., Ahmedabad).

colouration patterns, the specimen was identified as *Pangshura tecta*. Following available literature (Hossain et al. 2013), the identification was subsequently confirmed by Dr. Satish Kumar Sharma (pers. comm. 29 December 2025). Jaisamand Lake (also known as Dhebar Lake), Asia's second-largest artificial lake (~36 km^2), is subject to intensive tourism and fishing activities and serves as a major source of water supply for Udaipur City and surrounding areas. The lake receives water from four main rivers namely Gomti, Jhamari, Rooparel, and Bagaar; it also supports diverse aquatic biota (Balai et al. 2020). The occurrence of the turtle on the roadside suggests that the individual may have been accidentally captured in fishing gear and subsequently released, or that it had moved onto land for basking or dispersal. This species is frequently kept as a pet across India, even in cities not in its known distribution range (Choudhury & Bhupathy 1993). Release of a pet turtle into the Jaisamand Lake is also a possibility which cannot be discounted.

Although the broader IUCN distribution range of *P. tecta* marginally overlaps with the eastern and southern fringes of Rajasthan (Ahmed et al. 2021), confirmed locality records from these regions remain limited. Published accounts indicate that records of *P. tecta* from Rajasthan are extremely limited and fragmented, with most known occurrences concentrated in eastern parts of the state and adjoining river systems (Bhupathy & Mathur 2013). Therefore, a new record from Jaisamand Lake would represent an important range extension into southern Rajasthan and improve current understanding of the species' regional distribution. Considering the relative number of seasonal and perennial wetlands in southern Rajasthan, as well as the conservation perspective, targeted species-specific surveys are urgently required to assess the current distribution, habitat associations, and population status of *P. tecta* across the state.

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SHORT COMMUNICATION

Observations on the dental morphology of the North African Sandfish *Scincus scincus* (Squamata: Scincidae)

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Abstract: The dental morphology of the North African Sandfish Lizard *Scincus scincus* (Linnaeus, 1858) was studied using field emission scanning electron microscopy. The primary aim of the study was to observe structural features of teeth in the species and generalize functional adaptations with respect to its feeding ecology. Specimens were euthanized, decapitated, the cranial removed and tissues macerated, using standard protocols. Cranial elements, including maxillary and mandibular elements were prepared separately using an ethanol series, critically point-dried, and examined under an electron microscope. *S. scincus* exhibits monostichous, bicuspid, sub-equal, sub-conical, posteriorly-oriented mandibular, and maxillary teeth rows comprising of faint ridges. The dentition appeared to mirror a predator of arthropods, as in a majority of members of the lineage, in addition to adaptations for larger prey, such as small vertebrates.

Keywords: Cranial elements, dentition, feeding ecology, generalize functional, sandfish skink, scanning electron microscopy, structural features of teeth.

The Scincidae is one of the largest families within the Squamata (Uetz et al. 2026) and exhibits a wide array of ecologically diverse species (Greer 2007). While the greatest diversity is associated with tropical forests, significant numbers are to be encountered in more arid regions, such as steppes and deserts (Greer 2007; Melville & Swain 2000). Their diets are also diverse, including herbivory, carnivory, and omnivory (Greer 2007). Skinks exhibit polyphyodontic dentition, where teeth are replaced multiple times in their life time (Ramzade et al. 2024). Based on dietary adaptations, dental morphology can be characterized as narrow and cylindrical tooth, these being bluntly pointed or with sharp edges and may either show multiple ridges, a feature that is sometimes absent (Townsend et al. 1999; Greer 2007; Bhattacharya & Das 2026). However, little is known about the adaptations of dental morphology, especially macro or micro dentition structures, their specific functions and correlation with feeding ecology.

The genus *Scincus* comprises five species from the Saharo-Arabian region (Šmíd et al. 2021). The Sandfish Lizard, *Scincus scincus* (Linnaeus, 1758), arguably the most familiar amongst these, is a diurnal, deserticole species and known from across northern Africa and south-western Asia (Schleich et al. 1996; Stadler et al. 2016). Due to extreme environmental conditions of such areas, including high temperatures and low humidity, morphological, and physiological adaptations are necessary for survival of species inhabiting such extreme environments (Stadler et al. 2016). *S. scincus* maintains its body temperature by burying itself in sand layers, only surfacing for foraging, mating, and

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defecating (Hetherington 1992; Stadler et al. 2016). Its movement in sand is characterized as 'fish-like', hence its name in English, as well as in numerous vernacular names (Stadler et al. 2016).

Scincus scincus is reportedly a dietary generalist (Attum et al. 2004, 2006; Kosma 2004; Salem et al. 2017), its diet including members of the orders Coleoptera, Araneae, Diptera, Orthroptera, and Lepidoptera (Attum et al. 2004). Additionally, seeds and vegetation have also been found in stomachs of the species, assumed to be intentionally consumed due to their high frequency of occurrence. The occurrence of *Acanthodactylus longipes*, a diurnal species of Lacertidae in a stomach sample of *S. scincus*, suggests opportunistic feeding of small vertebrates. Wind-blown detritus materials, such as seeds and dry leaves, have also been recorded in its diet (Attum et al. 2004).

In the present study, we observed structural features of dentition and attempted to correlate with the known feeding ecology of *S. scincus*. Two individuals of the lizard from the pet trade were examined, and were of unknown origin, although the nominotypical subspecies is the most commonly encountered in the pet trade, and reportedly originates from Egypt (Al-Johany et al. 2021).

Material and Methods

Two specimens of adult *S. scincus* (UNIMAS 9812, 9813) were used for studying gross dental morphology. The specimens obtained from a commercial importer and euthanized using tricaine injection. Subsequently, they were decapitated, the cranium macerated and manually cleaned with commercial detergents for removal of skull muscles and tissues in the laboratory. Mandibles and maxillae were dehydrated using ethanol series and critically point dried (Das & Coe 1994) with Quotum™ K 850 Dryer (12 V dc), riveted to 4 mm aluminum stubs, platinum-coated using a Jeol™ JEC-3000FC autofine coater, set to auto function at 300 secs / 20 mA. The prepared samples were observed using field-emission scanning electron microscope (FE-SEM) (Jeol™ JSM-IT500) (Delgado et al. 2003).

Screen captures of key areas were saved as tiff files and edited using Photoshop 2024 (version 26.1). Voucher specimens were retained in the systematic collection of the Museum of the Institute of Biodiversity and Environmental Conservation, UNIMAS (UNIMAS 9812, 9813).

For nomenclatural conformity, we use cusps to refer to obtuse, rounded structures on occlusal surfaces of teeth of both jaws, ridges for striations on body of tooth ('crests' of Caputo 2004; 'apicobasal striations' of Cernanský et al. 2019); and occlusal grooves ('sulcus' of Caputo 2004). Tooth counts were made on the left/right (L/R) sides of maxilla (including premaxillary and maxillary bones) and the mandible.

Results

Teeth were observed to be monostichous, bicuspid, sub-equal, sub-conical, and posteriorly-oriented, both mandibular and maxillary teeth showing weak ridges (Image 1). The occlusal surfaces were flat and rounded. maxillary tooth counts were 17/18, while mandibular counts were 16/17.

The maxillary teeth were oriented obliquely towards the oral cavity. Dental cusps were well defined, each tooth basally with weak longitudinal ridges (Image 1D). Anterior mandibular teeth exhibited recurved, pointed tips, as well as faint ridges (Image 1F), followed by sub-equal and sub-conical teeth in mesial and posterior mandible. Lingual aspect of both maxillary and mandibular teeth was characterized by flattened surfaces with indistinct ridges; whereas the labial aspect was smooth with absence of ridges or cusps. No diastema was observed in either maxillary or mandibular teeth rows. Apical tooth crown of maxillary and mandibular teeth comprised of flattened surfaces (characterized by a distinctly smooth appearance, rendered shiny due to platinum coating in the FE-SEM images). The resorption pits were primarily circular in shape.

Discussion

Our findings match the brief morphological description of *S. scincus* dentition by Kosma (2004), with teeth crowns being bicuspid, conical, consisting of constricted faint ridges on the lingual side. The bicuspid squamate tooth is considered an adaptation for grasping and manipulating prey, primarily insects (Townsend et al. 1999; Caputo 2004). The anterior teeth of mandible exhibited recurved tooth crowns, whereas mesial and posterior teeth were observed to be flattened and rounded, similar to *Scincella lateralis* (Townsend et al. 1999; see Image 1). Recurved teeth have been considered adaptative for rupturing slippery prey items such as earthworms in *Coeranoscincus reticulatus* (Greer 2007) which can be compared to the presence of larvae and pupae of Coleoptera in the diet of *S. scincus* (Attum et al. 2004; Kosma 2004). Unlike *S. lateralis* which exhibits both labial and lingual cusps, the latter was not observed in *S. scincus* (Townsend et al. 1999).

Blunt and flattened tooth crowns have been considered as an adaptation for either durophagy or omnivory (Townsend et al. 1999; Caputo 2004), and

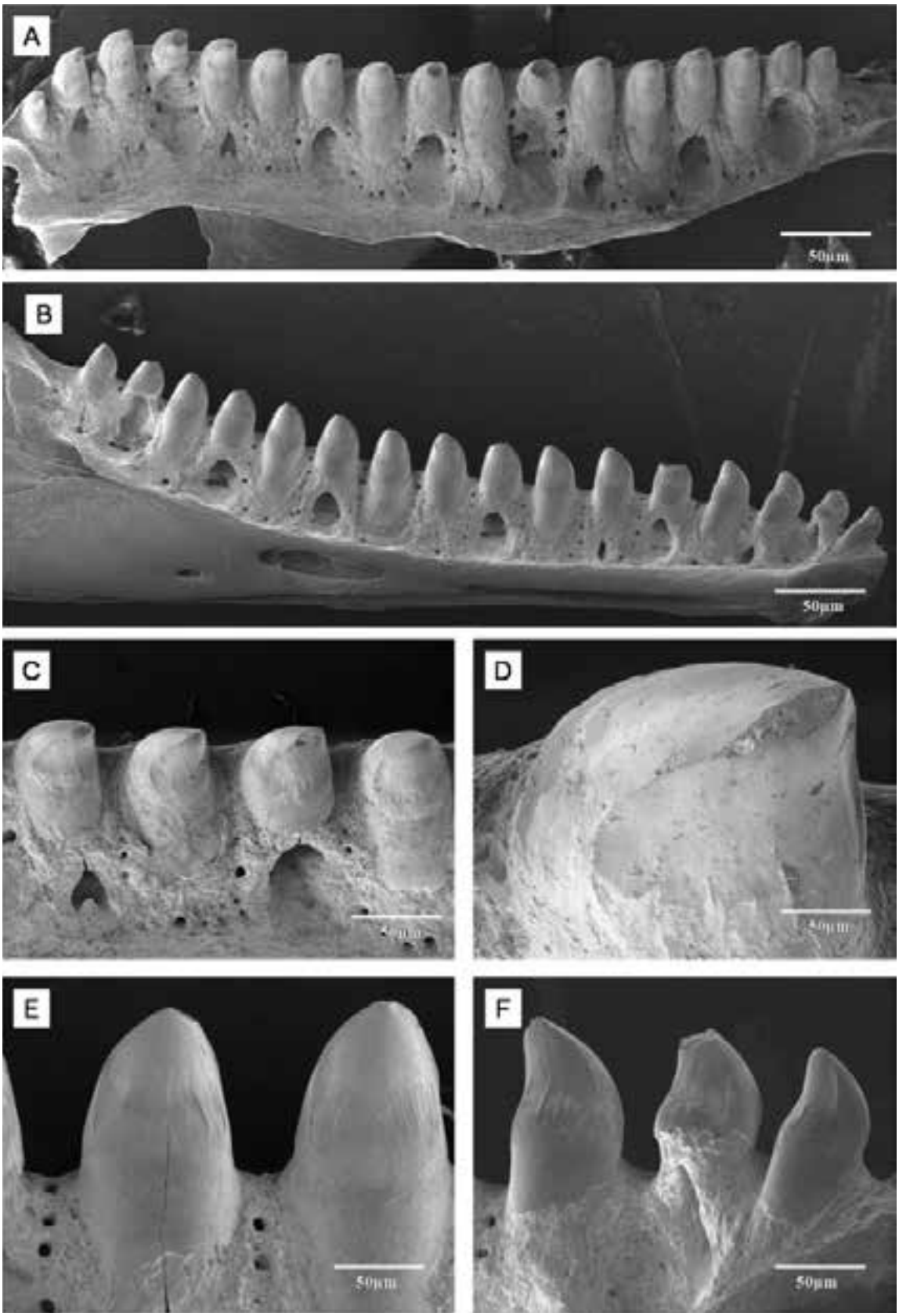

Image 1. Maxilla and mandible of *Scincus scincus* (UNIMAS 9812, 9813): A—Right maxilla | B—Right mandible | C—Maxillary teeth rows | D—Magnified (300x) image of maxillary teeth (dorso-lateral view) | E—Posterior mandibular teeth (row) | F—Magnified (100x) image of anterior mandibular teeth. © Shreya Bhattacharya and Indraneil Das.

are comparable to maxillary, mesial, and posterior mandibular teeth in *S. scincus.* The current species is known to feed on scorpions, coleopterans of genus *Phyllognathus*, *Pentodon*, and *Pimelia*, among others that possess strong exoskeleton (Attum et al. 2004; Kosma 2004). Vegetation, including flowers (*Genista saharae*) and seeds (*Aristidia pungens*, *Retama raetam*, *Cyperus conglomeratus*) has also been recorded in its diet (Attum et al. 2004; Kosma 2004). It can be concluded that the dental morphology is adaptive for both durphagy and omnivory. *S. scincus* is opportunistically known to feed on *Acanthodactylus longipes,* a syntopic desert lizard (Attum et al. 2004). The anterior recurved, mandibular teeth, along with flattened, blunt maxillary teeth are suspected to serve as adaptations for capturing, holding, and processing large prey types. A similar dental pattern has been observed in the omnivorous *Varanus olivaceus*, which exhibits recurved conical mesial teeth, followed by blunted posterior teeth, possessing faint ridges (Melstrom 2017), features reminiscent of the non-familial species being reported.

Squamates can be considered as ideal study subjects for exploring relationships between dentition morphology and dietary patterns, as they exhibit diverse feeding preferences and variation in dentitional complexities (Christensen & Melstrom 2021). Research on squamate dentition is rare, compared to mammals and hence, there exists a considerable knowledge gap in understanding of dentitional morphology and function (Razmadze et al. 2024). The outcomes of the present study contribute to our understanding of dental adaptations and its potential functions.

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SHORT COMMUNICATION

New distribution records of two *Lithurgus* bee species (Hymenoptera: Megachilidae) from Jammu & Kashmir, India

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Abstract: The present study provides new distributional record of *Lithurgus* bees of the family Megachilidae. *Lithurgus albofacialis* (Gupta) and *Lithurgus atratus* (Smith) are new records for Jammu & Kashmir region. Detailed notes on diagnostic features, material examined, and precise locality data are provided. These findings extend the known geographical range of both species in the region and contribute to the understanding of Megachilidae diversity in India. The study underscores the importance of continued faunal surveys for documenting the bee fauna of the Himalayan biodiversity hotspot.

Keywords: Habitat, morphology, new records, pollination, sampling Himalaya, solitary bees, systematics, taxonomy, wild bees.

Lithurgus Berthold, 1827 is a genus of solitary bees belonging to the family Megachilidae. Members of this genus are commonly known as wood-borer bees because females excavate nests in dead or decaying wood (Michener 2007). The genus is placed within the tribe Lithurgini and subfamily Lithurginae, which are characterized by the absence of arolia in females and the presence of a pygidial plate, which is situated on T7 in males (Michener 2007; Gonzalez et al. 2013). The genus *Lithurgus* is widely distributed in tropical, subtropical, and America (Michener 2007). Species of *Lithurgus* are important pollinators of various wild and cultivated plants and are generally univoltine in nature (Michener 2007). In India, the genus is poorly represented and remains inadequately studied, only 12 species of genus *Lithurgus* are known (Javid et al. 2023). However, regional faunal surveys suggest that additional undocumented diversity may exist, particularly in underexplored areas such as the northwestern Himalaya. Further taxonomic and distributional studies are therefore essential to understand the diversity and ecological significance of *Lithurgus* in India.

The Jammu & Kashmir region harbours a unique bee fauna exhibiting a striking similarity to the Palaearctic fauna in contrast to the rest of India which is typical of the southeastern Asian tropical fauna. In India, the Megachilidae family is taxonomically the most diverse, comprising about 40% of the country's bee fauna. (Gupta 1993). Based on the biogeographic distribution in India, 102 species are found in the Himalayan region and the genera *Megachilie*, *Osmia*, *Coelioxyus*, & *Anthidium* show widespread distribution both in the Himalaya and southern India (Javid et al. 2023)

Materials and Methods

Study site

Specimens were collected from diverse localities across Jammu & Kashmir, between 2023 and 2024 during April–September, which corresponds to the peak

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flowering season. Sampling was conducted on sunny days from a wide range of habitats, including agricultural fields, orchards, grasslands, extending from the plains to the higher Himalayan regions. The study area covered an altitudinal range of 1,641–3,200 m. Representative sampling localities included Darhal, Rajouri (33.425^0 N, 74.420^0 E), Aru Valley Pahalgam, Anantnag (**34.091**^{0} N, 75.263^0 E), & Shopian (33.68^0 N, 74.77^0 E).

Methods

Bee specimens were collected from flowering plants, *Hibiscus syriacus*, using a standard sweep insect net. The collected specimens were killed in a glass killing bottle containing ethyl acetate and subsequently pinned, labelled, and preserved following standard entomological procedures. Morphological identification was carried out to the species level using an Olympus SZX10 stereo zoom trinocular microscope. Species identification was done using original description by Smith (1853) & Gupta (1993) and by comparison with relevant taxonomic literature. Photographs were taken using a NIKON DS-Ri2 camera attached to a SMZ25 stereo zoom microscope and processed with NIS-Element's software.

Results

***Lithurgus* (*Lithurgus s. str.*) *atratus* Smith, 1853**

Lithurgus (*Lithurgus*) *atratus* Smith, 1853

(Image 1)

Integuments: Black pubescence on legs, golden yellow on inner side of fore basi tarsi; greyish and white dense pubescence on side and apex of the mesosoma.

Head: Shiny pubescence on face; clypeus roughly punctate and without median longitudinal line, basally produced into a prominent triangular ridge, apically curved fulvous pubescence.

Mesosoma: Disc of the scutum and scutellum convex, transverse rugose with short white and black pubescence along the border; posterior margin of

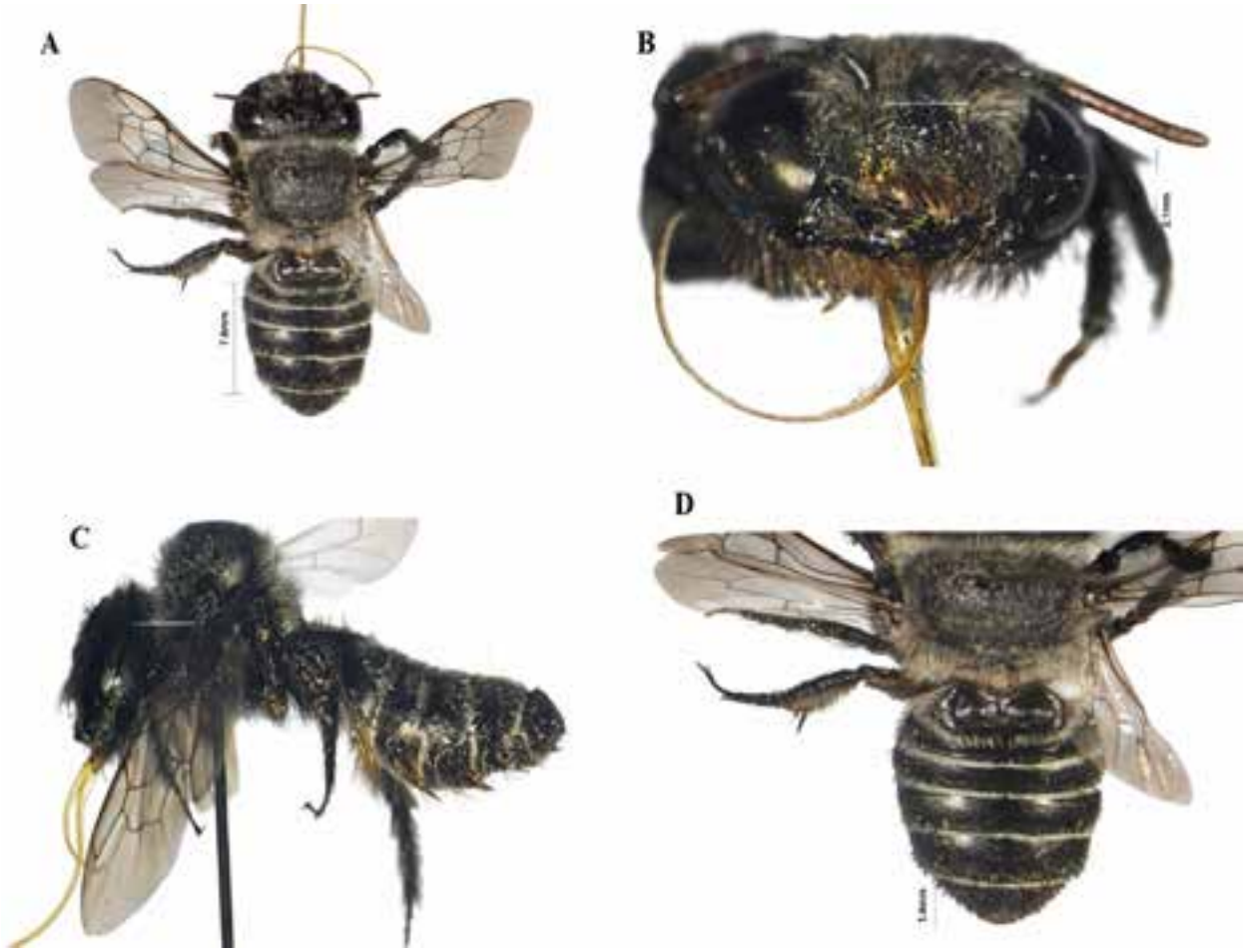

Image 1. *Lithurgus atratus* female: A—Habitus dorsal side | B—Head | C—Lateral view | D—Terga dorsal view and hind tibial spur. © PM Osman Javid

scutellum rounded; wings subhyaline.

Metasoma: T1–T5 apical margin ciliated with white fasciae, interrupted in the middle of T1; on each side of T5 with sparse black erect pubescence; T6 covered with dense suberect pubescence, sub apical spines on either side, with a median apical large spine; scopa brownish-black.

Material examined: 2 females, India: Darhal (Rajouri), 22.vi.2024, sweep net, coll. Osman Javid. Deposited in Dept. of Zoology, BGSB, University, Rajouri. (Accession No. BGSBU/ZOOL/2024/112)

Distribution: India: Jammu & Kashmir (New record); Uttarakhand (Dehradun) (Gupta 1993).

***Lithurgus* (*Lithurgus*) *albofacialis* (Gupta, 1993)**
(Image2)

Male: Total length 11 mm

Integument: Black with rugose surface; tegulae, flagellum, apices of tarsi 2–5.

Pubescence: In general white but all fringes of legs, mese-& mete-pisternites, discal on tergites more greyish or dusty; scopa reddish-brown, darker at apex.

Head: F1 long than F2; Clypeal margin transverse; protuberence little broad, thoroughly punctured (larger at apex).

Mesosoma: vestibule reaching base of hind coxae in repose; scutum and scutellum medio-posteriorly with sooty black bristles; spicules of fore and mid tibiae arranged in rows; hind tibiae slightly bent

Metasosma: Tergum 7 spine acute at apex; terga 6 densely covered with violet-red hairs. T6 covered with dense suberect pubescence, sub apical spines on either side, with a median apical large spine.

Legs: Arolia present supra present on hind tibia, two rows of tubercles on fore and mid tibia; outer surface of tibiae with coarse tubercles that do not end in bristles; Male metatarsus, depicting modification of metabasitarsus.

Material examined: 2 males, India: Kashmir, Aru valley, Pahalgam (Anantnag), 07.vi.2024, sweep net, coll. Osman Javid. Deposited in Dept. of Zoology, BGSB, University, Rajouri (Accession No. BGSBU/ZOOL/2024/114)

Distribution: India: Jammu & Kashmir (New record), Uttarakhand (Dehradun), and Haryana (Gupta 1993).

Discussion

The present study documents two species of the genus *Lithurgus*, *Lithurgus atratus* (Smith) and *Lithurgus albofacialis* (Gupta), as new distributional records for

Image 2. *Lithurgus albofacialis* male: A—Habitus dorsal side | B—Metasoma terga | C—Head front (Clypeus) | D—Antenna | E—Tarsal claws with arolia. © PM Osman Javid.

Image 3. A—Habitat of *Lithurgus* bee | B—Host plant *Hibiscus syriacus* of collected specimen. © PM Osman Javid.

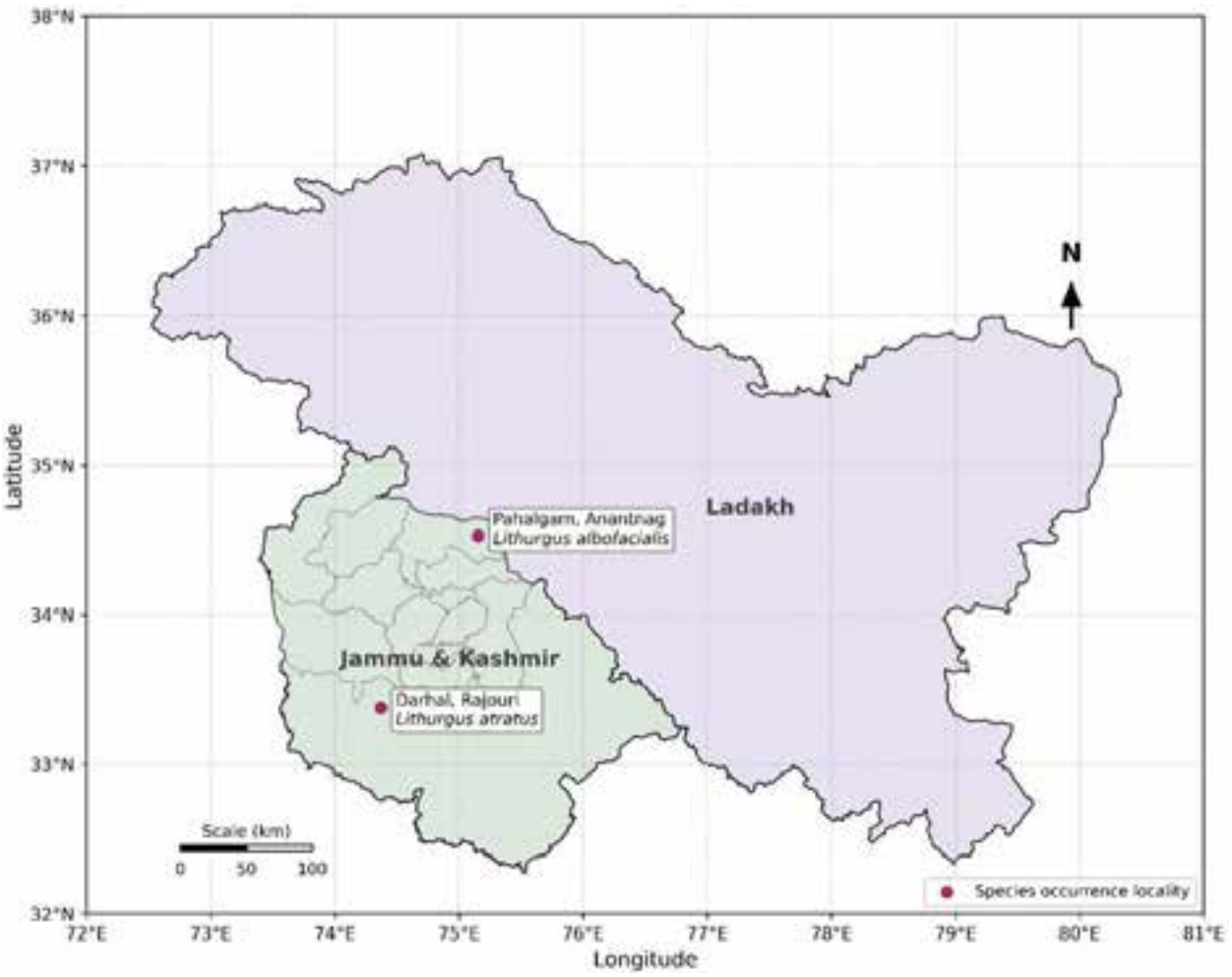

Image 4. Sampling sites in Jammu & Kashmir and new records of *Lithurgus atratus* and *Lithurgus albofacialis*.

the Jammu & Kashmir, India. These records significantly extend the known distribution of both species into the northwestern Himalaya and contribute to the growing knowledge of the bee fauna of this biogeographically important region. The occurrence of these species suggests that the megachilid diversity of Jammu & Kashmir remains insufficiently explored and that additional systematic surveys are likely to reveal further distributional records and potentially undescribed taxa.

The northwestern Himalaya encompassing the Indian states of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand represent a significant biodiversity hotspot with a rich array of bee species (Dar & Khuroo 2020). Within this ecological landscape, bees of the family Megachilidae, which includes leafcutter, mason, and wood-borer bees, play a crucial role in ecosystems they contribute to the health and sustainability of plant communities by supporting plant reproduction and genetic diversity (Ollerton et al. 2011). The Himalayan region is recognized as a global biodiversity hotspot characterized by remarkable habitat heterogeneity and high levels of endemism. Nevertheless, information on the diversity and distribution of solitary bees in this region remains fragmentary. As emphasized by Michener (2007), solitary bees are key pollinators in natural ecosystems and contribute substantially to the reproduction of alpine and temperate flowering plants. The addition of *L. atratus* and *L. albofacialis* to the bee fauna of Jammu & Kashmir highlights the importance of continued taxonomic exploration, biodiversity documentation, and long-term monitoring of native pollinator communities. Such studies are essential for understanding species distributions, assessing the impacts of environmental change, and developing effective conservation strategies for pollinators in the fragile Himalayan ecosystems.

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NOTE

Small Wild Cats Special Series

Striped Hyena *Hyaena hyaena* (Linnaeus, 1758) carrying a carcass of a Rusty-spotted Cat *Prionailurus rubiginosus* (I. Geoffroy Saint-Hilaire, 1831) in Rajasthan, India

Akshay Jain [1], Debashish Panda [2], Rajasekar Rajaraman [3], Sanjeev Sharma [4], Sugna Ram Jat [5] & Kamlesh K. Maurya [6]

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From April to May 2024, we conducted a camera trapping survey in the Indergarh Range of Ramgarh Vishdhari Tiger Reserve, Rajasthan (Image 1). This survey yielded two photographs of a Striped Hyena *Hyaena hyaena* carrying a carcass of a Rusty-spotted Cat *Prionailurus rubiginosus* at an elevation of 358 m (Images 2 & 3).

Ramgarh Vishdhari Tiger Reserve harbours tropical dry deciduous forest, with dominant tree species including *Acacia catechu*, *Anogeissus pendula*, *Butea monosperma*, *Lannea coromendelica* (Champion & Seth 1968; Prasad 2014). Our study area in the reserve's buffer zone encompassed about 200 km^2 (Jain et al. 2025). We deployed camera traps at 55 locations in pairs positioned opposite each other to record both flanks of mammals. We considered each pair as a single sampling location.

During our total sampling effort of 1,696 camera trap days, the Striped Hyena was recorded at 23 locations (42% of all) and the Rusty-spotted Cat at eight locations (15%). The camera traps also photographed the Leopard *Panthera pardus*, Jungle Cat *Felis chaus*, Afro-Asiatic Wildcat *F. lybica*, Golden Jackal *Canis aureus*, Bengal Fox *Vulpes bengalensis*, Sloth Bear *Melursus ursinus*, Small Indian Civet *Viverricula indica*, and Honey Badger *Mellivora capensis* (Jain et al. 2025).

The Striped Hyena was also photographed carrying carcass remains of an Indian Peafowl *Pavo cristatus* and a Chital *Axis axis.* The Chital carcass was identified based on the white spots on the golden-rufous body (Menon 2023). However, none of the photographs show a killing event. This corroborates the notion that the Striped Hyena is a facultative scavenger of carrion (Alam & Khan 2015; Bhandari et al. 2020; Panda et al. 2023a,b; Mwebi et al. 2024). Possible explanations for the dead cat are that it died due to a natural cause or was killed and abandoned by other carnivores. It may also have been a roadkill (Nayak et al. 2017).

Our record contributes to the understanding of the opportunistic feeding behaviour of the Striped Hyena and complements the limited documentation of interaction between carnivores.

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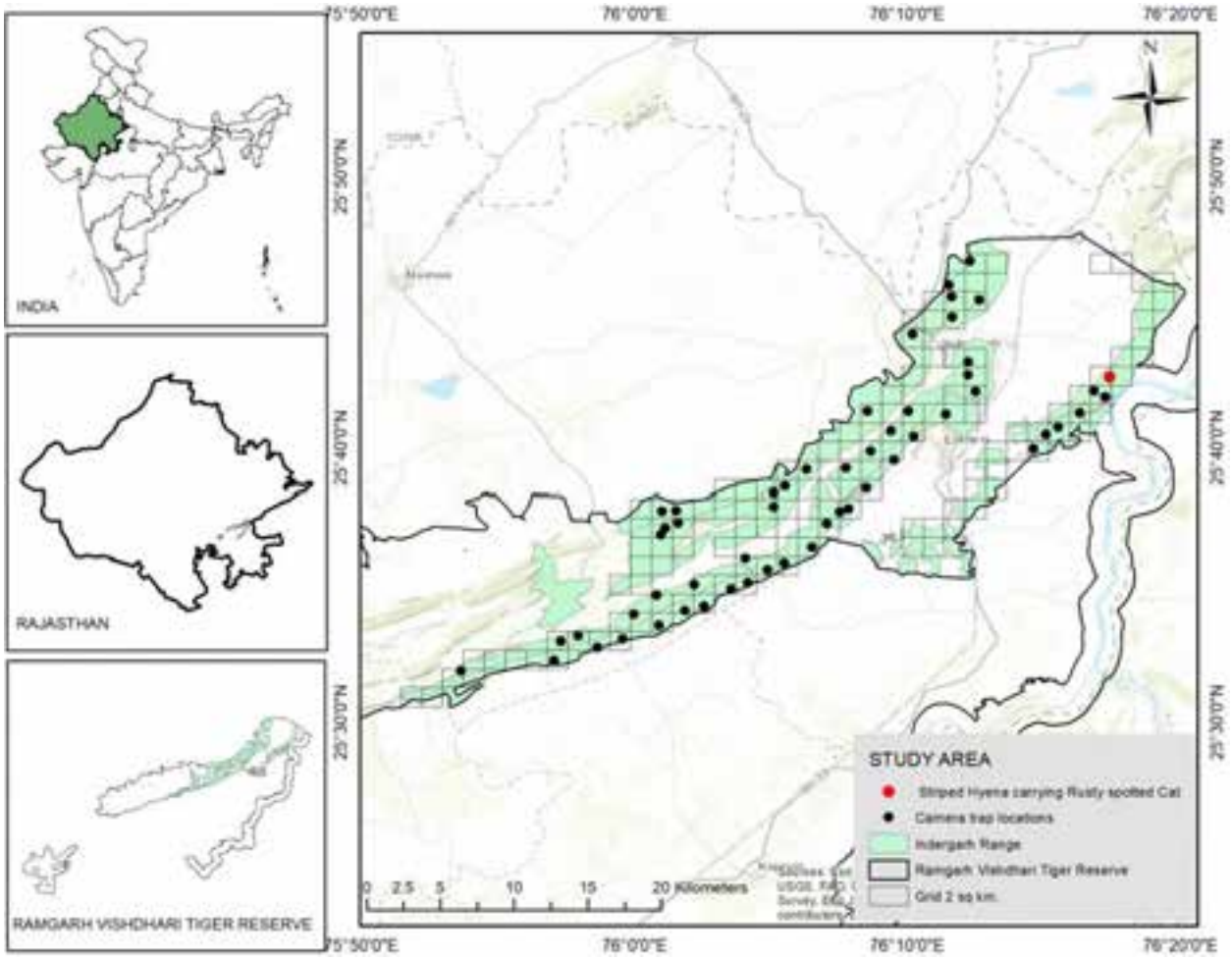

Image 1. Map showing the study area in Ramgarh Vishdhari Tiger Reserve, Rajasthan.

Images 2 & 3. Striped Hyena with the carcass of a Rusty-spotted Cat on 5 May 2024. © WWF India and Rajasthan Forest Department.

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NOTE

Amomum pauciflorum Baker (Zingiberaceae), an addition to the flora of Manipur, India

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Manipur is a state in India with very rich flora and fauna. Geographically, it is situated between 23.80°–25.70° N and 93.50°–94.80° E and bounded by the Indian states of Nagaland to the north, Mizoram to the south and Assam to the west, and Myanmar to the east. There are 16 districts and biogeographically, it is placed within the Indo-Burma Biodiversity Hotspot, one of the world's most biologically diverse regions. The state is very rich in floral diversity comprising of 2,796 dicotyledons and 1,232 monocotyledons with high degree of endemism consisting of 117 endemic species (Agrawala et al. 2023). There are several reports on Zingiberaceae in Manipur, Singh et al. (2012) recorded 42 species from the state; Sharma et. al. (2009) reported nine genera and 22 species and one variety; Devi et al. (2014) recorded 24 species and six genera from Imphal valley and one new species *Zingiber kangleipakense* (Kishor & Leong-Škorničková 2013).

During the field surveys in the year 2022–2023 in the Kamjong area at "Ningchou", which is 85 km away from Ukhrul District, a species of *Amomum* was collected with flowers and detailed study was done (Image 1). The collected specimens were dried and herbarium were prepared according to Botanical Survey of India (BSI) standard way of preparing herbarium. The species was identified as *Amomum pauciflorum* Baker with the help of the available literature (regional flora, viz., Manipur, Nagaland, Sikkim, Assam, and Meghalaya) and also got confirmed by consulting with V.P. Thomas (an expert on Indian *Amomum*). The voucher specimens are deposited in the Botanical Survey of India, Eastern Regional Centre, Shillong (ASSAM) and Botany Department, Visva-Bharati, Santiniketan.

The genus *Amomum* Roxb. is the sixth largest among the 53 genera of the family *Zingiberaceae* and represented by about 120 species (POWO 2026) distributed mainly in the tropical and subtropical regions of the world with its centre of diversity in the Indo-Malayan region (Sabu 2006). In India, the genus is represented by 18 species and one variety (Singh et al. 2025) and confined mostly in the northeastern and peninsular regions of the country, of which seven are considered to be endemic to eastern Himalaya (Partap et al. 2014). *Amomum pauciflorum* Baker (Images 2 & 3) was described on the basis of a solitary collection by J.D. Hooker (1892) from the locality "Nunklow" now "Nongkhlaw" in Khasia Hills which is part of the Meghalaya state, India. Rao & Verma (1966) reported

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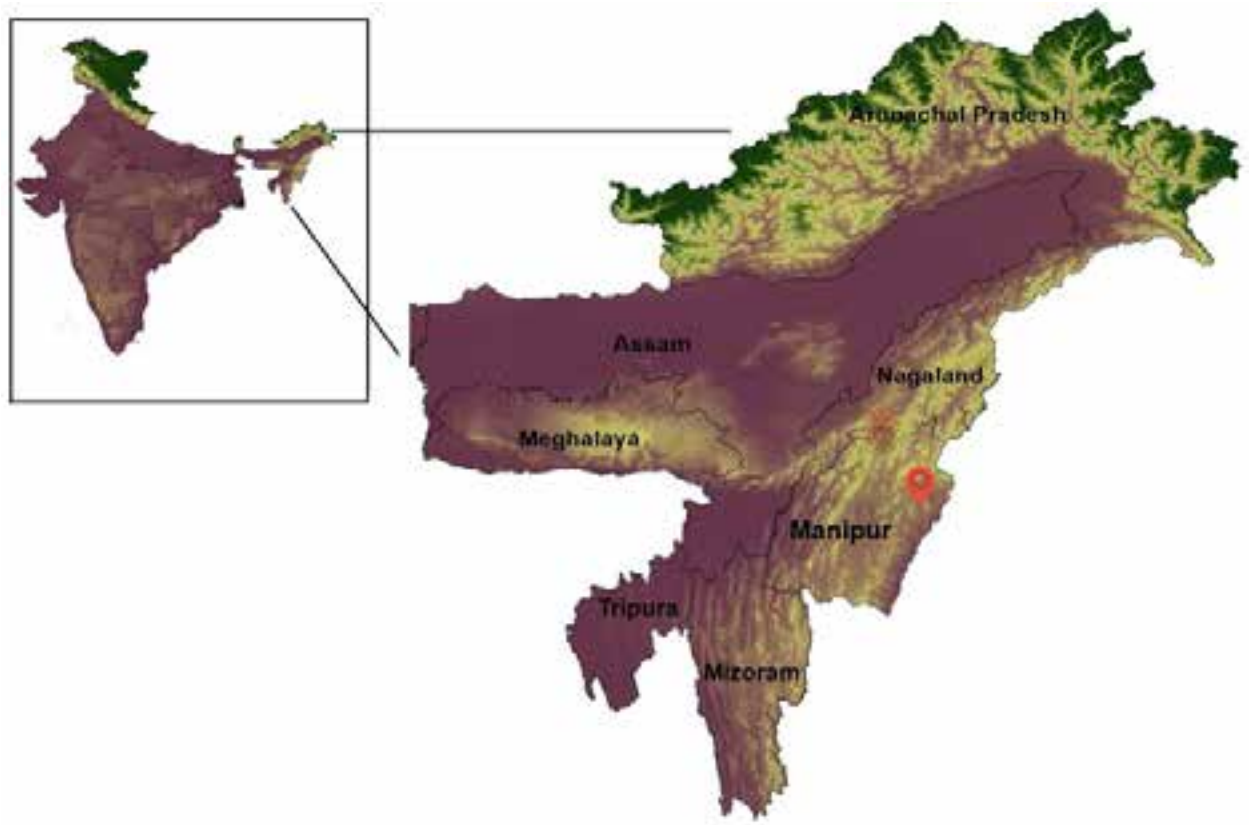

Image 1. Map of northeastern India, showing the location of *Amomum pauciflorum* collected in Manipur.

the same species from another locality "Umsning" forest in Khasia Hills, Meghalaya. Later it is reported from different states of northeastern region such as Arunachal Pradesh, Assam, Mizoram and Nagaland (Thomas & Sabu. 2023; Singh et al. 2025). Since it is not reported so far from the state Manipur, a description is made and with photographs communicated here for easy identification.

Amomum pauciflorum was synonymized with *Amomum hypoleucum* by Thomas & Sabu (2023) in the genus *Amomum* Roxb. s.l. and this was accepted by POWO. However, Singh et al. (2025) has identified as a separate species on the basis of having entire, transversely oblong anther crest which is obscurely 3-lobed with involute sides and revolute tip; bracteoles non tubular.

Taxonomic treatment

Amomum pauciflorum Baker in Hook.f., Fl. Brit. India 6: 238. 1892; A.S. Rao & D.M. Verma in Bull. Bot. Surv. India 11 (3 & 4): 245.1969; Karthik. et al., Fl. Ind. Enum. Monocotyl. 290. 1989; S.K. Singh & S.C. Srivastva, Fl. Pl. India Annot. Checklist Monocot. 118. 2020; V.P. Thomas & M. Sabu, Gen. *Amomum* India: 71. 2023; Singh et al, Fl. India. 27: 28. 2025.

Perennial herb; rhizome stoloniferous, bright red, long creeping, slender, scaly. Pseudostems 30–50 cm high, swollen at base, sheathed, reddish-green. Leaves 4–13 per shoot, oblong-lanceolate, 29–32 x 5–6 cm, base acute-attenuate, margins entire, apex caudate and glabrous adaxially, silvery and pubescent abaxially; petioles 1–3 cm long; ligule 0.1–0.2 cm long, bilobed at apex, membranous, pubescent. Inflorescence radical, 6–8 cm long, slender, 1–3 flowered, borne on slender or creeping runners; peduncles 3–3.5 cm long, covered with 2–3 sheaths, bearing 1–3 successively opening flowers on a very short rachis, appearing as if in a cluster; flower bearing bract lanceolate, 3–5 x 1–1.3 cm, apex acute, pinkish, membranous, prominently veined, pubescent; bracteoles 4–6 x 0.5–1.0 cm, non-tubular. Flowers white, 6–8 cm long, Calyx tubular 3–6 x 0.4–0.6 cm, 3-lobed near apex, deeply split on one side, membranous, white, tinged with pink at apices. Corolla white, tube 3–4 cm long, dorsal corolla lobe oblong, 2–3 x 1–1.2 cm, white except greenish yellow at apex, glabrous, apex obtuse; lateral lobes oblong, 3–3.6 x 1–1.2 cm white except greenish yellow at rounded apex. Labellum white, obovate, 3–4 x 2–3 cm, with a median red band towards

Image 2. *Amomum pauciflorum* Baker: A—Habit | B—Flower | C—Roots, rhizome, and inflorescence | D—Basal parts of plants showing inflorescence | E—Inflorescence | F—Single flower | G—Bracts | H—Calyx | I—Central and lateral corolla lobe | J—Floral tube with stamen | K—Labellum | L—Stamen (front view) | M—Ovary with style | N—C.S. of ovary. © Lolia Hepuni.

base and yellowish towards tip, prominently veined, margin crisped flabellate, dentate; lateral staminodes a pair of subulate processes at the base of labellum, c. 0.5 cm long, pinkish-white, hairy. Filaments 1–2 x 0.2–0.3 cm red near base, white near apex, pubescent; connective puberulous; anther crest entire transversely

Image 3. Herbarium sheet of *Amomum pauciflorum* Baker.

oblong, obscurely 3-lobed, sides involute, tip revolute, 0.4–0.5 x 0.6–0.7 cm creamy-white, glabrous; anther thecae oblong, 1–2 cm long, white, puberulous. Ovary oblong, 0.4–0.5 x 0.2 cm, villous; style puberulous near apex; stigma cup-shaped, white, ciliate at mouth.

Flowering & Fruiting: May to August.

Habitat: In moist places in dense, evergreen, mixed forests.

Specimen examined: Lolia Hepuni, 11.v.2024, Manipur, Kamjong District, Ningchou, 24.8615° N, 94.5106° E, 1,542 m, Coll. No. 038 (ASSAM); Acc. No. 103685, Coll. No. 039 (Department of Botany, Visva-Bharati).

Distribution: India (Arunachal Pradesh, Assam, Manipur (present report), Meghalaya, Mizoram, Nagaland); Myanmar.

Ex situ conservation: Since the species is rare, we have collected only five live plants with rhizome, planted and conserved at Botanical Survey of India (Eastern Reginal Center), Shillong, Meghalaya.

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NOTE

Toil in the soil: putative nest excavation by an adult female Panther Chameleon *Furcifer pardalis* (Cuvier, 1829) in moist, clayey soil on Nosy Komba, Madagascar

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The Panther Chameleon *Furcifer pardalis* (Cuvier, 1829), is common across various parts of Madagascar, especially in the central-northeastern and northwestern regions (Ferguson et al. 2004). It inhabits a variety of environments, including humid, semi-humid, and transitional areas (Andreone et al. 2005; Glaw & Vences 2007; Deso et al. 2022). These chameleons are primarily edge dwellers (Ries et al. 2017), found in undisturbed canopy forests and capable of adapting well to anthropogenic habitats. They have also been introduced to disparate regions around the world (e.g., Florida, USA, and Réunion Island; Cheke 1987; Rabearivony et al. 2007; Rochford et al. 2013; Deso et al. 2022). Despite being actively collected and traded internationally as pets (Andreone et al. 2005; Carpenter et al. 2005), there is limited knowledge about the natural history and reproductive behaviour of *F. pardalis* in the wild (Rabearivony et al. 2007; Eppley 2019), but all records we were able to find either attest exclusively to the use of sandy soils as the site for oviposition (Rabearivony et al. 2007; Negro & Negro 2017; Eppley 2019; Laube et al. 2021) or are silent on the matter (e.g., McGeough 2016). We here present the first observation of an adult female *F. pardalis* digging in moist non-sandy soil under circumstances consistent with nest excavation, thereby expanding our understanding of the species' reproductive ecology.

The observation was made on 03 February 2020 at 1153 h on Nosy Komba (also known as Nosy Ambariovato), a small island (13.4506° S, 48.3421° E; area 27.9 km^2) located off the coast of northwestern Madagascar between the main island and Nosy Bé. The

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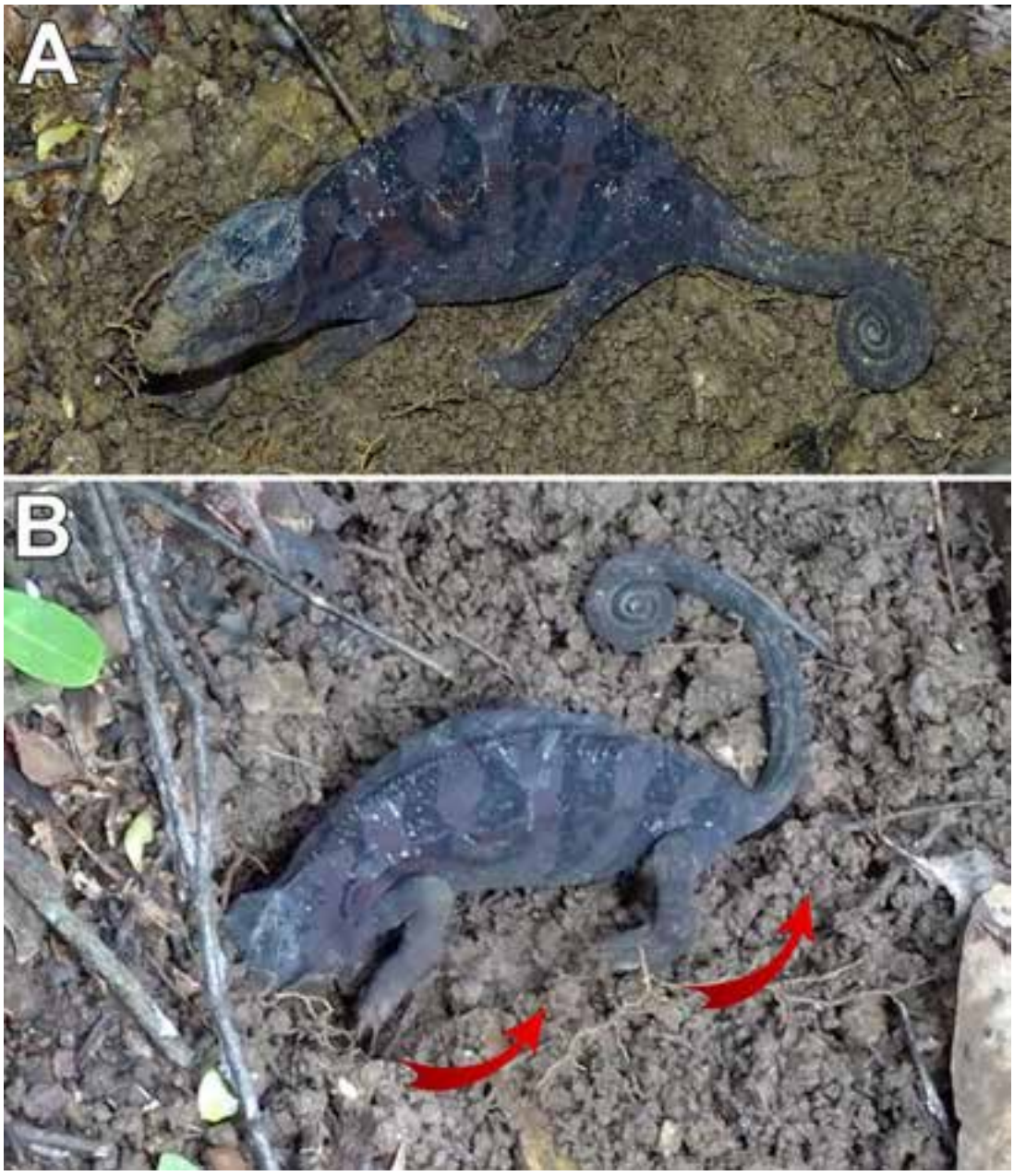

Image 1. An adult female *Furcifer pardalis* observed digging a burrow in moist, clayey soil on Nosy Komba, Madagascar: A—During a brief pause in the digging process, she was photographed with her snout covered in mud, showing that the head is involved in the excavation by pushing into the soil | B—Digging of the heavy soil was accomplished by using her left limbs alternately. As the forelimb moved soil out of the hole, the hind limb would be used to push it behind the body. © Hinrich Kaiser.

observation occurred in a typical secondary tropical forest (Hyde Roberts & Daly 2014) at an elevation of ca. 300 m, which was classified as a "closed canopy forest" of native non-cultivated species that may include mango and jackfruit by Blumgart et al. (2017). A deep blue-violet *F. pardalis* (snout–vent length ca. 12 cm) was observed actively excavating a burrow (Image 1A). The approximate size of the lizard, indicative of its maturity level, and its colouration are associated with gravid adult females approaching oviposition (Eppley 2019). The observer's attention was drawn to the moist, compacted soil ("clayey soil"; Firoozi et al. 2016), in which the female dug using her left limbs in concert, the front limb to excavate and the rear limb to move the soil further behind her (Image 1B). While no soil samples were taken for further analysis, qualitative evaluation showed that this type of dark soil had relatively high moisture content and felt very sticky (hence our use of the term "clayey"),

very unlike the type of sandy soil depicted by Laube et al. (2021). The temperature at the time of observation was 29°C with > 80% humidity, no wind, and clear skies above the canopy cover. To avoid disturbing the animal, the observation lasted only 5 min, during which several photos and videos were taken from a suitable distance. Because these obligatorily arboreal lizards rarely descend to the ground and do not dig for foraging or escape, the observed digging is most parsimoniously interpreted as oviposition behaviour. The combination of size and colouration associated with the pre-oviposition condition by an adult female and directed burrow excavation is consistent with previously described nest-digging behaviour in *F. pardalis*.

Data on the reproduction of *F. pardalis* in the wild remain limited, and available published observations have associated oviposition with sandy soils (e.g., Rabearivony et al. 2007; Eppley 2019; Strand 2023). To the best of our knowledge, our observation is the first documented instance of a *F. pardalis* female digging in moist, clayey soil under circumstances consistent with nest construction. Egg deposition was not observed, and we therefore cannot confirm that the excavation ultimately resulted in a completed nest or oviposition. Nevertheless, the female's size, colouration and directed excavation behaviour are consistent with previously described pre-oviposition behaviour in *F. pardalis* (e.g., Rabearivony et al. 2007; Eppley 2019). The observation therefore demonstrates that *F. pardalis* can excavate a moist, cohesive, non-sandy substrate during probable nest construction. Whether such substrates are regularly used for completed oviposition will require additional field observations.

Females of this species may have a limited home range or microhabitat preferences (Gehring et al. 2008), which could indicate that this individual might return to this location or has already used it, but this is speculative. *Furcifer pardalis* females rarely survive longer than a year in the wild; they exhibit high fecundity, with clutch sizes ranging from 10–40 eggs, and reproductive activity begins at around 6 mo old, followed by additional clutches every 3 mo thereafter (Müller et al. 2004; Andreone et al. 2005). Nest construction usually takes several hours, and females lay their eggs within an hour or two (Bolton & Abate 2002), which, to some extent, explains the choice of a loose substrate in terms of energy cost. Eppley (2019) showed the first evidence of spatiotemporal oviposition planning by this species. Observations such as these, even as single events, can broaden the scope of information about the natural history and ecology of *F. pardalis* and their reproductive behaviour.

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