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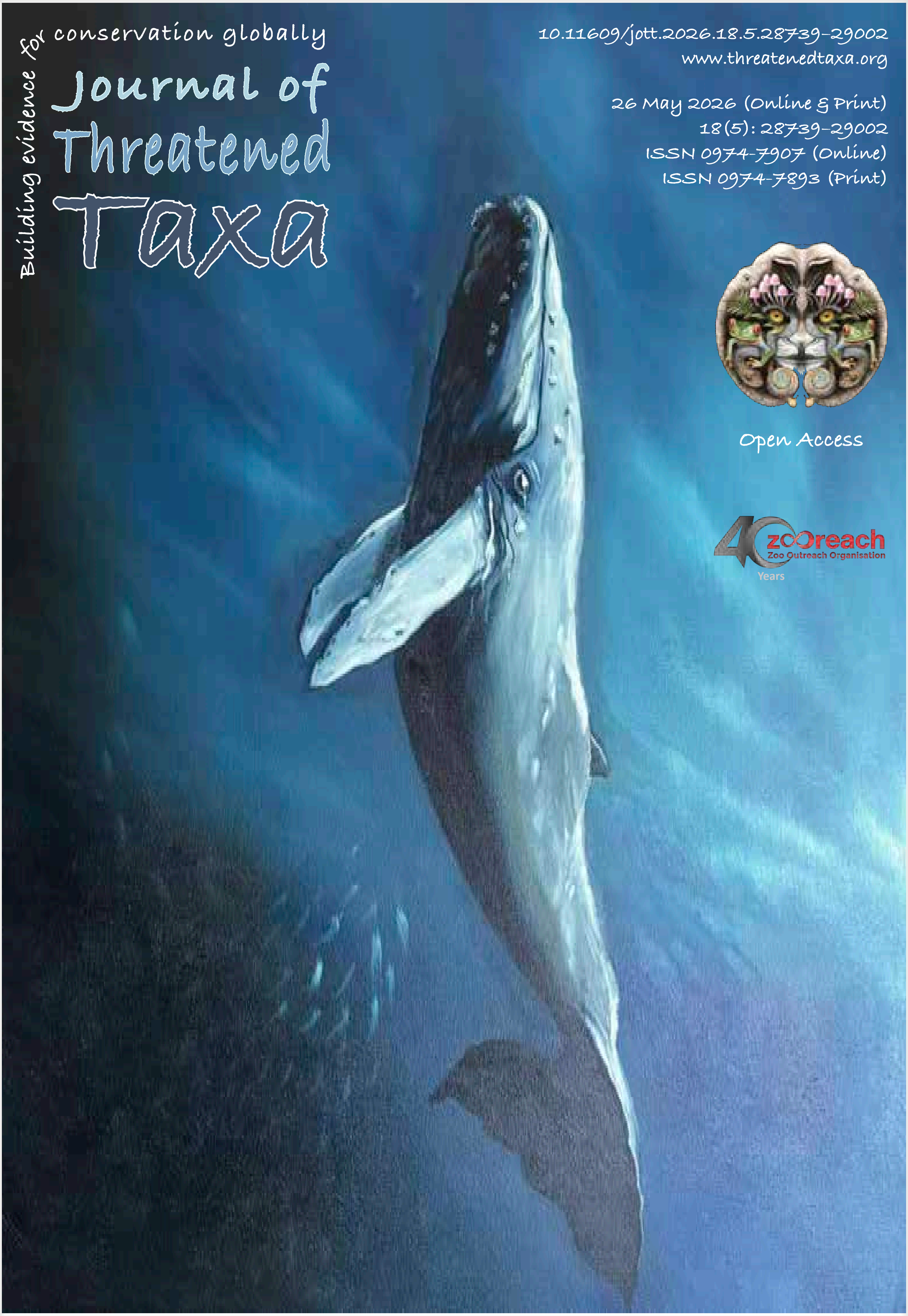

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Srivari Illam, No. 61, Karthik Nagar, 10th Street, Saravanampatti, Coimbatore, Tamil Nadu 641035, India
Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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Cover: Oil painting of Humpback Whale *Megaptera novaeangliae*. © R. Mahesh.

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ARTICLE

Large mammal diversity of Vietnam's Chu Yang Sin National Park and the first experimental assessment of their vulnerability to snaring

Minh Thi Anh Nguyen [1], Thuy Thi Bich Vo [2], Quy Tan Le [3], Vy Tran Nguyen [4], Vu Linh Nguyen [5], R.J. Timmins [6] & Anthony J. Giordano [7]

[1] Department of Fish, Wildlife and Conservation Biology, Warner College of Natural Resources, Colorado State University, Fort Collins, CO 80523, USA.
[2,5] Faculty of Environment and Natural Resources, Nong Lam University – Ho Chi Minh City, Thu Duc City, Ho Chi Minh City 70000, Viet Nam.
[1,6] Saola Foundation for Annamite Mountains Conservation, Milwaukee, WI 53208, USA.
[3] Center for Ecology and Resources, Institute of Advanced Technology, Viet Nam Academy of Science and Technology, 1B TL 29, Thanh Loc Ward, District 12, Ho Chi Minh City, Viet Nam.
[4] Institute of Life Sciences, Vietnam Academy of Science and Technology, District 3, Ho Chi Minh City, Viet Nam.
[4,7] S.P.E.C.I.E.S. – The Society for the Preservation of Endangered Carnivores and their International Ecological Study, Ventura, CA 93006, USA.
[7] Center for Human-Carnivore Coexistence, Colorado State University, Fort Collins, CO 80523, USA.
[1] minh.nguyen@colostate.edu (corresponding author), [2] thuy.vothibich@hcmuaf.edu.vn, [3] tanquyle.2409@outlook.com, [4] vychim@gmail.com, [5] vu.nguyenlinh@hcmuaf.edu.vn, [6] rjtimmins@saolafoundation.org, [7] species1@hotmail.com

Abstract: The Annamite Mountains of Indochina have high mammal endemism but also face a mammalian extinction crisis, primarily from the indiscriminate use of snares. Chu Yang Sin National Park in the southern Annamites of Vietnam is one of the few forests in Vietnam where the Critically Endangered Annamite endemic Large-antlered Muntjac is predicted to be present. The objectives of this study were to experimentally investigate and quantify the relative impact of snaring on local mammal populations by using camera trapping, with a focus on muntjac, and to provide a checklist of the large mammal species of the park. In 2020, a preliminary survey was executed to determine a study site in the park by observing the prevalence of signs indicative of large mammals. From December 2020 to February 2021, a 515-m long simulated continuous snare-line was constructed at the study site by five experienced local hunters. Camera-traps were then set up along 240-m of the snare-line to monitor animal movement. A total of 4,747 working camera-trap nights were logged and recorded the Large-antlered Muntjac and 10 other large mammal species along the snare-line. It was found that the Large-antlered Muntjac was more vulnerable to snares relative to the other mammals detected, exhibiting the highest probability of being 'captured' by a snare if an individual animal encountered the snare-line ($p = 0.67$). The finding suggests, as already theorized, that prolonged exposure to a snare-line will greatly reduce local large mammal populations, because with repeated encounters by an individual animal, the probability of capture increases close to $p = 1$. The study demonstrates here for the first time how some species are potentially more susceptible to snaring than others. Building on the experimental approach, future research could yield new insights into managing snare hunting more efficiently, using more data from other locations and over longer periods.

Keywords: Annamite Mountains, snare, Large-antlered Muntjac, tropical forests, Indochina, camera-trapping, poaching.

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INTRODUCTION

Southeast Asia has some of the richest biodiversity in the world (Hall 1998; Sodhi et al. 2010). It encompasses four of the 25 global biodiversity hotspots (Myers et al. 2000), and harbors one of the highest proportions of country-endemic mammal species (Sodhi et al. 2010). The Annamite Mountains of Indochina are perhaps best known for their particularly high levels of mammal endemism. This region has seen many extraordinary recent discoveries of large mammals (Coudrat 2022). Despite receiving significantly increased attention to conservation over the past few decades, continued survey and research efforts are needed to thoroughly investigate and monitor the ecosystems of the Annamite Bioregion (Hughes 2017).

The biodiversity of the Greater Annamites Ecoregion is experiencing a severe mammal extinction crisis; it also currently has the highest proportion of threatened species globally, many of which are large mammals (Conrad 2012; Duckworth et al. 2012). Forming much of the border between Vietnam, Laos, and Cambodia, the Annamites have been experiencing high-intensity illegal hunting, which is almost singularly driving the depletion of the region's large mammal populations; consequently, this is causing the spread of "empty forest syndrome" (Corlett 2007; Duckworth et al. 2012; Harrison et al. 2016). Given that illegal hunting is behind these current population declines (Rija et al. 2020), improved knowledge around how it impacts large mammals differently may be critical to developing effective and nuanced management responses and more effectively deploying law enforcement.

Large mammals (following the list noted by Duckworth et al. 1999) are hunted by many means, but primarily ground-dwelling large mammals are mainly hunted in the Annamite Mountains using snares, which can be categorized as primarily "opportunistic/passive", based on the way hunters use them (Harrison et al. 2016; Dobson et al. 2019). Snares are widely employed across large areas of tropical forests in the Annamite Mountains to meet the intensive demand of domestic and international trade markets (Duckworth et al. 2012). They are easily made from readily available cable wires, cheap to make and deploy, resilient for months in the forests, require less effort and skill than using a gun (per unit of catch), are hard to detect, and can be indiscriminate in what species they catch (Harrison et al. 2016; Gray et al. 2018; Dobson et al. 2019). The use of snares can be particularly effective when combined with simple "drift fences" made from forest undergrowth, which leads to a "snare-line" of alternating fences and "snare-gaps" (O'Kelly et al. 2018). Snare-fences function as a channeling device, encouraging animals to 'seek' the 'gaps' as a way to pass through the fence, and thus encounter the actual snare strategically placed in the 'gap'. Each local hunting team might create several kilometers of these snare-lines, altogether incorporating hundreds of snares (Harrison et al. 2016). Despite this massive effort, many animals that get caught are left to die and rot, especially when snares are not checked in a timely way or ultimately abandoned by the hunters (Gray et al. 2017, 2018). Somewhat counter intuitively, snares have been found to be used more intensively in very depleted forests relative to those with more intact fauna as a way to catch any remaining wildlife in the area (Branch et al. 2013); although this may not be a widespread phenomenon, especially in the Annamite Mountains. Among those cultures where hunting rare wildlife is celebrated, and the established norm is that "wild meat is healthier than domestic meat", this extinction driver can be a particularly serious challenge to overcome (Brodie et al. 2009; Drury 2009; Dobson et al. 2019). The primary driver challenging effective solutions to snaring in the Annamite Mountains is poor legislation and poor enforcement due to a paucity of government resources and capacity.

In this study, we conducted the very first experimental effort to investigate the impact of snaring on large mammal species in the context of events occurring at a snare line. A checklist of large mammal species is presented for Chu Yang Sin National Park (NP), a critically important protected area located in the southern Annamite Mountains range of Vietnam.

Abbreviations: CR—Critically Endangered | CT—Camera-Trap | EN—Endangered | LC—Least Concern | MTAN—Minh Thi Anh Nguyen | NP—National Park | O—Observation | p(C/Cr)—the probability of capture by the theoretical snare noose if the animal crossed the snare-gap, as a function of all snare-gap crossing events for a species | p(C/E)—the probability of capture by any theoretical snare-noose if the animal was detected along the snare-line (snare-line encounter event), as a function of all snare-line encounter events for a species | p(Cr)—the probability of crossing the snare-gap if the animal encountered (was camera-trapped adjacent to) the snare-gap, as a function of all snare-gap encounter events for a species | p(E)—daily encounter rate with the snare-line for a species | p(Sn/E)—the probability of encountering at least one snare-gap if the animal was detected along the snare-line, as a function of all snare-line encounter events for a species | VU—Vulnerable.

MATERIALS AND METHODS

Study Area

Chu Yang Sin NP covers an area of 590 km^2 in southeast Dak Lak Province in southern Vietnam with elevations ranging from less than 600 m to 2,442 m at the summit of Mount Chu Yang Sin (BirdLife International 2010) (Image 1). It is part of an extensively forested landscape in the southern Annamites, and is connected to several other protected areas, such as Bidoup–Nui Ba National Park to the south. Chu Yang Sin NP harbours exceptionally high biodiversity: its diverse forest types are home to at least 65 mammals, 250 birds, 112 amphibians and reptiles, 81 fish, and 248 butterflies species (BirdLife International 2010). Chu Yang Sin NP is one of only a few areas in Vietnam that may still hold a viable population of Large-antlered Muntjac *Muntiacus vuquangensis*, a 'Critically Endangered' (CR) ungulate endemic to the region (Timmins et al. 2016). Although there had been no further records of the species in the park since 2009, there had also not been sufficient survey effort in the intervening period. It was believed that extensive suitable habitat, and its connection with large, protected forested areas, would have helped increase the probability that Large-antlered Muntjac persist in the park. It was also determined that for this reason, Chu Yang Sin NP was a potential site for the present study on the impact of snaring, with a particular focus on the species.

Snare experimental design

From 27 August to 02 September 2020, Minh Thi Anh Nguyen (MTAN) conducted a pilot survey to identify a field site inside Chu Yang Sin NP for the experimental snare-line project. The survey involved walking a 58 km route spanning various habitats at elevations ranging 750–1,300 m to record large mammal signs. Positive indications included direct species observations, frequent sightings of fresh tracks, and a diversity of track types, reflecting the presence of a diverse assemblage

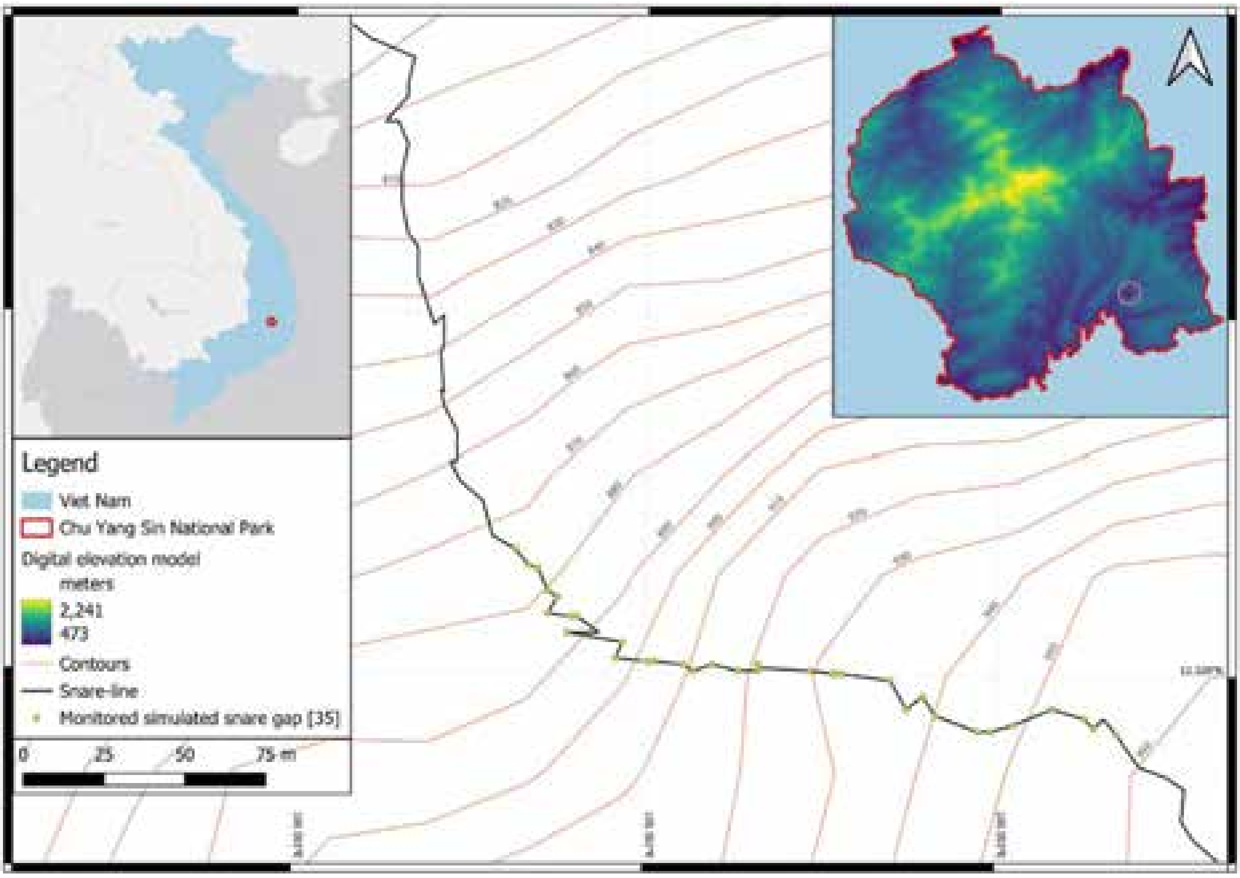

Image 1. Location of Chu Yang Sin National Park and the study site. The location of the simulated snare-line within Chu Yang Sin National Park is shown in the upper right inset; note shading reflects elevation with yellow highest and purple lowest. The simulated snare-line (main figure) was in reality relatively straight with regular placement of snare-gaps, but errors in GPS location coordinates give rise to an irregular alignment and placement of snare-gaps in the figure; all snare-gaps were at least 10 m apart. Scale bar and coordinates relate to the main figure only.

of mammal species. From 10–18 December 2020, work was conducted with local communities to identify five experienced hunters and learn about their snaring methods. At the field site, each hunter independently walked us through what a "real snare-line setup" would entail, even though no actual snares were ever set. Hunters explained how and where to set up the snare-line and snares, and this information was carefully recorded. Following this, all the hunters were asked to agree on where to place a single snare-line (Image 1). A typical snare-line, of alternating snare-fence and snare-gaps, but without actual snares, 515 m long, with 70 snare-gaps, was then constructed by the hunters. 101 camera-traps (Covert illuminator) were deployed along 240 m of the snare-line, beginning at the 28th snare-gap from the starting location of its construction. Two camera-traps in video mode, one on either side of the snare-line were used for monitoring animal movement at 35 consecutive snare-gap locations along the snare-line. The remaining camera-traps in photo mode were used to monitor animal movement along the snare-fence between snare-gaps; one camera between successive snare-gaps, with cameras alternating between the two sides of the snare-fence. This setup allowed us to understand which species encountered the snare-line, and whether, once encountering the snare-line, an individual animal subsequently crossed the snare-line through a snare-gap (or not), and whether (if they crossed) they would have been captured (or not) by putting a foot within the simulated (theoretical) snare-noose. All camera-traps were active between 18 December 2020 and 03 February 2021 (a total of 4,747 camera-trap nights, 47 camera-trap nights for each camera-trap unit). Consecutive photo and video captures less than 30 min apart for the same species, at any camera-trap location, were treated as a single snare-line encounter event. If there was more than one animal in a photograph or other evidence indicating the presence of two animals in the event, the single event was divided into a number of events equal to the number of animals. Note, there was no evidence of detections of individual animals at impossibly distant locations in quick succession, which would have indicated the presence of spatially separated individual animals being counted as a single event. The impossible distance is defined as the scenario where two photos taken within a 1-min interval cannot be captured by two cameras positioned more than 30 m apart. The exception to this was macaques, which proved problematic because they occur as groups of multiple individuals; thus, a minimum number of certainly different individuals were recorded in an event. But this is probably an underestimate of the number of actual individuals present at an event. This allowed us to calculate the daily encounter rate with the snare-line p(E) for an individual animal of each species as the total number of events divided by 47 camera-trap nights.

For analysis of capture probabilities resulting from snare-line encounter events, the following protocol was used. For each snare-line encounter event (i.e., captured by any camera-trap adjacent to the snare-fence and or snare-gap within a 30-min period), the outcome of an individual animal's interaction with snare-gaps, and the simulated (theoretical) snare-noose at each snare-gap, was recorded. This included recording how many snare-gaps the animal encountered (snare-gap encounter event), and for each one, recording firstly whether it crossed the snare-gap (with potential outcomes recorded as - yes/no/unclear), and secondly, if it did cross the snare-gap, whether it put a foot within the simulated (theoretical) snare-noose (with potential outcomes recorded as — yes/no/unclear). In one snare-line encounter event, an individual animal might cross snare-gaps multiple times; for this analysis, each was counted as an independent 'snare-gap crossing' event, and for each such event, the outcome with regard to putting a foot within the simulated snare-noose was recorded. In the rare event of an animal crossing a snare-gap, and then subsequently in the same event recrossing the very same snare-gap (from the opposite side of the fence), this was treated as an additional snare-gap encounter event, with the outcome relative to the simulated snare-noose recorded for that event. Probabilities of theoretical capture in the simulated snare-noose p(C/E) were thus calculated as:

$$p(Cr) = \frac{\text{Total number of times the species crossed snare - gaps for all snare - line encounter events}}{\text{Total number of snare - gaps the species encountered for all snare - line encounter events}}$$

$$p(C/Cr) = \frac{\text{Total number of times the species stepped into the simulated snare noose (was captured) for all snare - line encounter events}}{\text{Total number of times the species crossed snare-gaps for all snare - line encounter events}}$$

$$p(Sn/E) = \frac{\text{Number of snare - line encounter events the animal encountered at least one snare-gap}}{\text{Total number of snare - line encounter events}}$$

$$p(C/E) = p(Sn/E)p(Cr)p(C/Cr)$$

where p(Cr) is the probability of the animal crossing the snare-gap if the animal encountered (was camera-trapped adjacent to) the snare-gap; p(C/Cr) is the probability of capture by the theoretical snare-noose if the animal crossed the snare-gap; p(Sn/E) is the probability of the animal encountering at least one snare-gap per snare-line encounter event; p(C/E) is the probability of being captured by the theoretical snare-noose per snare-line encounter event.

RESULTS AND DISCUSSION

Species detected

A total of 4,747 working camera-trap nights identified a total of 27 species of birds and mammals along the simulated snare-line; 11 of these were large mammals (excluding squirrels and treeshrews), two of which are classified as 'Vulnerable' (VU), and another as CR (Table 1). In addition, on 02 September 2020, during the pilot survey, a group of Black-shanked Douc *Pygathrix nigripes* was observed at 12.31° N, 108.56° E at 0700 h, and a male Stump-tailed Macaque *Macaca arctoides* killed by a real snare-line in the study area (Image 2) was brought back to the camp by team members, but neither species were captured by the camera-traps.

Although we only surveyed a small area of forest with the camera-traps (total ca. 240 m x 10 m = 2.40 ha) for 47 total nights, this intensive survey (i.e., a high density of sampling units) revealed that a good diversity of ground-dwelling large mammals was still present. This helps confirm Chu Yang Sin NP is still potentially important as a key protected area for large mammal conservation, especially for Annamite endemics like the Large-antlered Muntjac, which we successfully documented. Not surprisingly, our list of recorded species reflects a similar checklist of mammals compiled from a previous camera-trap survey by BirdLife International (2010) (see Table 1), except for the Sambar *Rusa unicolor* and Large Indian Civet *Viverra zibetha* which we did not detect during the survey. A similar pattern of occurrence was also found during a recent camera-trap survey in Chu Yang Sin NP to investigate more widely the occupancy of mammals (Vy T. Nguyen & Anthony J. Giordano, unpub. data). In this camera-trap survey, Vy T. Nguyen and Anthony J. Giordano recorded four more mammal species including Long-tailed Macaque *Macaca fascicularis*, Asian Brush-tailed Porcupine *Atherurus macrourus,* Sunda Pangolin *Manis javanica*, and Lesser Chevrotain *Tragulus kanchil* (see Table 1 & Image 3a–c). Together, findings from these surveys provide a representative picture of the diversity and abundance of large mammals still present in the protected area (Table 2).

Image 2. The carcass of a snared male Stump-tailed Macaque found in a real snare-line encountered during the pilot survey. © MTAN.

This survey is also a commentary on the impact of illegal hunting on large mammal populations in Chu Yang Sin NP, especially ungulates and carnivores. It was noted that high levels of hunting had previously been recorded during surveys by Birdlife International between 2006 and 2009, especially the use of snares. In 2020, for example, signs of hunting were observed that included areas of forest undergrowth burnt for hunting purposes, snare-lines, single snares, and hunting camps; in addition, hunters were encountered in the forest almost every day during the pilot survey. The carcass of a rotten muntjac was observed that had died in an abandoned snare-line, and a male Stump-tailed Macaque that died similarly. Vy T. Nguyen and Anthony J. Giordano recorded a male Northern Red Muntjac *Muntiacus vaginalis* missing his left hind leg on their camera-traps. Prolonged and high intensity snare hunting is a primary reason for the disappearance of many mammal species in the region (Harrison et al. 2016). Carnivore species with large home ranges and long ranging movements, including Leopard *Panthera pardus*, Asian Golden Cat *Pardofelis temminckii*, Mainland Clouded Leopard *Neofelis nebulosa*, and Dhole *Cuon alpinus*, are among the most vulnerable to snaring (Gray 2013; Sukmasuang

Table 1. Large mammals recorded in Chu Yang Sin National Park.

Species	Scientific name	IUCN Red List 2023	BirdLife International 2010	Pilot survey 2020	Snare-line experiment 2021	Vy T. Nguyen & Anthony J. Giordano (unpubl. data)
East Asian Porcupine	*Hystrix brachyura*	LC		O	CT	CT
Asian Brush-tailed Porcupine	*Atherurus macrourus*	LC				CT
Northern Pig-tailed Macaque	*Macaca leonina*	VU	CT		CT	CT
Stump-tailed Macaque	*Macaca arctoides*	VU	CT, O	O		CT
Long-tailed Macaque	*Macaca fascicularis*	EN				CT
Black-shanked Douc	*Pygathrix nigripes*	CR	O	O		
Southern Yellow-cheeked Gibbon	*Nomascus gabriellae*	EN	O			
Sunda Pangolin	*Manis javanica*	CR				CT
Mainland Leopard Cat	*Prionailurus bengalensis*	LC	CT		CT	CT
Large Indian Civet	*Viverra zibetha*	LC	CT			
Northern Common Palm Civet	*Paradoxurus hermaphroditus*	LC			CT	CT
Masked Palm Civet	*Paguma larvata*	LC			CT	CT
Owston's Civet	*Chrotogale owstoni*	EN	O			
Yellow-throated Marten	*Martes flavigula*	LC			CT	CT
Ferret Badger	*Melogale* sp(p).	LC			CT	CT
Lesser Chevrotain	*Tragulus kanchil*	LC				CT
Eurasian Wild Pig	*Sus scrofa*	LC			CT	CT
Sambar	*Rusa unicolor*	VU	CT			CT
Northern Red Muntjac	*Muntiacus vaginalis*	LC	CT		CT	CT
Large-antlered Muntjac	*Muntiacus vuquangensis*	CR	CT		CT	CT
Western Serow	*Capricornis sumatraensis*	VU			CT	CT

Key: CT—camera-trap detection | O—direct observation | IUCN—International Union for Conservation of Nature | CR—Critically Endangered | EN—Endangered | VU—Vulnerable | LC—Least Concern. **Note:** Scientific and common names used are following Wildlife Conservation Society (WCS) 2024. Only species recorded by camera-traps and direct observation in Chu Yang Sin NP are included

et al. 2020; Giordano 2022). Although during 2006–2009, surveys conducted by Birdlife International detected two individuals of Asian Golden Cats in Chu Yang Sin NP, neither this species nor other larger carnivores, including Leopard, and Mainland Clouded Leopards, have officially been confirmed in southern Vietnam for more than a decade (Wilcox et al. 2014; Hoffmann et al. 2019). These species probably have been extirpated from the national park given that our and the other survey by Vy T. Nguyen and Anthony J. Giordano (unpub. data) have failed to detect them in Chu Yang Sin NP.

Populations of large-bodied ungulates are following the same declining pattern as the country's large carnivores, including the Large-antlered Muntjac (Timmins et al. 2015, 2016). This species has declined rapidly in recent years and has now disappeared from most of the Annamite landscape (Timmins et al. 2016). Recent intensive camera-trapping surveys in Vietnam have largely confirmed that remaining Large-antlered Muntjac populations now appear small, fragmented, and isolated (Alexiou et al. 2022; Nguyen et al. 2024; Tilker et al. in press). The presence of Large-antlered Muntjac might suggest a potential source population for the recovery of this CR species. This can only occur if illegal hunting can be successfully controlled in the very near future. Because Chu Yang Sin NP is part of one of the largest remaining contiguous forested landscapes in Vietnam, connecting with Bidoup–Nui Ba National Park, Phuoc Binh National Park, other nature reserves, and state forest companies through its eastern and southern borders, recovery could have significant ramifications for the species' long-term future.

Species vulnerability to snares

Among all species we detected, we recorded the highest encounter rate for Ferret Badger (*Melogale* sp.) (p(E) = 0.91); this was followed by Mainland Leopard Cat *Prionailurus bengalensis*, East Asian Porcupine

Table 2. Annotated checklist of large mammal species historically presumed native to Chu Yang Sin National Park.

Name used following WCS (2024)	IUCN Red List scientific name	Current status
Elephas maximus Asian Elephant	*Elephas maximus*	EX
Tupaia belangeri Northern Treeshrew	*Tupaia belangeri*	Y*
Dendrogale murina Northern Slender-tailed Treeshrew	*Dendrogale murina*	Y*
Galeopterus sp. Indochinese Colugo	*Galeopterus variegatus*	Y
Nycticebus pygmaeus Pygmy Loris	*Nycticebus pygmaeus*	Y
Macaca leonina Northern Pig-tailed Macaque	*Macaca leonina*	Y*
Macaca arctoides Stump-tailed Macaque	*Macaca arctoides*	Y*
Macaca fascicularis Long-tailed Macaque	*Macaca fascicularis*	?M[1]
Trachypithecus germaini Indochinese Silvered Leaf Monkey [including '*margarita*']	*Trachypithecus margarita*	?M
Pygathrix nigripes Black-shanked Douc	*Pygathrix nigripes*	Y
Nomascus gabriellae Southern Yellow-cheeked Gibbon	*Nomascus gabriellae*	Y
Nesolagus timminsi Annamite Striped Rabbit	*Nesolagus timminsi*	Y
Hystrix brachyura East Asian Porcupine	*Hystrix brachyura*	Y*
Atherurus macrourus Asian Brush-tailed Porcupine	*Atherurus macrourus*	Y
Ratufa bicolor Black Giant Squirrel	*Ratufa bicolor*	Y
Callosciurus erythraeus Pallas's Squirrel	*Callosciurus erythraeus*	Y*
Menetes berdmorei Berdmore's Squirrel	*Menetes berdmorei*	?M
Tamiops rodolphii Cambodian Striped Squirrel	*Tamiops rodolphii*	?
Tamiops maritimus Eastern Striped Squirrel	*Tamiops maritimus*	Y*
Dremomys rufigenis Red-cheeked Squirrel	*Dremomys rufigenis*	Y*
Hylopetes spadiceus Red-cheeked Flying Squirrel	*Hylopetes spadiceus*	?
Hylopetes alboniger Particolored Flying Squirrel	*Hylopetes alboniger*	?
Hylopetes phayrei Phayre's Flying Squirrel	*Hylopetes phayrei*	?
Petinomys setosus White-bellied Flying Squirrel	*Petinomys setosus*	?
Belomys pearsonii Hairy-footed Flying Squirrel	*Belomys pearsonii*	?
Biswamoyopterus laoensis Lao Giant Flying Squirrel	*Biswamoyopterus laoensis*	?
Petaurista petaurista Red Giant Flying Squirrel	*Petaurista petaurista*	?
Petaurista philippensis Indian Giant Flying Squirrel	*Petaurista philippensis*	Y
Petaurista elegans Lesser Giant Flying Squirrel	*Petaurista elegans*	Y
Manis pentadactyla Chinese Pangolin	*Manis pentadactyla*	?
Manis javanica Sunda Pangolin	*Manis javanica*	Y
Prionodon pardicolor Spotted Linsang	*Prionodon pardicolor*	Y
Prionailurus viverrinus Fishing Cat	*Prionailurus viverrinus*	?M
Prionailurus bengalensis Mainland Leopard Cat	*Prionailurus bengalensis*	Y*
Catopuma temminckii Asian Golden Cat	*Catopuma temminckii*	EX
Pardofelis marmorata Marbled Cat	*Pardofelis marmorata*	Y
Neofelis nebulosa Mainland Clouded Leopard	*Neofelis nebulosa*	EX
Panthera pardus Leopard	*Panthera pardus*	EX
Panthera tigris Tiger	*Panthera tigris*	EX
Viverra zibetha Large Indian Civet	*Viverra zibetha*	Y
Viverricula indica Small Indian Civet	*Viverricula indica*	?M
Paradoxurus hermaphroditus Northern Common Palm Civet	*Paradoxurus hermaphroditus*	Y*
Paguma larvata Masked Palm Civet	*Paguma larvata*	Y*
Arctictis binturong Binturong	*Arctictis binturong*	Y
Arctogalidia trivirgata Small-toothed Palm Civet	*Arctogalidia trivirgata*	Y
Chrotogale owstoni Owston's Civet	*Chrotogale owstoni*	Y
Urva javanicus Javan Mongoose	*Herpestes javanicus*	?M
Urva urva Crab-eating Mongoose	*Herpestes urva*	Y
Canis aureus Golden Jackal	*Canis aureus*	?M
Cuon alpinus Dhole	*Cuon alpinus*	EX
Ursus thibetanus Asian Black Bear	*Ursus thibetanus*	Y
Ursus malayanus Sun Bear	*Helarctos malayanus*	Y
Mustela kathiah Yellow-bellied Weasel	*Mustela kathiah*	Y
Mustela strigidorsa Stripe-backed Weasel	*Mustela strigidorsa*	Y
Martes flavigula Yellow-throated Marten	*Martes flavigula*	Y*
Arctonyx collaris Greater Hog Badger	*Arctonyx collaris*	Y
Melogale personata Large-toothed Ferret Badger	*Melogale personata*	?M
Melogale moschata Small-toothed Ferret Badger	*Melogale moschata*	Y
Lutra lutra Eurasian Otter	*Lutra lutra*	Y
Lutra sumatrana Hairy-nosed Otter	*Lutra sumatrana*	?M-EX
Lutrogale perspicillata Smooth-coated Otter	*Lutrogale perspicillata*	?M-EX
Aonyx cinereus Oriental Small-clawed Otter	*Aonyx cinereus*	Y
Rhinoceros sondaicus Javan Rhinoceros	*Rhinoceros sondaicus*	EX
Dicerorhinus sumatrensis Sumatran Rhinoceros	*Dicerorhinus sumatrensis*	EX
Sus scrofa Eurasian Wild Pig	*Sus scrofa*	Y*
Tragulus kanchil Lesser Chevrotain	*Tragulus kanchil*	Y
Rusa unicolor Sambar	*Rusa unicolor*	Y
Muntiacus vaginalis Northern Red Muntjac	*Muntiacus vaginalis*	Y*
Muntiacus vuquangensis Large-antlered Muntjac	*Muntiacus vuquangensis*	Y*
Bos gaurus Gaur	*Bos gaurus*	Y
Pseudoryx nghetinhensis Saola	*Pseudoryx nghetinhensis*	?
Capricornis sumatraensis Western Serow	*Capricornis sumatraensis*	Y*

Key: Y—Presumed native and still to be present | EX—Presumed to be extirpated | ?EX—Possibly extirpated | M—Possibly present, but would be very marginal (lowland and open country species) | ?—Presence and distribution (historically and at present) are uncertain in the southern Annamites | *—Species detected during the study | 1—Although detected by Vy T. Nguyen and Anthony J. Giordani (unpub. data, Image 3B), it is unclear if the species is native to Chu Yang Sin NP, as animals confiscated from the wildlife trade network in Vietnam are routinely released in protected areas, and the habitats in Chu Yang Sin NP are somewhat atypical for this species. Note: Presumed historical status was determined by R.J. Timmins via reference to a large number of published and unpublished studies and other data sources on species distribution and ecological factors relevant to compatibility of habitats in Chu Yang Sin NP with species native presence; key references included but are not limited to Dang et al. (1994), Duckworth et al. (1999), Duckworth & Hills (2008), Francis (2017), Hoffmann et al. (2019), Nguyen & Timmins (2020), WCS (2024), along with reference to current IUCN Red List species accounts (iucnredlist.org) to provide further data on most likely current status.

Table 3. Summary of encounters with the simulated snare-line (events) and snare-gaps, crossing the snare-gap and being captured by the simulated snare-noose, and capture probabilities.

Species	Total number of events	Total number of snare-gaps encounters for all events	Number of events with at least one snare-gap encounter	Total number of times snare-gaps were crossed for all events	Total number of captures by simulated snares for all events	p(E)	p(Cr)	p(C/Cr)	p(Sn/E)	p(C/E)
Large-antlered Muntjac	4	9	4	6	6	0.09	0.67	1	1	0.67
Mainland Leopard Cat	8	9	7	4	4	0.17	0.44	1	0.88	0.39
Common Palm Civet	3	2	2	1	1	0.06	0.5	1	0.67	0.34
East Asian Porcupine	7	10	7	3	3	0.15	0.3	1	1	0.3
Ferret Badger	43	29	28	8	8	0.91	0.28	1	0.65	0.18
Masked Palm Civet	5	6	5	1	1	0.11	0.17	1	1	0.17
Northern Red Muntjac	5	5	4	1	1	0.11	0.2	1	0.8	0.16
Northern Pig-tailed Macaque	6	5	5	0	0	0.13	0	0	0.83	0
Western Serow	1	5	1	1	0	0.02	0.2	0	1	0
Eurasian Wild Pig	2	1	1	0	0	0.04	0	0	0.5	0
Yellow-throated Marten	5	8	5	1	0	0.11	0.125	0	1	0

Hystrix brachyura, Northern Pig-tailed Macaque *Macaca leonina*, Masked Palm Civet *Paguma larvata*, and Northern Red Muntjac (p(E) varied from 0.17 to 0.11). Western Serow *Capricornis sumatraensis*, Eurasian Wild Pig *Sus scrofa*, and Northern Common Palm Civet *Paradoxurus hermaphroditus* had the lowest encounter rates (p(E) 0.02 – 0.06). Large-antlered Muntjac and Yellow-throated Marten *Martes flavigula* also showed low encounter rates of p(E) 0.09 and 0.11, respectively (Table 3).

Although our sample size is small for most species, our data suggested that overall, most ground-dwelling large mammals are vulnerable to snares in some way. One of the most compelling results was the apparent effectiveness of the construction of the snare-gap in the resulting probability of an animal being captured by a snare strategically placed in the snare-gap. Every snare-gap crossing event recorded (n = 25; Table 3), across all species (n = 8), with a single exception, resulted in the theoretical capture of the animal. In other words, if an animal crosses a snare-gap, its probability of capture would appear to be very high. However, other factors interact to determine the theoretical probability of capture at a snare-line; for example, Large-antlered Muntjac was the most vulnerable with a high probability of capture per snare-line encounter event (p(C/E) = 0.67), thus although the species' encounter rate was low, theoretically most animals in the vicinity of the snare-line were likely to have been captured. Data for the Large-antlered Muntjac came mostly from a single juvenile animal and one event of an adult female; if the snare-line had real snares the probability of capture of the juvenile over the entire period would have been p(C/E) = 1 (100%). In contrast, Ferret Badger was less likely to be captured per event (p(C/E) = 0.18), the high encounter rate (p(E) = 0.91) is likely to ensure in reality a high probability of being captured over the lifetime of the snare-line. Based on our conversations with hunters, we know that hunters in Chu Yang Sin NP often abandon actual snare-lines after three months, with no snares ever being removed from the forest. Interestingly, Western Serow, Northern Pig-tailed Macaques, Eurasian Wild Pig, and Yellow-throated Marten, all had low capture rates with evidence visible on the videos and photographs to suggest that behaviour might play a crucial role in lowering their susceptibility to being captured in snares; including potentially increased wariness and active avoidance of the snare-gap, avoidance of crossing snare-gaps for other reasons and crossing the snare-line by other means (e.g., through the fence or climbing vegetation adjacent to the snare-line).

Image 3. Some mammal species recorded by VT. Nguyen & A. J. Giordano (unpublished data): A—Lesser Chevrotain | B—Long-tailed Macaque | C—Sunda Pangolin.

For example, in the only encounter of Western Serow (one individual) with the snare-line the animal appeared to show a high level of caution. It appeared to actively avoid crossing the first three snare-gaps that it met, attempted but failed to get through/over the vegetation of a section of snare-fence, before finally crossing the fourth snare-gap, but in a way that avoided placing any of its feet within the theoretical snare. Yellow-throated Marten tended to move over/through the snare-line by climbing trees or jumping over the gap directly, rather than going through the center of the snare-gap (five events with eight snare-gaps encountered and one crossing but none captured). Northern Red Muntjac (at least two different individuals encountered) also appeared to show indications of wariness on the videos and photographs with the probability of being captured four times lower than Large-antlered Muntjac (p(C/E) = 0.16). The data for Large-antlered Muntjac was largely based on a single juvenile animal, and it is plausible that significant differences exist in behaviour between juveniles and adults.

This experiment showed important empirical evidence supporting the assumption that different species display different levels of vulnerability to capture in snare-lines. From this it can be theorized that different species potentially have very different thresholds to 'intensity' of snaring that affect their population viability. Understanding these thresholds potentially opens the door to better management of the snaring crisis. Tackling the snaring crisis is a highly complex problem, requiring both in situ and ex situ interventions at multiple levels, with many different stakeholders. Knowledge of population viability thresholds can guide conservation planning by prioritizing the protection of species most sensitive to snaring. Since snares are difficult to detect and snare eradication efforts are constrained by limited resources, achieving zero snaring is unrealistic at least in the short-term. Biodiversity conservation effort and resources therefore need to be strategically targeted to interventions that prevent local population extirpation of priority species. To achieve this, continuously monitoring population viability thresholds in response to 'intensity' of snaring can help answer critical questions about the intensity of snaring that could be tolerated to prevent species' local population extirpations. Determining the effort and spatial scale required for snare removal activities to reduce snare intensity below species viability thresholds to ensure the continued survival of large mammal populations is essential for guiding law enforcement actions. Over the long term, this approach can potentially help identify priority areas for in situ conservation where targeted snare removal supports population recovery.

CONCLUSION

This study is the first of its kind in the world to use camera-traps in an innovative context to directly simulate the impact of snare hunting on large mammals. Although the analysis was simple and the sampling period was short, our results yield new insights into the snaring crisis and "empty forest syndrome" especially highlighting the potential differential vulnerability among species. It is believed that with more replication and analysis of larger datasets based on similar methods, these approaches may offer promising new opportunities to address the snaring crisis. Until such time, greatly enhanced, strategic, and highly focused law enforcement is needed in critical protected areas of Vietnam to effectively mitigate illegal hunting in key locations and ultimately prevent widespread extirpation of many species, but particularly the Annamite endemic species.

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Tóm tắt: Dãy Trường Sơn trên bán đảo Đông Dương có mức độ đặc hữu thú cao nhưng đồng thời cũng đang bị đe dọa tuyệt chủng nghiêm trọng, chủ yếu do săn bắt trái phép bằng bẫy dây phanh tràn lan. Ở phía nam của dãy Trường Sơn thuộc Việt Nam, Vườn quốc gia Chư Yang Sin là một trong số ít các khu rừng ở nước này được dự đoán vẫn còn sự hiện diện của Mang lớn, một loài thú chỉ được ghi nhận ở dãy Trường Sơn và đang có tình trạng bảo tồn ở mức Cực kỳ Nguy cấp. Mục tiêu của nghiên cứu này là 1/ thực nghiệm điều tra mức độ tác động của bẫy dây phanh lên các quần thể thú tại vườn bằng phương pháp bẫy ảnh, tập trung vào các loài mang, và 2/ cung cấp một danh lục các loài thú lớn cho vườn. Năm 2020, một khảo sát tiền trạm được tiến hành nhằm xác định địa điểm thực nghiệm trong vườn quốc gia dựa trên việc ghi nhận các dấu vết gợi ý sự hiện diện của các loài thú lớn. Từ tháng 12/2020 đến tháng 02/2021, một tuyến đường bẫy dây mô phỏng dài 515 m đã được xây dựng tại địa điểm thực nghiệm bởi năm thợ săn địa phương có kinh nghiệm trong vùng. Các bẫy ảnh được lắp đặt sau đó dọc theo 240 m của tuyến đường bẫy nhằm theo dõi sự di chuyển của động vật. Các bẫy ảnh hoạt động tổng cộng 4.747 đêm đã ghi nhận sự hiện diện của Mang lớn và 10 loài thú lớn khác. Nghiên cứu cho thấy Mang lớn dễ bị dính bẫy dây hơn so với các loài thú khác, có xác suất "dính bẫy" cao nhất nếu cá thể gặp phải đường bẫy (p = 0,67). Phát hiện này củng cố giả thuyết trước đây rằng việc tiếp xúc kéo dài với tuyến đường bẫy sẽ làm suy giảm mạnh các quần thể thú lớn, vì khi một cá thể nhiều lần tiếp xúc một tuyến đường bẫy, xác suất "dính bẫy" sẽ tăng gần đến p = 1. Nghiên cứu này lần đầu tiên cho thấy một cách thực nghiệm rằng các loài khác nhau có mức độ nhạy cảm với bẫy dây khác nhau. Dựa trên phương pháp thực nghiệm này, các nghiên cứu trong tương lai có thể mang lại những hiểu biết mới nhằm quản lý hoạt động săn bắt bằng bẫy dây phanh hiệu quả hơn, thông qua việc kết hợp dữ liệu từ nhiều khu vực khác và tiến hành trong thời gian dài hơn.

Author details: Minh Thi Anh Nguyen (MTAN) is a PhD candidate at Colorado State University and a research associate at the Saola Foundation, working on mammal conservation in Viet Nam and Lao PDR. Thuy Thi Bich Vo (TTBV) is a lecturer at Nong Lam University – Ho Chi Minh City and a specialist in eco-tourism. Quy Tan Le (QTL) is a field researcher at the Center for Ecology and Resources, Institute of Advanced Technology, Viet Nam Academy of Science and Technology in Viet Nam. Vy Tran Nguyen (VTN) is the head of the Department of Biological Resources, Institute of Life Sciences. Vu Linh Nguyen (VLN) is a lecturer at Nong Lam University – Ho Chi Minh City and possess expertise in and environmental management and engineering. R.J. Timmins is the technical director at the Saola Foundation for Annamite Mountains Conservation, with three decades of field-work and conservation experience in Indochina. Dr. Anthony J. Giordano (AJG) holds the position of CEO and Chief Conservation Scientist at S.P.E.C.I.E.S. with more than three decades of field work on carnivores and other mammals; he is also an adjunct professor at the Centers of Human-Carnivore Coexistence, and Collaborative Conservation, at Colorado State University.

Author contributions: MTAN and RJT conceived and designed the study. VLN, MTAN, and TTBV obtained funding. TTBV obtained permissions for the study in CYS, managed logistic and communication with local government and local communities. MTAN and QTL conducted fieldwork, collected and collated data and performed the analysis. RJT identified the survey locations for the pre-survey, drafted the annotated checklist of large mammal species in CYS, conceptualized the data analysis, and revised the manuscript. AJG helped with the writing, significant editing, and revision of the manuscript and advised on data analysis and design. AJG and RJT helped with the structure and content of the paper. AJG and VTN contributed the mammal species list from their wider scale camera trap data in CYS in 2022. MTAN led the writing with QTL's assistance; all authors edited and approved the manuscript.

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ARTICLE

Rapid camera-trap assessment of mammals in Tripura, India: new records and implications for conservation

Omkar Patil [1], Ashutosh Joshi [2], Rutuja Digaskar [3] & Amey Parkar [4]

[1–4] Vivek PARC Foundation 208, 2nd Floor, Shilpin Centre, 40, GD Ambekar Marg, Dadar East, Wadala, Mumbai, Maharashtra 400031, India
[1] opatil934@gmail.com (corresponding author), [2] asjoshis@gmail.com, [3] rutujadigaskar01@gmail.com, [4] ameyparkar9@gmail.com

Abstract: This study presents first ever rapid camera-trapping assessment of mammals across protected areas of Tripura, northeastern India, located within the Indo-Burma biodiversity hotspot. Surveys were conducted between January and April 2024 in Sepahijala Wildlife Sanctuary, Clouded Leopard National Park, Trishna Wildlife Sanctuary, Bison National Park, and Gumti Wildlife Sanctuary, resulting in 469 trap nights. A total of 19 mammalian species belonging to 16 genera, 10 families, and four orders were documented. Trishna Wildlife Sanctuary recorded the highest species diversity, followed by Sepahijala and Gumti. This study features the first photographic evidence of the Ferret Badger, range extensions for the Malayan Porcupine and the Fishing Cat. These findings fill important distribution gaps and highlight the conservation significance of Tripura's fragmented forests and wetland mosaics. Despite their small size and increasing anthropogenic pressures, the protected areas of Tripura support a diverse mammalian assemblage. The study demonstrates the value of rapid, pragmatic field approaches for generating essential ecological information under resource constraints and underscores the need for continued monitoring and regional connectivity planning.

Keywords: Biodiversity monitoring, camera-trapping, habitat connectivity, Indo-Burma biodiversity hotspot, landscape fragmentation, pragmatism.

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Author details: Omkar Patil is an ecologist whose work primarily revolves around carnivore & landscape ecology and human animal interactions. Ashutosh Joshi functions as a research advisor to the wildlife research division of the Vivek PARC Foundation. He holds a PhD in environmental sciences. Rutuja Digaskar is an ecologist whose work focuses on wild carnivores in high altitude landscapes. Amey Parkar is currently pursuing masters in Zoology from the Homi Bhabha State University & functioned as an intern in the Vivek PARC Foundation. He actively works in understanding the ecology of mammals & birds.

Author contribution: OP, AJ and AP contributed to data collection. Study conception, study design, preparation, data collection and analysis were performed by OP & AJ. The first draft of the manuscript was written by OP and all authors contributed to refining & revising the manuscript.

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INTRODUCTION

Tropical regions of southern and southeastern Asia support some of the richest yet most threatened biodiversity on Earth (Woodruff 2010). Within this region, India harbours exceptional mammalian diversity across varied landscapes ranging from the Himalaya to the Indo-Burma and Western Ghats hotspots (Myers et al. 2000). Despite this richness, many landscapes remain poorly studied due to their remoteness, limited accessibility and research bias toward established protected areas (Datta et al. 2008; Jhala et al. 2020). These gaps limit our ability to generate spatially explicit and quantitative data on species occurrence and abundance, particularly in smaller or peripheral reserves that function as critical ecological corridors.

Tripura, located in the northeastern corner of India, forms an ecological bridge between the Indian subcontinent and southeastern Asia. The state lies within the Indo-Burma biodiversity hotspot and supports a mosaic of tropical evergreen, semi-evergreen and moist deciduous forests (Champion & Seth 1968; Deb 1981). Its geographic position between the hill forests of Bangladesh and Mizoram enables biological exchange between the Indian and southeastern Asian faunal realms (Datta et al. 2008). While previous studies have documented mammalian diversity in Tripura through checklists and regional accounts (Majumder et al. 2015; Majumdar & Datta 2018; Talukdar et al. 2021), these efforts have been descriptive and presence-based.

Existing knowledge of mammals in Tripura is therefore limited in three key ways: (i) a lack of standardised, effort-based surveys, (ii) absence of quantitative data on relative abundance and detection patterns, and (iii) minimal understanding of species distribution across multiple protected areas within a unified sampling framework. Most available studies rely on opportunistic records, localised surveys or species-specific investigations, such as those of Western Hoolock Gibbon *Hoolock hoolock* and Gaur *Bos gaurus* (Gupta et al. 2005; Dasgupta et al. 2008). While valuable, these studies do not provide comparable or landscape-level insights necessary for conservation planning.

In this context, camera-trapping offers a robust, non-invasive and standardised method for generating comparable data on species occurrence, detection, and relative abundance across sites. However, prior to this study, no landscape-scale, systematic camera-trapping assessment had been conducted across the protected areas of Tripura. This represents a critical knowledge gap, particularly given the increasing anthropogenic pressures on the state's forests.

Tripura's forest landscapes are undergoing rapid change due to shifting cultivation, illegal logging, expansion of rubber plantations and infrastructure development (Gupta 1998; Chatterjee 2008). These drivers contribute to internal fragmentation and alter habitat connectivity. In such dynamic and resource-constrained contexts, long-term ecological studies are often challenging. Rapid, exploratory biodiversity assessments when implemented using standardised protocols, provide an effective approach to generate baseline data and identify conservation priorities within limited time frames (Wearn & Glover-Kapfer 2017)

A pragmatic research approach is therefore essential, one that balances scientific rigor with logistical feasibility. Such approaches emphasize adaptive field strategies, stakeholder participation and collaboration with local forest departments to ensure both data quality and management relevance (Sutherland et al. 2004; Mishra et al. 2017; Palencia et al. 2022).

Against this backdrop, the present study was designed as an exploratory, landscape-scale camera-trapping assessment to address critical data deficiencies in Tripura. Specifically, the study aimed to: (i) document mammalian occurrence using standardized camera-trapping across protected areas, (ii) generate effort-based indices of relative abundance and detection, and (iii) establish a baseline dataset to support future monitoring and management interventions by the Tripura Forest Department.

This study represents the first systematic, multi-site camera-trapping exercise conducted across protected areas in Tripura, moving beyond opportunistic and checklist-based approaches to provide a quantitative and comparable understanding of mammalian communities. The rapid assessment was conducted between January and April 2024 as a collaborative initiative between the Vivek PARC Foundation, The Habitats Trust, and the Tripura Forest Department.

MATERIALS AND METHODS

Study area

The study was conducted across the protected areas of Tripura: Sepahijala Wildlife Sanctuary (SWS), Clouded Leopard National Park (CLNP), Trishna Wildlife Sanctuary (TWS), Bison National Park (BNP), Gumti Wildlife Sanctuary (GWS), and Rowa Wildlife Sanctuary (RWS). CLNP falls within SWS and is hereafter collectively referred to as SWS. Similarly, BNP, located within TWS, is referred to as TWS. Together they represent the principal habitats of the state, covering approximately 613 km². These areas include tropical evergreen, semi-evergreen and moist deciduous forest types interspersed with bamboo brakes and cultivation zones (Deb 1981) (Table 1, Figure 1).

Tripura has about 59.89% forest cover (Majumdar & Datta 2018). Historical accounts indicate that the forests of Tripura have long been subjected to anthropogenic pressures, particularly shifting cultivation, timber extraction, and plantation expansion (Gupta 1998). Climatically, the region experiences four distinct seasons, winter, summer, monsoon, and post-monsoon, with annual rainfall of 2,000–2,500 mm (Debnath et al. 2021). The present survey, conducted between January and April 2024, represents a winter to pre-monsoon sampling. This period was suitable for camera trapping as reduced water availability concentrates animal activity around water sources, enhancing detection probability. Additionally, soft substrates near water bodies facilitated the identification of animal signs such as pugmarks, aiding in optimal camera placement (Rovero & Zimmermann 2016).

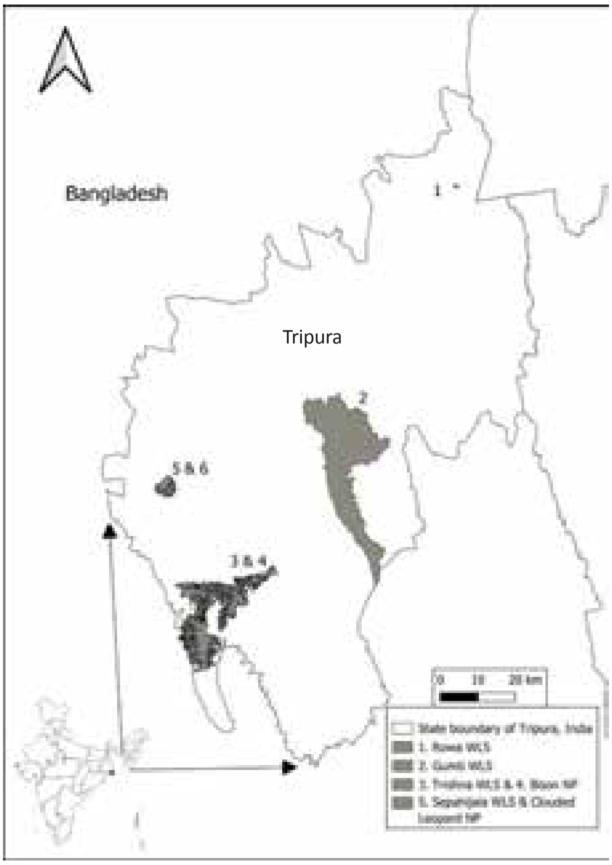

Figure 1. All the protected areas of Tripura along with the state boundary. WS—Wildlife Sanctuary | NP—National Park.

Sampling design

A grid-based camera-trap sampling framework was used following Rajaratnam et al. (2007) and Rovero & Zimmermann (2016). Grids of 2 km² were overlaid across each protected area. Camera traps were deployed in singles and pairs wherever feasible. In smaller reserves such as Rowa and Sepahijala, the grid layout was adjusted to accommodate limited area and access. Camera placement was guided by evidence of animal activity, such as pugmarks or scats, and grids with excessive human disturbance were avoided to minimize the bias and theft. Within TWS, 25 grids were selected for sampling, of which 14 were sampled, with all trap stations equipped with paired camera traps. In GWS, 48 grids were selected, of which 29 were sampled; camera traps were deployed in pairs at 15 stations and singly at 14 stations. In SWS, seven camera trap locations were selected, all with paired deployments. Similarly, in RWS, four camera trap locations were sampled, each with paired camera traps. Camera traps deployed singly were placed in areas with high human activity to reduce the risk of theft; this approach may have introduced detection bias, as a single camera covers a limited field of view compared to paired deployments.

The study followed a rapid assessment protocol emphasizing spatial coverage and standardized deployment over long-term replication. This design provides robust data on species presence and relative abundance but does not allow estimation of absolute densities or seasonal variation (O'Brien 2011).

Infrared and white-flash cameras (Cuddeback

Table 1. Details of the protected areas of Tripura.

Protected area	Size (km²)	Habitat type	Elevation range (in m)	Disturbance level
Sepahijala WS	18.5	Moist mixed deciduous forest	10–50	High
Trishna WS	194.71	Moist mixed deciduous forest	51–82	Moderate to high
Gumti WS	389.5	Tropical semievergreen forest	40–300	High
Rowa WS	0.8	Moist deciduous forest	70	Moderate to high

X-Change and Spartan Lumen models) were deployed for a maximum of 10 nights per location. Each site was geo-referenced, and details such as habitat type, elevation and proximity to human settlements were recorded. Cameras were positioned along trails or watercourses frequently used by wildlife. At certain locations, cameras were placed facing each other to document both flanks of patterned species (Johnson et al. 2009). Camera traps were mounted on trees or placed within small rock cavity-like structures at a height of approximately 30–45 cm above ground to target small-to medium-sized mammals. Additionally, two camera traps were opportunistically installed on trees at higher positions to sample arboreal mammals.

Camera traps were checked periodically by Tripura Forest Department staff and Banmitras. Cameras were concealed using natural vegetation and secured with locking cables.

Captured images were reviewed manually, and species identifications were verified independently by two observers (Images 1–17). Ambiguous images were labelled as "unidentified" and excluded from species-level analyses.

Detection bias and limitations

Camera detection probability varies among species due to body size, activity pattern and vegetation density. Smaller or arboreal mammals are generally under-detected (Burton et al. 2015). Consequently, relative abundance index (RAI) values are interpreted as indices of activity rather than true abundance. For species with fewer than 10 independent detections, results were treated qualitatively. Future monitoring could adopt occupancy or spatially explicit capture-recapture (SECR) models when sample sizes meet analytical thresholds (Efford & Fewster 2012; Wearn & Glover-Kapfer 2017).

Further, rarefaction curves were used to standardize species richness across sites with unequal sampling effort, enabling robust comparisons despite differences in trap-nights and detectability. They also help assess sampling adequacy by indicating whether additional effort is likely to record new species, making them particularly suitable for camera-trap studies (Gotelli & Colwell 2001; Magurran 2004).

Training, community engagement and ethics

Before field deployment, hands-on training sessions were organized for forest staff and Banmitras, focusing on equipment setup, troubleshooting and maintenance. Local communities around each protected area were informed about camera placement to minimize interference and promote awareness. No animals were handled or disturbed during the study, and all research was conducted under permits issued by the Tripura Forest Department.

Data management and quality control

All image files were systematically named using protected area and grid identifiers in the following format- 'Name-of-PA_Forest-Range_Grid-ID' (for example, *GUM_GAN_CT1*). Metadata, including coordinates, habitat type, deployment date and personnel involved, were recorded in standardized field sheets. Images and metadata were stored in duplicate on external drives.

Data analysis

Relative abundance index (RAI):

RAI was used to estimate species activity across protected areas, serving as a cost-effective, non-invasive index widely applied in wildlife monitoring and management (O'Brien 2011).

RAI = (No. of independent detections/Total trap nights) * 100

Independent detections were defined as images of the same species separated by at least 30 min to avoid false replication (Rovero & Marshall 2009), and RAI values were calculated per protected area for comparative assessment of relative occurrence.

Diversity indices and hill numbers:

Biodiversity was quantified using two commonly applied indices: the Shannon-Wiener index (H') and the Simpson's index (D or 1–D).

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the proportion of detections of species *i* and *S* is the total number of species detected. A higher H' value indicates greater species diversity and evenness (Spellerberg & Fedor 2003).

Simpson's index (D) was calculated as

$$D = 1 - \sum_{i=1}^{N} (p_i)^2$$

where p_i is the same as above. Higher values of D indicate dominance by few species, whereas values of (1–D) closer to 1 represent higher overall diversity. These indices were calculated for each protected area to compare community structure and dominance patterns (He & Hu 2005).

To facilitate more intuitive and comparable interpretation of diversity across sites, the Shannon-Wiener (H') and Simpson (D) indices were converted to hill numbers (Hill 1973; Jost 2006). Traditional diversity indices are non-linear and expressed in units that are difficult to compare directly, whereas hill numbers transform these indices into the "effective number of species," representing the number of equally abundant species required to produce the observed diversity. This approach enables meaningful comparisons across sites with varying sampling effort and community structure, and is increasingly recommended as a standard in ecological studies (Jost 2006; Chao et al. 2014).

Shannon-Wiener (H′) and Simpson (D) indices were converted to Hill numbers using

$$^{1}D = e^{H'}$$

$$^{2}D = \frac{1}{D}$$

Rarefaction curve analysis

Independent camera-trap detections filtered using a 30-min temporal independence threshold were used to construct species-by-sampling-unit incidence matrices for each protected area, excluding cattle to avoid bias from domestic animals. Each grid cell (grid_id) was treated as a sampling unit and species presence-absence was calculated for per unit. Sample-based rarefaction curves were generated using the '*specaccum()*' function in the '*vegan*' package in R, applying the random method with 1,000 permutations to estimate mean richness and associated 95% confidence intervals (Oksanen et al. 2022), following established protocols for sample-based accumulation curves (Gotelli & Colwell 2001; Magurran 2004). Although coverage-based standardization is recommended when detection probabilities vary across sites (Chao & Jost 2012), sample-based rarefaction was used here to align with the dataset structure and sampling design.

Analytical approach

Given moderate detection rates, RAI and diversity indices were used as the primary comparative metrics. Occupancy or SECR models were not applied since individual recaptures per species were below the analytical threshold of 20 independent detections (Efford & Fewster 2012). All calculations were performed using Microsoft Excel and biodiversity indices were computed using R v4.3.2. Spatial visualization was conducted in QGIS 3.30.2.

RESULTS

A total of 19 mammalian species were documented from all the protected areas through a rapid camera-trapping survey conducted between January and April 2024 (Table 2). Rowa Wildlife Sanctuary was not included in the analysis due to insufficient data from camera traps. During field surveys, Barking Deer *Muntiacus vaginalis* was captured in a single camera trap, and direct sightings of Capped Langur *Trachypithecus pileatus*, Phayre's Leaf Monkey *Trachypithecus phayrei*, and Rhesus Macaque *Macaca mulatta* were recorded, indicating the continued presence of these species in the sanctuary. A cumulative sampling effort of 469 trap nights was achieved across all three protected areas, with the highest effort recorded in GWS (280 trap nights), followed by TWS (122) and SWS (77) (Table 3). Five cameras that malfunctioned or were lost were excluded from analyses.

The number of independent detections ranged from 46 in GWS to 150 in SWS (including 114 detections from TWS), collectively yielding 292 independent photographic captures. Despite variation in sampling effort, all the protected areas exhibited substantial mammalian activity, indicating diverse assemblages across the landscape.

Across all study sites, 19 species belonging to 10 families and four orders were recorded (Table 4). These included representatives of Carnivora, Primates, Artiodactyla, and Rodentia. Out of the 19 species, 17 were recorded in the camera traps while Capped Langur and Western Hoolock Gibbon *Hoolock hoolock* were sighted.

Key species detected were Rhesus Macaque, Pig-tailed Macaque *Macaca leonina*, Phayre's Leaf Monkey, Leopard Cat *Prionailurus bengalensis*, Common Palm Civet *Paradoxurus hermaphroditus*, Small Indian Civet *Viverricula indica*, Wild Pig *Sus scrofa*, and Barking Deer.

The photographic evidence of Fishing Cat *Prionailurus viverrinus* in TWS and Small-clawed Otter *Aonyx cinerea* in TWS provides significant records of wetland-dependent species within the Indo-Burma landscape.

Abundance Index (RAI)

The relative abundance index (RAI) revealed spatial variation in species activity across the three protected areas. In SWS, the Rhesus Macaque exhibited the highest RAI (69.12 ± 34.74), indicating strong primate activity within the sanctuary. Other frequently captured species were Large Indian Civet *Viverra zibetha* (25.00 ± 14.43), Pig-tailed Macaque (17.65 ± 8.66) and Common Palm Civet (14.71 ± 10.03). Herbivores such as Barking

Table 2. Summary of the camera-trapping effort undertaken in all the protected areas of Tripura. Note: Rowa Wildlife Sanctuary was not included in the analysis due to insufficient camera-trap data. Records from camera traps and opportunistic sightings were documented during field surveys.

Protected area	No. of camera-trap stations	Active trap nights	Period (2024)
Rowa WS	4	12	29 Jan– 04 Feb
Sepahijala WS	8	77	10 Feb–18 Feb
Trishna WS	15	112	19 Feb–08 Mar
Gumti WS	29	280	09 Mar–05 Apr
Total	**56**	**481 (469)**	-

Table 3. Camera-trap effort, number of species detected, number of independent captures and total trap nights across protected areas of Tripura.

Protected area	No. of species detected	No. of independent captures	Total trap nights
Sepahijala WS	9	107	77
Trishna WS	12	114	112
Gumti WS	8	71	280
Total	-	292	469

Deer (11.76 ± 6.42) and Wild Pig (10.29 ± 5.94) were also well represented.

In TWS, the Common Palm Civet (21.95 ± 10.03) and Pig-tailed Macaque (8.13 ± 8.66) were most abundant, while Gaur *Bos gaurus* (4.88 ± 2.82) and Small-clawed Otter *Aonyx cinerea* (3.25 ± 1.88) represented key large and semi-aquatic mammals, respectively. The photographic record along with numerous sightings of multiple troops of Phayre's Leaf Monkey reaffirmed the site's role as a crucial habitat for this threatened primate.

In GWS, overall detection rates were lower, with Crab-eating Mongoose *Urva urva* (16.37 ± 8.20) and Leopard Cat (2.49 ± 0.55) being the most frequently recorded. The presence of Leopard Cat and Masked Palm Civet *Paguma larvata* (0.36 ± 0.21) reflects habitat heterogeneity.

The dominance of adaptable species such as civets, macaques and small carnivores suggests that the mammalian community remains resilient under moderate anthropogenic pressure (Burton et al. 2015).

Species diversity

The Shannon-Wiener (H') and Simpson's diversity ndices (1–D) along with Hill numbers were calculated for each protected area (Table 5).

- Trishna Wildlife Sanctuary (H' = 1.984; 1–D = 0.8294) exhibited the highest diversity and lowest dominance (D = 0.1706), indicating a well-balanced species distribution.

- Sepahijala Wildlife Sanctuary (H' = 1.917; 1–D = 0.8194) showed moderate diversity, reflecting a stable community dominated by primates and civets.

- Gumti Wildlife Sanctuary (H' = 1.853; 1–D = 0.7843) displayed lower diversity and higher dominance (D = 0.2157), suggesting localized concentration of a few species such as Crab-eating Mongoose and Leopard Cat.

- Conversion of diversity indices to Hill numbers indicated that Trishna Wildlife Sanctuary exhibited the highest effective number of species (^1D = 7.27; ^2D = 5.86), followed by Sepahijala Wildlife Sanctuary, and Gumti Wildlife Sanctuary . The larger difference between ^1D and ^2D in GWS suggests greater dominance by a few species and lower community evenness, whereas TWS showed comparatively higher evenness and a more balanced species assemblage.

These results collectively indicate that Trishna supports the most even and balanced mammalian assemblage, followed by Sepahijala, while Gumti, though larger, is more ecologically heterogeneous.

Rarefaction curves

The rarefaction curve (Figure 2) for GWS shows a steady increase in species richness with increasing sampling units, with the curve beginning to approach an asymptote near the highest sampling intensity. This suggests that sampling captured most of the detectable species in this landscape, though a small number of undetected species may still remain. The gradually narrowing confidence interval indicates increasing precision at higher sampling effort. The curve's shape is consistent with well-sampled assemblages reported in other camera-trap studies where species detection stabilizes after sufficient spatial coverage (Kays et al. 2020).

The rarefaction curve (Figure 3) for SWS rises sharply during the initial sampling units, reaching approximately 8–9 species before showing signs of flattening. Due to the relatively low total number of sampling units (1–7), this apparent plateau may reflect limited sampling effort rather than true community saturation. Small sample sizes can give the illusion of convergence even when many species remain undetected (Gotelli & Colwell 2001). Thus, while the curve suggests moderate richness, additional sampling is likely necessary for a robust estimate.

The rarefaction curve (Figure 4) for TWS reaches the highest richness values among the three groups, with the

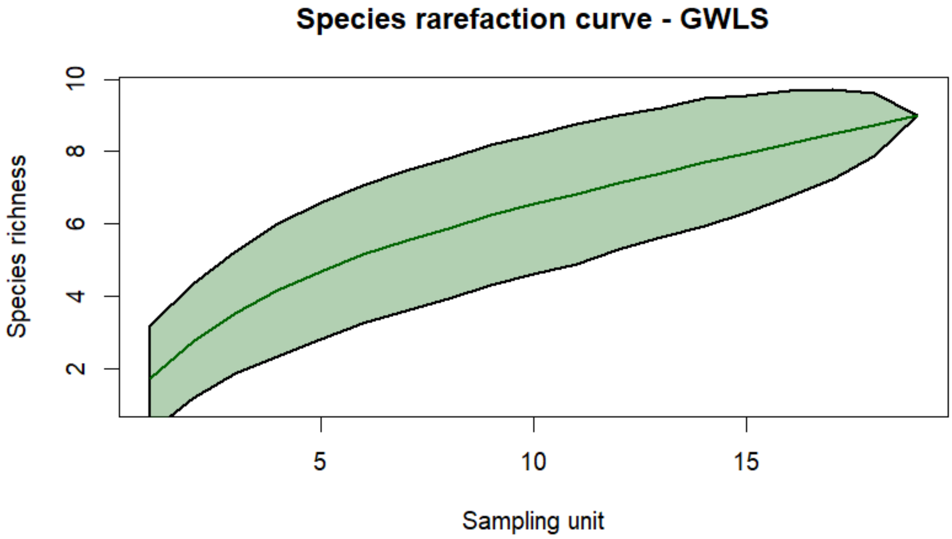

Figure 2. Species rarefaction curve for Gumti Wildlife Sanctuary.

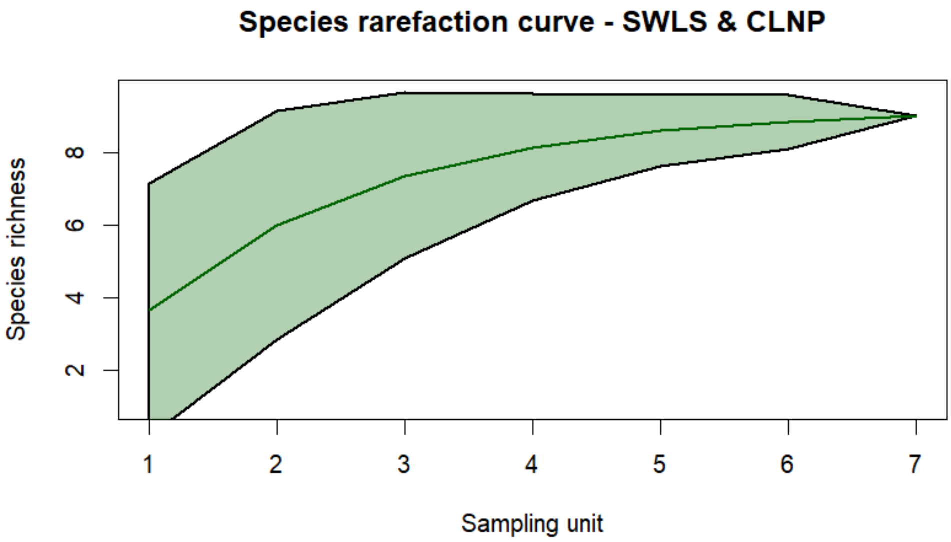

Figure 3. Species rarefaction curve for Sepahijala Wildlife Sanctuary & Clouded Leopard National Park.

upper confidence envelope exceeding 12 species. Unlike GWS, this curve continues to rise at higher sampling effort, indicating incomplete sampling and a higher likelihood of undiscovered species. This pattern aligns with studies showing that species-rich or structurally complex habitats require higher sampling intensity to capture full community composition. The combination of high richness and a non-asymptotic curve suggests TWS supports a relatively diverse mammalian assemblage and would benefit from expanded sampling.

Sample-based rarefaction curves provide a standardized comparison of species richness across protected areas in Tripura. GWS appears near-saturated, indicating adequate sampling. SWS shows moderate richness but requires additional sampling to confirm community estimates. TWS exhibits the highest richness and incomplete saturation, highlighting the need for increased sampling to fully document the species assemblage.

Noteworthy records

Several key species records obtained during the survey represent important contributions to the faunal inventory of Tripura:

1. This study provides the first camera-trap-based photographic record of the Ferret Badger *Melogale*

Table 4. Checklist of mammalian species recorded from the protected areas of Tripura with relative abundance index (RAI) values.

Common name	Scientific name	Order	Family	RAI SWS	RAI TWS	RAI GWS
Northern Red Muntjac	*Muntiacus vaginalis*	Artiodactyla	Cervidae	11.76 ± 6.42	1.42 ± 6.42	-
Wild Boar	*Sus scrofa*	Artiodactyla	Suidae	10.29 ± 5.94	-	-
Gaur	*Bos gaurus*	Artiodactyla	Bovidae	-	4.88 ± 2.82	-
Common Palm Civet	*Paradoxurus hermaphroditus*	Carnivora	Viverridae	14.71 ± 10.03	21.95 ± 10.03	2.14 ± 10.03
Large Indian Civet	*Viverra zibetha*	Carnivora	Viverridae	25.00 ± 14.43	-	-
Small Indian Civet	*Viverricula indica*	Carnivora	Viverridae	-	0.81 ± 0.41	0.36 ± 0.41
Masked Palm Civet	*Paguma larvata*	Carnivora	Viverridae	-	-	0.36 ± 0.21
Crab-eating Mongoose	*Urva urva*	Carnivora	Herpestidae	-	7.32 ± 8.20	16.37 ± 8.20
Ferret Badger	*Melogale* sp.	Carnivora	Mustelidae	-	-	1.78 ± 1.03
Asian Small-clawed Otter	*Aonyx cinerus*	Carnivora	Mustelidae	-	3.25 ± 1.88	-
Leopard Cat	*Prionailurus bengalensis*	Carnivora	Felidae	1.47 ± 0.55	1.63 ± 0.55	2.49 ± 0.55
Fishing Cat	*Prionailurus viverrinus*	Carnivora	Felidae	-	-	2.68 ± 2.09
Jungle Cat	*Felis chaus*	Carnivora	Felidae	-	0.81 ± 0.47	-
Malayan Porcupine	*Hystrix brachyura*	Rodentia	Hystricidae	7.35 ± 4.25	-	-
Phayre's Leaf Monkey	*Trachypithecus phayrei*	Primates	Cercopithecidae	-	0.81 ± 0.47	-
Capped Langur	*Trachypithecus pileatus*	Primates	Cercopithecidae	-	-	-
Rhesus Macaque	*Macaca mulatta*	Primates	Cercopithecidae	69.12 ± 34.74	40.65 ± 34.74	-
Northern Pig-tailed Macaque	*Macaca leonina*	Primates	Cercopithecidae	17.65 ± 8.66	8.13 ± 8.66	0.36 ± 8.66
Hoolock Gibbon	*Hoolock hoolock*	Primates	Hylobatidae	-	-	-

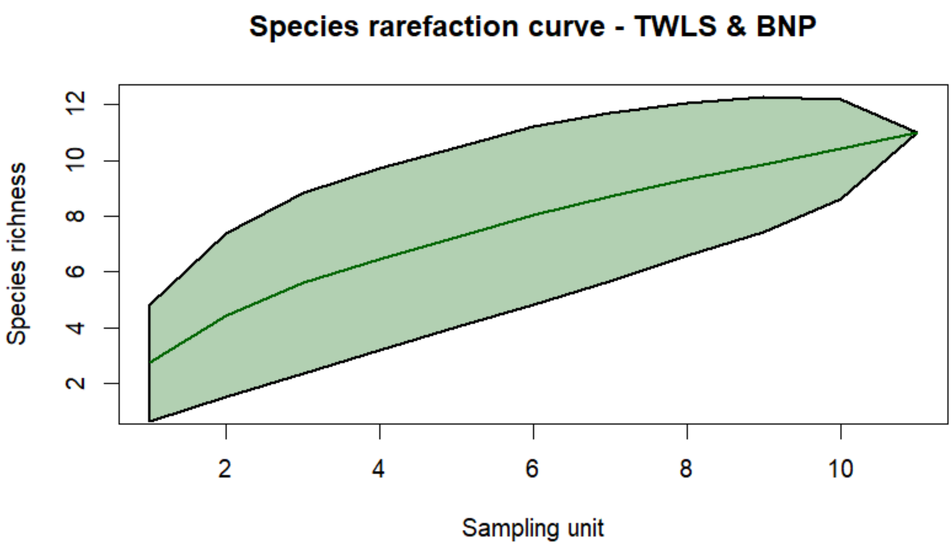

Figure 4. Species rarefaction curve for Trishna Wildlife Sanctuary & Bison National Park.

sp. from the state, reconfirming its presence in Tripura within the Indo-Burma biodiversity hotspot (Patil et al. 2025a).

2. Confirmed locality records were obtained for the Malayan Porcupine *Hystrix brachyura* and the Fishing Cat *Prionailurus viverrinus* from western and southern Tripura, respectively (Patil et al. 2025b). While both species are widely distributed across northeastern

Table 5. Simpson's (1–D) and Shannon-Wiener (H') diversity indices, along with hill numbers for mammals across protected areas of Tripura. Diversity indices and corresponding Hill numbers (q = 1 and q = 2) across SWS, TWS, & GWS representing the effective number of common and dominant species, respectively.

	SWS	TWS	GWS
Total individuals (N)	196	192	130
Simpson's dominance index (D)	0.1805861	0.1705934	0.2157424
Simpson's index of diversity (1-D)	0.8194139	0.8294066	0.7842576
Shannon's index (H')	1.917	1.984	1.853
Hill number ($^{1}D=e^{H'}$)	6.80	7.27	6.38
Hill number ($^{2}D=1/D$)	5.54	5.86	4.63

India, these represent the first systematic photographic records from the state, thereby strengthening their known occurrence and contributing to finer-scale range documentation.

3. A small subpopulation of Gaur *Bos gaurus* was documented in TWS, representing the species' continued presence in the state despite its absence from current IUCN Red List distribution map (Duckworth et al. 2016).

These photographic confirmations strengthen the evidence base for Tripura's mammalian diversity and update species distributions within the Indo-Burma transition zone.

Despite the smaller area and higher human population density, Tripura's protected areas continue to sustain a diverse mammalian community representative of the Indo-Burma transition zone.

DISCUSSION

Mammalian assemblage and species composition

The present assessment provides an updated account of the mammalian community within Tripura's protected areas and confirms the persistence of 19 species representing 16 genera, 10 families and four orders. The assemblage is dominated by small to medium-bodied carnivores and primates, with ungulates contributing to the herbivore guild, a pattern typical of fragmented tropical forest systems in the Indo-Burma biodiversity hotspot, where adaptable species persist under anthropogenic pressure (Datta et al. 2008; Bhatt et al. 2022).

Across sites, TWS exhibited the highest species diversity and evenness, whereas GWS displayed lower diversity but harboured several rare and specialized species. SWS, despite higher human influence, recorded high primate activity. Together, these patterns indicate that Tripura's protected areas function as complementary components of the regional mammalian diversity.

The co-occurrence of multiple primate species, including Phayre's Leaf Monkey, Rhesus Macaque, and Pig-tailed Macaque, further reflects microhabitat heterogeneity and ecological continuity of arboreal habitats.

New records and biogeographic implications

Several notable records expand the known distribution of mammals in Tripura. The Malayan Porcupine recorded in SWS represents a westward range extension (unpublished), while the Fishing Cat documented in TWS provides the first photographic confirmation from this region (Patil et al. 2025b). Both species are habitat specialists, associated with mixed bamboo-deciduous forests and wetland ecosystems, respectively, highlighting the importance of heterogeneous habitats and small wetlands as refugia within modified landscapes. Similarly, the first photographic evidence of Ferret Badger adjacent to a Jhum cultivation reconfirms its presence within the region. Its occurrence in such a disturbed habitat corroborates its known ecological adaptability and highlights the species' resilience in a dynamic landscape (Patil et al. 2025a).

The species assemblage broadly aligns with patterns reported from Manas National Park, Dampa Tiger Reserve, and community reserves in Meghalaya, where generalist species such as Leopard Cat and Common Palm Civet dominate (Sethy et al. 2021; Bhatt et al. 2022; Lyngdoh et al. 2023). The occurrence of wetland and forest-edge specialists such as Fishing Cat and Small-clawed Otter underscores Tripura's unique position at the intersection of Indo-Gangetic and Indo-Burmese biogeographic zones. Despite their relatively small size and isolation, these protected areas continue to function as important refuges and potential dispersal corridors.

Conservation and management Implications

The presence of a small, isolated subpopulation of Gaur in TWS further enhances the site's conservation importance. Despite its exclusion from the IUCN distribution map, repeated photographic and direct observations confirm its persistence (Duckworth et al. 2016). This population likely represents a relict group isolated from the larger populations in Mizoram and Bangladesh, raising concerns regarding long-term genetic viability. In contrast, Asiatic Wild Dogs

Cuon alpinus, historically present, appear to be locally extirpated, likely due to restricted transboundary movement caused by border fencing. Such barriers limit dispersal of wide-ranging species including Dholes, Asian Elephants, and Gaur, reflecting the complex interface between conservation and national security.

The findings of this study underscore several key implications for conservation management in Tripura:

1. Habitat heterogeneity and wetland protection: The detection of Fishing Cat, Small-clawed Otter and Malayan Porcupine highlights the importance of conserving diverse habitats, including riparian zones, bamboo thickets and degraded mixed forests. Management plans should incorporate small wetlands and community-managed water bodies within buffer areas.

2. Connectivity and landscape integration: The isolation of *Bos gaurus* and the extirpation of *Cuon alpinus* highlight the vulnerability of wide-ranging species requiring large home ranges. Continuous border fencing has likely restricted transboundary movement, isolating populations within Tripura and limiting functional connectivity with Bangladesh. Conservation efforts should therefore prioritize strengthening ecological linkages within the state, particularly between protected and adjoining non-protected forests, and maintaining connections with forested landscapes of Mizoram. Enhancing habitat quality and reducing anthropogenic pressures will be critical to sustain viable populations in an increasingly fragmented landscape. Under the current landscape configuration, opportunities for functional transboundary conservation with Bangladesh are limited, as continuous border fencing restricts wildlife movement and dispersal. Consequently, populations on either side are likely to function independently, reducing the effectiveness of traditional transboundary conservation approaches that rely on ecological connectivity.

3. Monitoring small carnivores and lesser-known species: The first photographic record of *Melogale* sp. underscores the importance of long-term monitoring of cryptic species. Expanding camera-trap networks both temporally and spatially will help capture rare occurrences and establish reliable population baselines. Together, these findings emphasize that Tripura's small but ecologically varied protected areas remain critical for regional mammal conservation and warrant sustained management attention and monitoring, although interpretations are conservative given the rapid assessment nature of the survey.

Pragmatism in research

Conducting wildlife research in smaller northeastern states poses logistical, temporal and infrastructural constraints. The current study adopted a pragmatic research approach, emphasizing achievable, methodologically sound outcomes within the available time and resources. Limited camera availability was addressed through a rotating deployment strategy, while sampling grids were selected based on animal sign evidence to maximize detection probability and spatial coverage.

These decisions directly contributed to key outcomes of the study. The optimized camera deployment enabled coverage across multiple protected areas within a short duration, resulting in the documentation of 19 species, including rare and previously unrecorded taxa such as Ferret Badger. The targeted placement of cameras in areas with animal signs improved detection success, facilitating the recording of habitat specialists such as Fishing Cat and Malayan Porcupine and allowing estimation of relative abundance across sites.

Pragmatism in conservation research prioritizes the generation of actionable data that can directly inform management decisions even when comprehensive long-term datasets are unavailable (Sutherland et al. 2004).

In this study, a combination of structured sampling and flexible field design ensured that results remain both reliable and management-relevant, particularly for guiding rapid conservation interventions and strengthening baseline data for future monitoring in Tripura.

CONCLUSION

This assessment provides the most recent and one of the first systematic accounts of Tripura's mammalian fauna to date. The documentation of new species records, range extensions, and isolated subpopulations contributes substantially to regional biodiversity knowledge. Despite limited area and increasing anthropogenic pressures, the protected areas of Tripura retain ecological significance as functional refuges within the Indo-Burma biodiversity hotspot. The study reinforces the need for continuous monitoring, landscape-level habitat management and the integration of pragmatic research strategies into conservation planning.

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Image 1. Asian Small-clawed Otter *Aonyx cinereus*.

Image 2. Common Palm Civet *Paradoxurus hermaphroditus*.

Image 3. Crab-eating Mongoose *Urva urva*.

Image 4. Ferret Badger *Melogale* sp.

Image 5. Fishing Cat *Prionailurus viverrinus*.

Image 6. Gaur *Bos gaurus*.

Image 7. Indian Muntjac *Muntiacus vaginalis*.

Image 8. Jungle Cat *Felis chaus*.

Image 9. Large Indian Civet *Viverra zibetha*.

Image 10. Leopard Cat *Prionailurus bengalensus*.

Image 11. Malayan Porcupine *Hystrix brachyura*.

Image 12. Masked Palm Civet *Paguma larvata*.

Image 13. Phayre's Leaf Monkey *Trachypithecus phayrei*.

Image 14. Pig-tailed Macaque *Macaca leonina*.

Image 15. Rhesus Macaque *Macaca mulatta*.

Image 16. Small Indian Civet *Viverricula indica*.

Image 17. Wild Pig *Sus scrofa*.

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ARTICLE

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Distribution, habitat use, and abundance of the Caracal *Caracal caracal* (Schreber, 1776) (Mammalia: Carnivora: Felidae) in a semi-arid Indian landscape

Mohammad Mairaj [1], Dhruv Jain [2], Ramanand Bhakar [3] & Ayan Sadhu [4]

[1,3] Rajasthan Forest Department, Aranya Bhawan, Jhalana Dungri, Jaipur, Rajasthan 302004, India.
[2,4] Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India.
[1] mohammadmairaj1993@gmail.com, [2] dhruvjain4397@gmail.com, [3] ramanand.bhakar@gmail.com,
[4] sadhuayan@gmail.com (corresponding author)

Abstract: We collected Caracal *Caracal caracal* presence locations using camera traps in the human-dominated Kailadevi landscape in southeastern Rajasthan, India. Our survey effort of 5,258 camera trap days at 177 camera trap locations in a sampling area of about 600 km² yielded 92 independent photocaptures at 54 locations between January 2020 and March 2022. Relative abundance index values indicate that the Caracal has been consistently photocaptured over the three sampling sessions. We used these data to model potential Caracal habitats at the landscape level using MaxEnt, and we used generalized linear models to identify the factors influencing Caracal detection site at the camera trap level. The habitat suitability results indicate that, out of the entire extent of 109,663 km² spanning the Greater Ranthambhore Ecosystem from eastern Rajasthan to western Madhya Pradesh, an area of 14,284 km² constitutes suitable habitat for the Caracal, of which about 26% occurs within the protected area network. Of all the suitable habitats, about 1,230 km² was classified as highly suitable, with 41% distributed across the protected area network. The Ranthambhore–Kailadevi–Dholpur cluster harbours the largest contiguous patches. Suitable Caracal habitats showed positive association with open natural ecosystems, rugged terrain, and proximity to water, but negative association with human disturbance. At camera trap level, site use intensity of the Caracal was positively influenced by rugged terrain, open natural ecosystems, proximity to water, and distance from human settlements. Based on published estimates for home range size and the extent of suitable habitat predicted by the MaxEnt model, Kailadevi can potentially support 8 (4–24) male and 23 (14–55) female Caracal home ranges, followed by Ranthambhore with 4 (2–11) male and 10 (6–24) female home ranges, and Dholpur with 3 (2–8) male and 7 (5–17) female home ranges. In total, the Ranthambhore-Kailadevi-Dholpur landscape can potentially harbour 55 (33–139) Caracal home ranges, providing a preliminary indication of the potential population supported by the currently available suitable habitat. Our findings highlight the importance of conserving the open natural ecosystems, especially ravines, which provide refuge for the Caracal in this human-dominated landscape. Conservation strategies should prioritise to safeguard the potential Caracal habitats and maintain connectivity between these habitats to secure its long-term persistence.

Keywords: Camera traps, generalised linear model, home ranges, MaxEnt, open forests, population, Rajasthan, Greater Ranthambhore Ecosystem, ravines, small wild cat.

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Author details: Mohammad Mairaj (MM) and Ramanand Bhakar (RB) are affiliated with the Rajasthan Forest Department, Jaipur. Dhruv Jain (DJ) and Ayan Sadhu (AS) are affiliated with the Tiger Cell at the Wildlife Institute of India, Dehradun.

Author contribution: MM and AS conceptualised the study. MM and RB carried out the fieldwork and arranged the logistics. AS and DJ conducted the analyses. AS led the manuscript writing and interpretation of results. All authors reviewed the final draft, provided critical comments, and approved the final version of the manuscript.

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INTRODUCTION

The global decline in carnivore populations is largely attributed to habitat loss, fragmentation, and direct persecution by humans (Ripple et al. 2014). The ecology and distribution of many carnivore species remain poorly understood, posing a major challenge to formulating effective conservation strategies (Glen et al. 2014). The Caracal *Caracal caracal* is widely distributed in Africa, western and central Asia, and western parts of the Indian subcontinent (Avgan et al. 2016). Populations in northern Africa and parts of Asia are thought to have declined, mainly due to habitat conversion for human use (Avgan et al. 2016). The Caracal lives in diverse habitats, including savannas, arid regions, scrublands, and dry forests (Veals et al. 2020). In the Mediterranean region of southern Türkiye, it prefers heterogeneous pine forests with canopy closure below 70% (Ünal et al. 2020; İlemin et al. 2023). In Iran, it has been recorded in forest steppes, semi-arid montane woodlands, arid hilly terrain, well-vegetated foothills, dry riverbeds, and along the semi-desert coast of the Persian Gulf (Farhadinia et al. 2007; Ghoddousi et al. 2009; Moqanaki et al. 2016; Jamali et al. 2024).

Across much of its African range, the Caracal is more frequently associated with wooded grasslands and riparian zones within savannas than with contiguous forests, reflecting a preference for ecotonal and open habitats with sufficient cover and prey availability (Hanekom & Randall 2015; Ramesh et al. 2017; Mwampeta et al. 2020). These habitat associations highlight its reliance on structural complexity in vegetation and terrain to facilitate ambush predation and refuge from larger carnivores (Davis et al. 2023). Its low density makes it challenging to monitor, and the paucity of dedicated studies results in a lack of comprehensive data on its distribution and ecological requirements (Avgan et al. 2016).

Globally, the Caracal is classified as Least Concern on the IUCN Red List of Threatened Species (Avgan et al. 2016). In India, it is legally protected under Schedule I of the Wild Life (Protection) Amendment Act, 2022 (Ministry of Law and Justice 2022). Photographic records are limited to protected areas in southeastern Rajasthan (Singh et al. 2014; Khandal et al. 2020; Jhala et al. 2021; Thakar et al. 2025), desert landscapes of western Rajasthan (TNN 2026), and outside protected areas in northwestern Gujarat (Khandal et al. 2020; Jhala et al. 2021; Ganguly 2022; Mukherjee & Nandini 2024). Previous studies in India indicate that the Caracal prefers open forests with abundant rodent and ground-dwelling birds (Mukherjee et al. 2004; Jhala et al. 2021).

Understanding the habitat use of the Caracal is crucial for developing effective conservation strategies. Therefore, we aimed to identify key environmental factors influencing Caracal distribution in the Kailadevi landscape by addressing the following research questions:

1. Which ecological and anthropogenic factors influence the distribution of the Caracal?
2. How do anthropogenic pressures affect Caracal occurrence in the region?

Study Area

The study was conducted in Kailadevi Wildlife Sanctuary and its adjoining areas, which form the northern extension of the Ranthambhore Tiger Reserve (Figure 1). This protected area is situated in a semi-arid transition zone between the Thar Desert and peninsular India (Rodgers & Panwar 1988). It is bounded by the Banas River to the southwest and the Chambal River to the east (Yadav 2022). Its rugged terrain features rocky slopes, ravines, cave-like depressions and scrub forests, with scattered water sources and villages (Yadav 2022). The vegetation of this landscape is dominated by northern tropical dry deciduous forests and scrubland, with *Anogeissus pendula* covering 80% of the area, followed by *Acacia catechu*, *Butea monosperma*, and *Ziziphus* species (Yadav 2022). Moist valleys support species like *Ficus glomerata*, *Syzygium cumini*, and *Mitragyna parviflora*, while the undergrowth includes *Flacourtia indica*, *Grewia*, and *Barleria* species. Grass diversity varies with terrain and grazing pressure from *Apluda mutica* on slopes to *Aristida* in heavily grazed areas, and *Vetiveria* species along the streams (Ayan Sadhu, pers. obs.).

Pastoral communities living in villages graze their livestock in forest areas inside the sanctuary; this, coupled with the extraction of timber, fuelwood, and fodder leads to considerable degradation of wildlife habitat (Yadav 2022). However, the traditional lifestyle of the people allows space for wildlife that can tolerate low to medium human disturbances (Jhala 2013). Despite the anthropogenic pressure, Kailadevi Wildlife Sanctuary supports a low-density population of the Tiger *Panthera tigris* (Sadhu et al. 2017). It also harbours the Leopard *P. pardus,* Indian Wolf *Canis lupus*, Golden Jackal *C. aureus,* Striped Hyena *Hyaena hyaena*, Sloth Bear *Melursus ursinus,* Jungle Cat *Felis chaus*, Afro-Asiatic Wildcat *F. lybica*, and Honey Badger *Mellivora capensis* (Jhala et al. 2020). Ungulates like Nilgai *Boselaphus tragocamelus*, Chital *Axis axis*, and

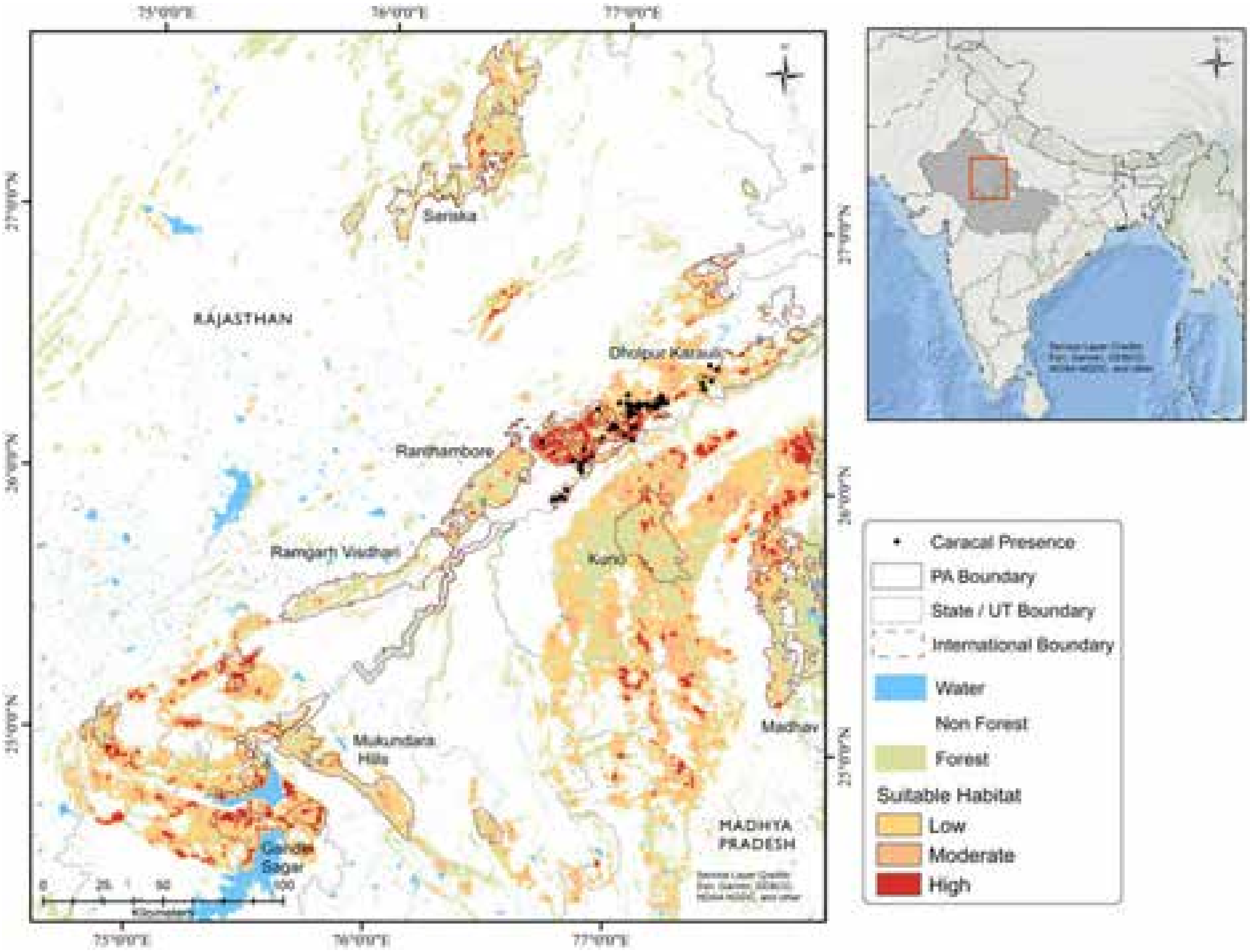

Figure 1. Map showing potentially suitable habitat of the Caracal predicted using species distribution modelling (MaxEnt) in the semi-arid western Indian landscape. The class 'Forest' includes scrublands, grasslands, open forests, moderately dense and dense forests.

Chinkara *Gazella bennettii* occur at low densities (Jhala et al. 2020), making Kailadevi Wildlife Sanctuary crucial for wildlife conservation.

While camera trapping was conducted in Kailadevi Wildlife Sanctuary, the potential distribution of the Caracal was predicted across the Greater Ranthambhore ecosystem comprising Ranthambhore National Park, Kailadevi Wildlife Sanctuary, Kuno National Park, Ramgarh Vishdhari Tiger Reserve, Mukundara Hills Tiger Reserve, Dholpur Karauli Tiger Reserve and adjoining areas (Qureshi et al. 2023), and Sariska Tiger Reserve (Figure 1).

MATERIAL AND METHODS

We used camera traps to record Caracal presence in the Kailadevi landscape and modelled potential Caracal habitats in the larger landscape to direct future conservation investments. Furthermore, we sought to identify the most impactful factors influencing Caracal distribution in this landscape.

Camera Trapping

As a part of the routine Tiger and co-predators monitoring surveys in the Kailadevi landscape, we conducted surveys between 2020 and 2022 using Cuddeback X–Change™ camera trap models. We programmed the camera traps to take one photograph per trigger with a time and date stamp on every photograph. We set the delay between two consecutive photographs to 'Fast As Possible' mode and turned off video mode. Each camera trap was assigned a unique ID.

We surveyed the entire area by foot to record the presence of carnivores from direct and indirect evidence like pugmarks and scat, and placed camera traps on the basis of the intensity of carnivore sign encounters. We also considered the knowledge of forest guards and local people acquainted with the area to find suitable areas for camera trap deployment. No bait was used. The coordinates of camera trap locations were determined using handheld Garmin 72™ and Garmin Etrex® 10 GPS devices set to WGS 84 geodetic datum.

The camera traps were deployed singly and active for 24 hours per day, henceforth called camera trap day. At 3–5 locations close to human settlements, we removed camera traps during the daytime to avoid theft or damage. People and livestock frequently visited these locations in the daytime, whereas wildlife was mostly active during the twilight and night hours. The camera traps were operational for about 30 days with a range of 8–44 days and were inspected every 2–3 days to ensure proper functionality and data retrieval. The photographs obtained were archived camera trap ID-wise and segregated to the species level.

When the interval between two or more consecutive photographs of the Caracal at the same camera trap location was more than 30 minutes, we considered them as independent photocaptures (O'Brien et al. 2003).

Relative Abundance Index

Relative abundance index (RAI) is widely used to monitor the trend of wildlife abundance, especially when individual identification is not possible (O'Brien et al. 2003). We defined the RAI of the Caracal as the number of independent photocaptures at each location per 100 camera trap days at this location (O'Brien et al. 2003). We averaged the RAI values obtained for all the locations with and without independent photocaptures in each sampling year to estimate the trend in Caracal abundance over three years of sampling.

$$\text{RAI}_{\text{Caracal}} = \textit{Average}\left(\frac{\textit{Independent photocapture of} \in \textit{camera trap } i}{\textit{Survey effort of camera trap } i} \times 100\right)$$

Preparation of Variables

Ecologically meaningful variables like distance from waterbodies, distance from grasslands-scrubland ecosystems, human footprint index, terrain ruggedness were selected (Appendix 1). All covariates were extracted at a 1 km² spatial resolution and projected using the WGS 1984 Lambert Conformal Conic (LCC) projection system. Variables were tested for collinearity, and only non-correlated variables ($r \leq |0.7|$) (Appendix 2) were used in the same model.

Habitat Suitability Modelling

We used Maximum Entropy Species Distribution Modelling (MaxEnt; Phillips & Dudík 2008) to predict suitable Caracal habitat within the study area. MaxEnt uses known presence locations and environmental variables to estimate species distribution ranging from '0' for unsuitable to '1' for highly suitable (Phillips et al. 2017). We used 80% of the presence points for model training and reserved 20% for testing. We performed 100 bootstrap runs to assess model uncertainty and kept 10,000 background points. The model was configured using linear and quadratic functions to analyse relationships between species presence and environmental factors. The output format was set to 'logistic', which provides a theoretically stronger interpretation than the logistic transform, particularly in modelling moderately high suitability areas (Phillips et al. 2017). The regularisation multiplier was optimised at 1.0 through incremental testing with a range of 0.7–1.5 in 0.1 intervals, and the highest area under the curve (AUC) value determines the best combination. Habitat suitability was categorised based on the average 'maximum test sensitivity plus specificity logistic threshold'. Model selection was guided by the AUC of the receiver operating characteristic (ROC) plot, comparing five ecologically relevant models. The final model with the highest AUC value was considered the best representation of Caracal habitat suitability. Variable selection and model evaluation were based on mean AUC values and the contribution of individual and combined variables (Appendix 3).

Generalised Linear Modelling

To assess the factors influencing Caracal habitat use, we employed generalized linear models (GLMs), a flexible statistical framework that extends linear regression to accommodate non-normal response variables by specifying an appropriate error distribution and link function (Guisan et al. 2002; Fox 2003). Given our binary response data (presence = 1, absence = 0), we used logistic regression, a GLM with a binomial error distribution and a logit link function (Agresti 2013). This approach allowed us to model the probability of Caracal presence as a function of key habitat variables, while addressing the bounded nature (0, 1) of binary outcomes (Zuur et al. 2009).

We extracted covariates at each camera trap presence point within a 500-m radius to discern the factors governing the habitat use of the Caracal in our study area. Model selection was conducted using a backward elimination process where the model with lowest Akaike's information criterion (AIC) value indicated the best fit model (Burnham et al. 2011, Appendix 4). We initially included all ecologically plausible predictor variables and iteratively removed non–significant terms ($p > 0.05$). Predictor significance was evaluated at a 95% confidence level of its coefficient.

Potential Population Size

We used the extent of suitable habitat predicted by the MaxEnt model above the cumulative threshold to approximate the potential Caracal population. We recognise that habitat suitability does not equate to species occupancy. Therefore, we restricted the extrapolation of home range based estimates exclusively to areas with consistent evidence of Caracal presence, i.e., Kailadevi, Ranthambhore, Dholpur, and adjoining areas (Singh et al. 2014; Khandal et al. 2020; Jhala et al. 2021). To estimate the number of potential male and female home ranges in this landscape, we divided the suitable Caracal habitat by the mean home range size derived from studies in semi-arid South African habitats (Appendix 5). As male and female home ranges vary substantially in size, with males typically occupying larger home ranges than females (Appendix 5), we performed these calculations separately for each sex. We estimated the mean home range and its associated uncertainty using non-parametric bootstrapping (10,000 resamples), and quantified uncertainty using percentile-based 95% confidence intervals derived from the bootstrap distribution of means.

RESULTS

Between January 2020 and March 2022, we deployed camera traps at 177 locations with a total survey effort of 5,258 camera trap days (Table 1). Our total study area encompassed ~600 km^2, of which ~450 km^2 was located inside Kailadevi Wildlife Sanctuary. We obtained a total of 92 independent photocaptures of the Caracal in 54 locations (Images 1–4).

Relative Abundance Index

The relative abundance index (RAI) of Caracal was highest in 2021 with a value of 2.113 (±0.626) and lowest in 2022 with a value of 1.838 (±0.541). There was no significant difference in RAI estimates between sessions (Kruskal–Wallis test: $H = 2.79$, $p = 0.247$, Table 1). In addition, we sighted Caracals on three occasions in 2020, on 12 occasions in 2021, and on seven occasions in 2022.

Habitat Suitability Modelling

The habitat suitability results indicated that out of the entire area of 109,663 km² spanning from eastern Rajasthan to western Madhya Pradesh, an area of 14,284 km² is suitable for the Caracal, of which about 26% lies within the protected area network (Table 2). About 1,230 km² of habitat was classified as highly suitable for the Caracal, of which 41% is distributed across the protected area network, with the Ranthambhore–Kailadevi–Dholpur cluster harbouring the largest contiguous patches (Figure 1).

Human footprint index and the presence of open natural ecosystems comprising open forests, grasslands, scrublands, and ravines contributed the most in predicting suitable Caracal habitat, followed by terrain ruggedness, distance from water, and distance from open natural ecosystem (ONE) (Figure 2). Open natural ecosystems influenced the probability of Caracal presence positively while increasing distance from open natural ecosystem reduced the probability, depicting the importance of these habitats for Caracal presence. The human footprint showed some tolerance towards human disturbance by Caracal. Terrain ruggedness index showed Caracal's positive response towards moderately rugged areas, however, highly rugged areas were not preferred by the species. Distance from water depicted the Caracal's positive response to proximity to water sources. The habitat suitability map also showed that

Table 1. Details of the survey effort, independent photocapture of the Caracal and relative abundance index in three sampling sessions in Kailadevi Wildlife Sanctuary, Rajasthan.

Year	Number of camera traps deployed	Total camera trap days	Average survey duration (range)	Number of camera trap locations where the Caracal was detected	Independent photo captures	Relative abundance index (SE)
January–March 2020	61	1,831	29.53 days (9–56 days)	22	35	2.025 (±0.382)
January–March 2021	50	1,294	25.37 days (8–31 days)	14	20	2.113 (±0.626)
December 2021–March 2022	66	2,133	32.21 days (11–44 days)	18	37	1.838 (±0.541)
	177	5,258		54	92	

Images 1–4. Caracals photographed in Kailadevi Wildlife Sanctuary during the surveys. © Ranthambhore Forest Department.

Table 2. Details of habitat suitability classes modelled using the MaxEnt framework and their relative proportion within the protected area network.

Suitability category (Habitat suitability value)	Total area	Area inside protected areas	Area outside protected areas
Low (≤ 0.46)	8,571 km^2	1,969 km^2 (22.97%)	6,602 km^2 (77.03%)
Moderate (≤ 0.68)	4,486 km^2	1,224 km^2 (27.28%)	3,262 km^2 (72.72%)
High (≤ 0.91)	1,227 km^2	510 km^2 (41.56%)	717 km^2 (58.44%)
Total (>0.2–≤0.91)	14,284 km^2	3,703 km^2 (25.92%)	10,581 km^2 (74.08%)

Table 3. Details of the best fit model along with the contribution of each covariate and their level of significance used in the generalised linear model framework to determine site-specific influencing factors.

	Estimate	Standard error	z value	P(>|z|)
(Intercept)	–7.93	1.29	–6.171	6.77E–10
Availability of open natural ecosystems	2.86	0.862	3.319	0.000904
Distance from built-up area (remoteness)	0.000372	0.0000903	4.117	3.83E–05
Distance from water	–0.000164	0.0000794	–2.069	0.038515
Terrain ruggedness Index (TRI)	0.0225	0.00401	5.608	2.04E–08

a substantial amount of Caracal habitat was present outside the existing protected area network (Figure 1).

Factors influencing Caracal distribution

The GLM indicates that Caracal habitat use in the Kailadevi landscape increased in areas with greater ONE cover and higher terrain ruggedness, closer proximity to water, and greater distance from built-up areas, underscoring a preference for open, rugged, and less human-disturbed habitats (Table 3). The area under ONE and ruggedness positively affected Caracal habitat

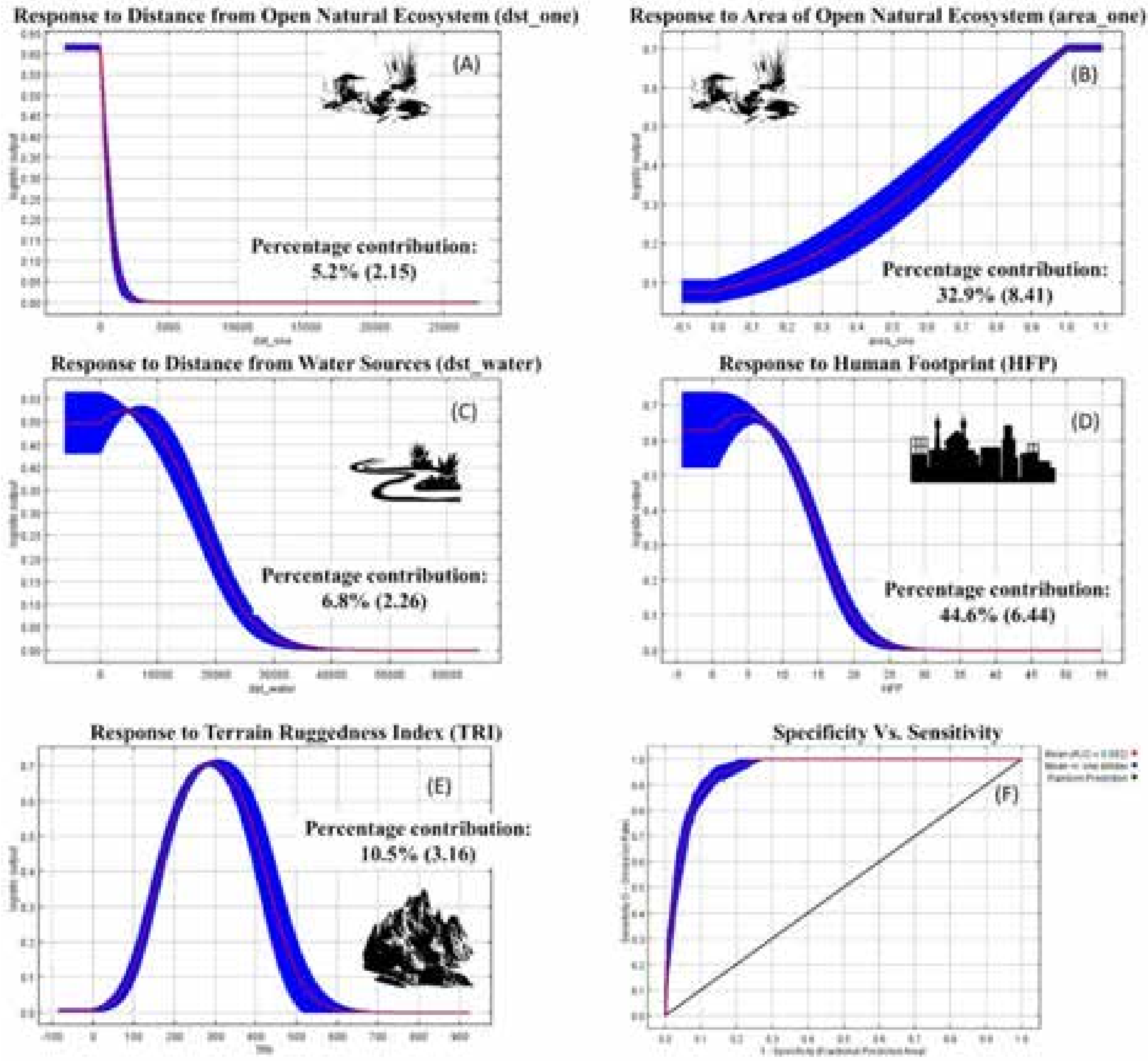

Figure 2. Response curves obtained from MaxEnt showing the relationship of different covariates with Caracal habitats: A—Distance from ONE | B—Area availability of ONE | C—Distance from water sources | D—Human foot print index | E—Terrain ruggedness index | F—Mean relation between sensitivity and specificity.

Table 4. Details of the site-wise estimates of potential number of Caracal home ranges derived from suitable habitat areas.

Site name	Suitable area	Number of male home ranges (range)	Number of female home ranges (range)	Total number of home ranges (range)
Ranthambhore	276.5 km²	4 (2–11)	10 (6–24)	14 (8–35)
Kailadevi	639.18 km²	8 (4–24)	23 (14–55)	31 (18–79)
Dholpur	192.69 km²	3 (2–8)	7 (5–17)	10 (7–25)
Total	1108.37 km²	15 (8–43)	40 (25–96)	55 (33–139)

use at the site level (Figure 3). Caracal used habitats closer to water bodies, with the probability of habitat use decreasing with increasing distance from water (Figure 3). Similarly, the probability of Caracal habitat use increased with greater distance from built-up areas (Figure 3), indicating higher use of areas with minimal human disturbance.

Potential Population Size

Our extrapolation indicates that the Ranthambhore–Kailadevi–Dholpur landscape can potentially accommodate 55 Caracal home ranges ($CI_{95\%}$ 33–139),

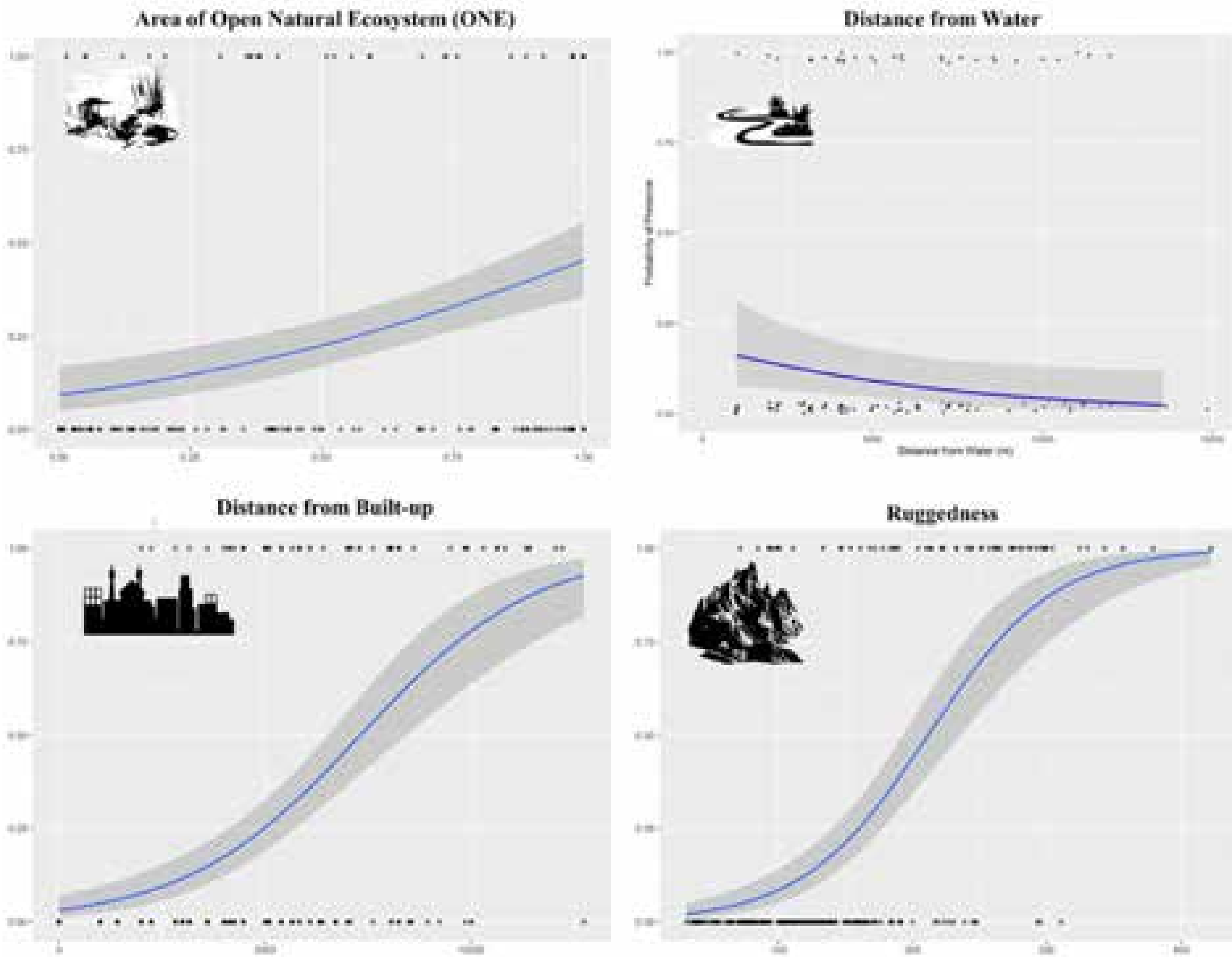

Figure 3. Factors influencing Caracal habitat use in the Kailadevi landscape, where availability of open natural ecosystems, distance from built up-area, and ruggedness show positive influence, while distance from water negatively influences Caracal habitat use.

including 15 male ($CI_{95\%}$ 8–43) and 40 female home ranges ($CI_{95\%}$ 25–96) (Table 4).

DISCUSSION

Our study in the Kailadevi landscape provides important insights into the distribution, abundance, and habitat use of the Caracal in a semi-arid ecosystem. The Caracal remains one of the least studied felids in India, and empirical information on its ecology, population status, and habitat associations remains limited. Using camera trap detections collected in the Kailadevi landscape, our study provides baseline ecological information on the Caracal and identifies key environmental and anthropogenic factors influencing its habitat use. These findings can help inform conservation planning to safeguard suitable habitats.

Relative Abundance Index and Potential Population Size

The RAI of Caracal recorded in the present study remained broadly consistent across the three sampling seasons. Although the mean RAI was lowest in the third year despite higher sampling effort, the confidence intervals overlapped across years, indicating no significant decline in the population trend. Similar inter-annual variation in relative abundance has also been reported in Ranthambhore National Park area, where Caracal RAI ranged 0.02–0.34 (Singh et al. 2014).

Obtaining reliable population estimates for low-density, wide-ranging species such as the Caracal is challenging; traditional population estimation methods, such as capture-recapture, distance sampling, occupancy modelling (mixture models), and total counts, are difficult to apply because of poor detectability and the lack of individually identifiable markings (Bookhout 1994). Information on abundance is often required by management authorities to guide conservation planning (Nichols & Williams 2006). Our estimates indicate that Ranthambhore National Park could potentially harbour a smaller Caracal population than Kailadevi. Camera trap surveys in Ranthambhore National Park yielded a relatively low RAI for Caracal (Singh et al. 2014; Latafat et al. 2023) compared with Kailadevi Wildlife Sanctuary (Table 1). While Ranthambhore National Park is largely characterized by *Anogeissus*-dominated woodlands with some mesic savanna patches, the Kailadevi landscape represents a more heterogeneous ecosystem, ranging from dense forest in narrow valleys to treeless scrublands and grasslands on plateau tops, often degraded due to prolonged anthropogenic pressure (Yadav 2022). Furthermore, Ranthambhore National Park supports high Tiger and Leopard population densities (Sadhu et al. 2017; Qureshi et al. 2024), which may influence Caracal abundance and detection through intraguild interactions or spatial avoidance (Davis et al. 2023). Our relative abundance estimates fall within the range reported in other parts of the Caracal's distribution, although considerable variation exists across landscapes. Studies in parts of the Arabian Peninsula and western Asia yielded higher encounter rates (Khorozyan et al. 2014; İlemin et al. 2023) than our estimates. The Caracal's low-density occurrence in our study area may be attributable to the circumstance that this area lies on the eastern edge of the global distribution of the Caracal, which may contribute to its inherently low-density occurrence in this region (McGill & Collins 2003).

The home range based population approximation presented here should be viewed primarily as a baseline for understanding the potential conservation significance of the Kailadevi–Ranthambhore–Dholpur landscape. This approach assumes uniform habitat quality across the landscape and non-overlapping home ranges within the identified suitable areas, which is rarely true in natural ecosystems. In addition, due to the lack of empirical home range estimates in Indian semi-arid ecosystems, we relied on values reported in semi-arid South African study areas. However, we omitted mean home range estimates for Caracals generated in arid savanna and steppe desert ecosystems, as these are larger than in semi-arid habitats (Bothma & Le Riche 1994; Van Heezik & Seddon 1998; Marker & Dickman 2005). Although derived from suitable habitat extent and published home range estimates, such approximations provide a useful starting point for guiding conservation planning and prioritising areas for monitoring and habitat management.

Habitat Suitability Modelling

The habitat suitability modelling indicates that potentially suitable habitat for the Caracal occurs in and around the Greater Ranthambhore ecosystem and Sariska landscape (Figure 1). These areas occur as relatively restricted pockets within the landscape. About 26% of this suitable habitat falls within the existing protected area network. Hence, a substantial proportion of potential Caracal habitat lies in multiple-use landscapes outside formally protected areas. This pattern highlights the importance of non-protected landscapes in sustaining a Caracal population and underscores the potential role of habitat connectivity across the broader landscape.

The habitat suitability model indicates that the presence of open natural ecosystems, distance from human settlements, and terrain ruggedness significantly influence Caracal habitat use in the landscape. The positive association with open natural ecosystems and terrain ruggedness in our model parallels patterns reported from arid and semi-arid systems in Iran and the Arabian Peninsula (Khosravi et al. 2018; Dunford et al. 2024; Jamali et al. 2024). Conversely, as the distance from ONE habitat increases, the probability of detecting Caracal declines, indicating decreasing habitat suitability. Similar observations of Caracal preferring open habitats over dense vegetation cover have also been reported in Sub-Saharan Africa and parts of western Asia (Hanekom & Randall 2015; Davis et al. 2023; İlemin et al. 2023).

Terrain ruggedness also emerged as a key factor influencing the distribution of Caracal. In our study area, rugged open natural ecosystems largely correspond to the ravines of the Chambal River and its tributaries, which form an intricate network of gullies across the landscape. These ravines function as important refuge habitats for several wildlife species, including Caracal (Sadhu 2020). The structural complexity and relative inaccessibility of these ravine systems may provide suitable hunting grounds as well as protection from human disturbance. Consequently, these findings suggest that conservation strategies should prioritise safeguarding the ravine habitats that may offer optimal ecological conditions for the persistence of Caracal populations.

The bell-shaped response curve for distance from human settlements highlights the Caracal's moderate tolerance to human activities. Caracals inhabiting multi-use landscapes often coexist with human presence but tend to prefer habitats that minimize direct encounters with people (Ünal et al. 2020). Our results indicate that while Caracals may adapt to low to moderate levels of human presence, densely populated areas could pose significant threats. Such patterns are consistent with findings on other medium-sized felids. For example, the Jungle Cat also persists within fragmented but suitable habitat mosaics in human-modified landscapes (Mukherjee & Nandini 2024, Ganguly et al. 2026).

Distance from water sources emerged as a notable factor influencing habitat suitability in the study area, although its relative contribution was lower compared to other predictors. Caracals were more likely to occur closer to water sources, a pattern consistent with observations of carnivores in arid ecosystems where water scarcity can strongly shape habitat use (Ramesh et al. 2017; Hadad et al. 2025). Although the Caracal is adapted to dry conditions, the presence of small water bodies such as seasonal streams or lakes can be important for sustaining both the species and its prey base (Dunford et al. 2024).

Generalised Linear Modelling

The Generalized Linear Model identified availability of open natural ecosystems, terrain ruggedness, distance from built-up areas, and proximity to water sources as significant predictors of Caracal detections at camera trap sites within the Kailadevi landscape. The positive association with open natural ecosystems highlights the importance of structurally open habitats that support key prey such as hares, rodents, and ground-dwelling birds (Mukherjee et al. 2004; Ramesh et al. 2017). Terrain ruggedness also emerged as a strong determinant of site use; in Kailadevi, such conditions are largely represented by the ravine systems of the Chambal River and its tributaries (Yadav 2022) and may provide denning opportunities, concealment cover, and refuge from predators or human disturbance (Ayan Sadhu, pers. obs.). Caracal detections increased with greater distance from built-up areas, indicating avoidance of human settlements, and suggesting that the species persists in human-dominated landscapes by preferentially using relatively undisturbed habitats. Distance from water sources also significantly influenced detections, with higher probabilities of occurrence closer to water bodies; although the Caracal is adapted to semi-arid environments, water availability can indirectly shape carnivore distribution by sustaining prey populations in dry landscapes (Ramesh et al. 2017).

Collectively, these results indicate that Caracal habitat use at the camera trap scale in Kailadevi is governed by a combination of habitat structure and anthropogenic pressures, underscoring the need to safeguard open natural ecosystems and ravine habitats that function as key refugia for the species within this human-dominated landscape.

A caveat of our study is that Caracal photocaptures were obtained as by-catch from camera traps deployed primarily for monitoring the Tiger. Therefore, camera trap placement was optimised for large carnivores rather than small cats, which may introduce sampling bias. However, our analysis is limited to broad habitat associations based on detection locations and does not attempt to estimate population density or detection-corrected occupancy. Our findings highlight the importance of open natural ecosystems and structurally complex habitats within the Kailadevi landscape for the Caracal.

Given the limited ecological information currently available for the Caracal in India, systematic and dedicated surveys across its potential range are necessary to improve understanding of its distribution and to identify areas that may support viable population units. Such efforts would help refine current knowledge on habitat associations and inform landscape-level conservation planning. As a considerable proportion of suitable habitats occurs outside legally designated protected areas, conservation strategies should also focus on safeguarding these ecologically significant but administratively unprotected landscapes. Rather than expanding conventional protected area frameworks, efforts should aim to maintain the ecological character of these open natural ecosystems while supporting sustainable land-use practices. Promoting livelihood options compatible with biodiversity conservation, such as sustainable grazing, low-intensity agriculture, and community-based monitoring initiatives, may help maintain habitat quality while supporting the needs of local communities (Sircely et al. 2022). At the same time, preventing the conversion of these habitats into intensive land uses such as large-scale mining, industrial development, or other forms of high-impact land transformation will be important for retaining suitable habitats for the Caracal. Finally, while the camera trap-based results presented here provide valuable baseline information, further research, particularly fine-scale resource selection, would improve understanding of Caracal movement patterns, resource selection, and seasonal space use in human-dominated semi-arid landscapes.

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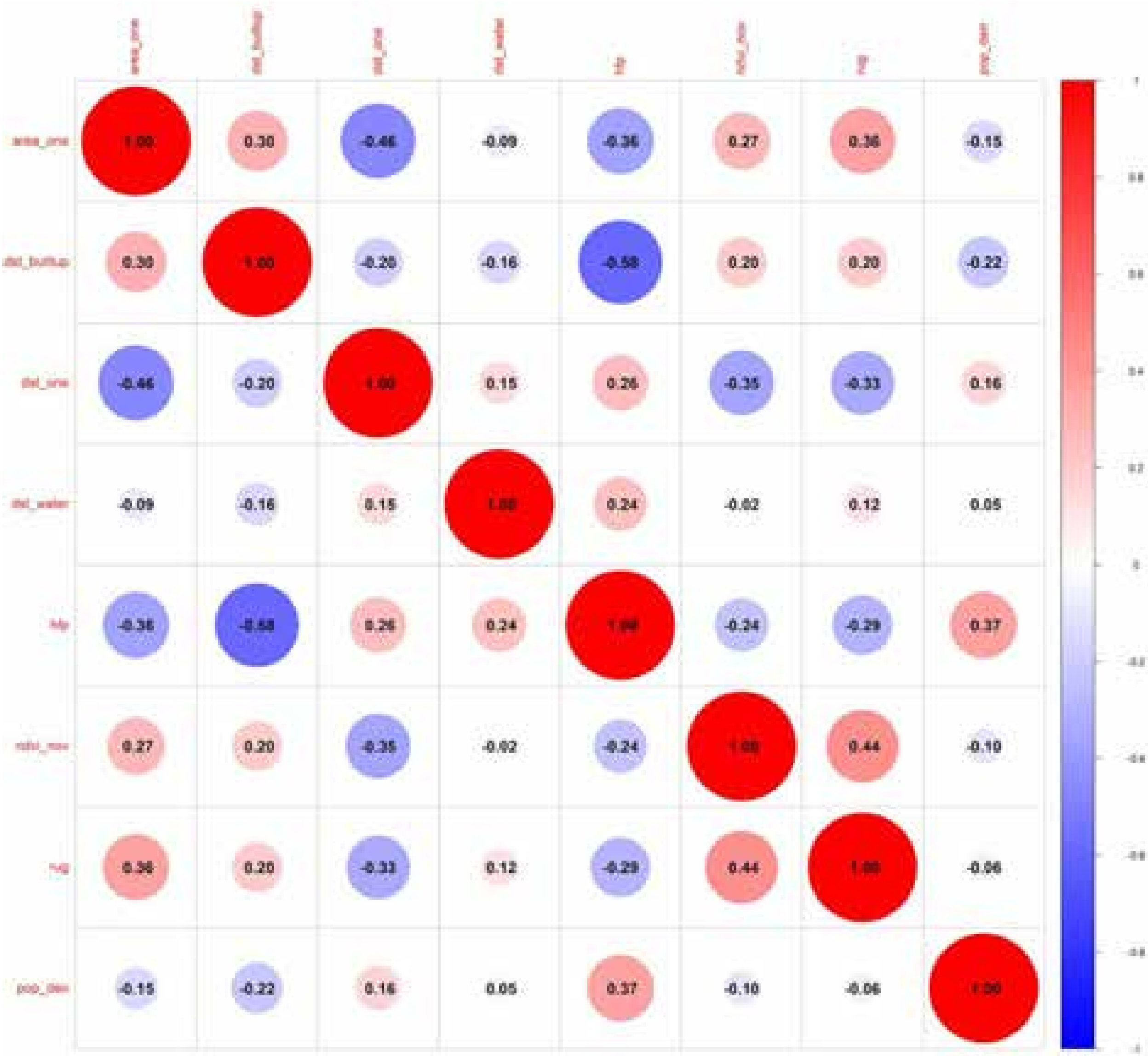
Appendix 1. Covariates used for predicting Caracal suitable habitat and habitat use in the study area.

Environmental variable	Resolution	Ecological justification	Source
Terrain ruggedness index (TRI)	30 m	Rugged areas in the landscape provides apt opportunity for the Caracal to take refuge during the day while foraging in the human-dominated landscape at night.	Farr et al. 2007
Human foot print index (HFP)	1,000 m	The Caracal is tolerant towards human disturbance to some extent, but avoids a higher degree of human disturbance	Mu et al. 2022
Built-up	10 m		Karra et al. 2021
Water source	30 m	In semi-arid landscapes, water is the key limiting factor, therefore, proximity to water source shall act as a major driving factor	Pekel et al. 2016
Open natural ecosystem (ONE)	30 m	The Caracal is known to inhabit open forest ecosystems, therefore, the ONE should positively influence its distribution	Madhusudan & Vanak 2023
Normalized difference degetation index (NDVI; for November)	30 m	NDVI reflects vegetation productivity and habitat quality, which influence prey availability and cover.	Derived from Landsat 8 satellite data images https://earthexplorer.usgs.gov/

Appendix 2. Correlogram showing relationships between different covariates used for the habitat suitability analysis.



Appendix 3. Table depicting different models used for modeling suitable habitat of the Caracal in the Greater Ranthambhore Ecosystem, with area under the receiver operating characteristic curve (AUC) and different model settings. All model combinations were replicated 100 times using the bootstrap type. Human footprint (HFP) | Terrain ruggedness index (TRI) | Area of open natural ecosystem (Area_ONE) | Distance to open natural ecosystems (Dst_ONE) | Distance to water (Dst_water) | Normalized difference vegetation index for November (NDVI_Nov) | Distance to built-up areas (dst_builtup).

Model combination	AUC	Model settings	Test data	Output format
HFP+ TRI+ Area_ONE+ dst_ONE+ dst_water	0.952	Linear + Quadratic + Product	20%	Logistics
NDVI_Nov+ Area_ONE+ TRI+ dst_water+ dst_one+ dst_builtup	0.941	Linear + Quadratic + Product	20%	Logistics
HFP + Dst_One+ TRI+ dst_builtup+ dst_water+ NDVI_Nov	0.917	Linear + Quadratic + Product	20%	Logistics
hfp+ dst_builtup+ dst_ONE+ ndvi_nov	0.915	Linear + Quadratic	20%	Logistics
hfp+ area_one+ dst_one	0.859	Linear + Quadratic + Product	20%	Cloglog

Appendix 4. Different models used in the generalised linear model framework to determine site-specific factors influencing Caracal habitat use in the semi-arid western Indian landscape. The best fit model glm3 was determined by the lowest AICc value. Terrain ruggedness index (TRI) | Open natural ecosystem (ONE) | Normalized difference vegetation index for November (NDVI)| Human footprint (HF) | Degrees of freedom (df^) | Akaike information criterion (AICc) with correction for small sample size (Δ AICc).

	Intercept	Area ONE	Distance to built-up areas	TRI	Distance to water	Distance to ONE	NDVI	HF	df^	AIC_c	ΔAIC_c	AIC_c weight
glm3	−7.932	2.862	0.000372	0.02251	−1.64E−04				5	144.3	0	0.71
glm2	−7.733	2.225	0.000311	0.02061					4	146.8	2.5	0.203
glm6	−3.103	2.838		0.01894	−1.60E−04			−0.154	5	149.0	4.76	0.066
glm5	−3.828	2.15		0.01783				−0.1176	4	151.7	7.47	0.017
glm11	−5.779		0.00034	0.01784					3	155.5	11.22	0.003
glm12	−5.576		0.000364	0.01809	−6.46E−05				4	156.7	12.41	0.001
glm4	−6.601			0.02026	9.19E−06	−0.00149	13.41		5	164.4	20.12	0
glm10	0.6702	1.504			−1.25E−04		6.724	−0.2212	5	176.4	32.1	0
glm7	3.356				−1.17E−04	−0.00085		−0.2266	4	177.1	32.79	0
glm8	−2.579		0.000428		−4.76E−05	−0.00092			4	192.4	48.09	0
glm9	−3.799	1.437	0.000443		−7.28E−05				4	193.9	49.58	0

Appendix 5. Home range estimates of radio-collared Caracals in semi-arid South African study areas.

Study area	Age class and sex	Home range size (km^2)	Fixes	Source
Stellenbosch Mountains, Cape Province	Young male	65	25	Norton & Lawson (1985)
Postberg Nature Reserve, West Coast National Park	Young male	27.5	298	Avenant & Nel (1998)
	Adult male	26.44	352	
	Young female	5.59	52	
	Adult female	8.91	558	
	Young female	7.66	375	
Agricultural landscape, Drakensberg Midlands, KwaZulu-Natal Province	Adult male	243.1	1349	Ramesh et al. (2017)
	Young female	25.88	1291	
	Adult female	64.38	1501	
	Young female	79.08	507	
	Adult female	6.96	1501	
	Adult female	26.39	1464	

Home range size based on non-parametric bootstrapping with 10,000 iterations

Sex	Average	Standard error	Lower limit	Upper limit
Male	90.71816	44.9277	26.97	189.2
Female	28.07304	9.333559	11.65	47.36

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ARTICLE

Avian richness and habitat selection patterns in Jhilmil Jheel Conservation Reserve, Uttarakhand, India

Ankita Das [1], Soumya Dasgupta [2] & Ramesh Krishnamurthy [3]

[1–3] Wildlife Institute of India, Post Box 18, Chandrabani, Dehradun, Uttarakhand 248001, India.
[1] mohantydasankita.91@gmail.com (corresponding author), [2] dgsoumya84@gmail.com, [3] ramesh@wii.gov.in

Abstract: A survey of avifauna was carried out in Jhilmil Jheel Conservation Reserve (JJCR) of Haridwar Forest Division, Uttarakhand, during 2018–2020. The point count method was used to count birds in six habitats, viz.: plantation, mixed deciduous forest, riverine habitat, scrub forest, grasslands, and agricultural field. Ten replications each were done in the summer and winter seasons. The sampling effort across the six habitats, namely, plantation, mixed deciduous forest, scrub forest, riverine, grassland, and agricultural field, was 280, 150, 120, 250, 210, and 150 man minutes, respectively, resulting in a total effort of 1,160 man-minutes. There were 110 bird species in summer season and 131 bird species in winter season and a richness index of 17.73. Muscicapidae family had the highest relative diversity, followed by Accipitridae and Cuculidae. Rank abundance curve showed dominance of a few birds during winter season. Using the resource selection function (RSF), we examined seasonal habitat preferences of avian communities in the JJCR landscape. A total of 48 bird species in summer and 71 bird species in winter exhibited 100% habitat selection for specific habitat types. Riverine habitats showed the highest ecological significance, with 20 and 30 species exhibiting complete selection during summer and winter, respectively. Among the 170 recorded species, habitat specialists (103) outnumbered generalists (63), though the latter were more abundant. The remaining four species are human commensals. Riverine habitats supported the maximum number of specialists due to their distinct riparian vegetation and transitional features. Grassland specialists such as the White-tailed Stonechat, Yellow-bellied Prinia, Striated Grassbird, and Bristled Grassbird (Vulnerable) highlight the conservation importance of grasslands. PERMANOVA confirmed significant seasonal and vertical variations in species composition (p = 0.0001), while indicator species analysis identified 60 and 64 key indicator species for summer and winter, respectively. The strong habitat specialization observed in riverine and grassland ecosystems underscores the need for prioritized management within this Important Bird and Biodiversity Area (IBA).

Keywords: Bird diversity, habitat heterogeneity, habitats, indicator species, microhabitats, rank abundance curve, relative abundance, resource selection function, terai grasslands, wetland.

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Author details: Dr. Ankita Das is an independent researcher and consultant specializing in wildlife and forestry, natural resource management, Environmental and Social Impact Assessment (ESIA), and climate action. A former PhD scholar and Project associate at the Wildlife Institute of India, her work focuses on bird community ecology, urban and agroforestry systems, restoration ecology, and traditional ecological knowledge. Dr. Soumya Dasgupta is an independent researcher and consultant specializing in biodiversity, forestry, and natural resource management. Formerly a project scientist at the Wildlife Institute of India, he led research under the NMSHE and NRCD funded projects. His expertise spans terrestrial ecology, human ecology, climate vulnerability, and animal behaviour studies. Dr. K. Ramesh is a senior scientist, heading the Department of Landscape Level Planning and Management at the Wildlife Institute of India, Dehradun, and has been adjunct professor at the University of British Columbia, Canada. He specialises in landscape ecology, species recovery strategies, and conservation technology integration. He serves as Vice President of the International Association for Landscape Ecology.

Author contribution: AD was responsible for conceptualizing and designing the study, conducting field data collection, organizing and analyzing the data, and drafting the manuscript. SD assisted with data analysis and contributed to the writing and refinement of the manuscript. RK provided overall supervision, strategic guidance, and critical review of the manuscript.

Data Availability Statement: The detailed data and the code is available with the first author and will be shared with the legitimate request made to the same.

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INTRODUCTION

The diverse habitats and microhabitats of forest ecosystems are home to the majority of the world's terrestrial species (Ozanne et al. 2003). But these biologically diverse systems are increasingly threatened by deforestation and forest degradation (Singh et al. 2001; Dirzo & Raven 2003). To monitor changes in forest biodiversity, indicators, which are surrogate measures of other components of forest biodiversity, are increasingly used (Boutin et al. 2009). They have also been described as ecological indicators of community or habitat types or indicators of environmental changes.

Birds are one of the best-studied taxonomic groups (Roberge & Angelstam 2006), and they are considered good indicators of biodiversity since they are present in almost all types of environments and sensitive to changes. The management of many bird species can be eased by considering only a group of indicator species, as monitoring the status of all species is difficult (Báldi 2003), so many natural resource managers want to monitor any focal species (Lambeck 1997) so that the impact of management can be understood. Habitat specialists reflect faster changes in a habitat than generalists, and resident species can also be used for year-round monitoring (Hilty & Merenlender 2000). They indicate the biological condition of the environment, thus considered as ecological disturbance indicator species (EDIS) as they have a strong association with their habitat.

The bird species assemblage of any particular location remains dynamic (Sinha et al. 2019). Species composition and abundance vary across the seasons and habitats (Lee & Kang 2019; Byju et al. 2025a). Spatial and temporal fluctuations in species richness and abundance are characteristic of most bird communities (Robinson et al 2000; Malizia 2001; Byju et al. 2025b). Therefore, understanding the spatio-temporal variations in bird species richness, diversity, and abundance from small habitat patches is equally important (Archana et al. 2024). Multiple factors influence the bird community composition spatially: habitat structure, vegetation strata, proximity of the surrounding patches, and temporally: season and other anthropogenic disturbances (Byju et al. 2025c; Naveen et al. 2025). The seasonal variation in temperature and rainfall, spatial and temporal microhabitat conditions affect the availability of food for birds (Aggarwal et al. 2023), the breeding success and survival of bird species (Kim et al. 2022; Byju et al. 2025d). Processes acting in breeding and wintering grounds determine the patterns and habitat occupancy and seasonal abundance in migratory bird species (García-Macía et al. 2025).

Birds select specific micro-habitats that may vary seasonally (Berlusconi 2025), and such habitat selection enables species coexistence (Bai et al. 2021). Resource Selection Functions (RSFs) help understand these patterns by comparing "used" versus "available" habitats (Jain & Balakrishnan 2011). RSFs estimate the probability of habitat use (Manly et al. 2002) and are widely applied to assess species distribution, abundance, and diversity (Boyce & McDonald 1999; Nielsen et al. 2003, 2005). Identifying selected resources provides insights into species' survival requirements (Manly et al. 2002).

The objective of the study was to assess the general pattern of bird assemblage and the resource selection function of birds in different habitats and identify the indicator bird species of different habitats in the summer and winter seasons. The research questions addressed in this study are: (i) What is the resource selection function of birds in different habitats? (ii) What is the general pattern of bird assemblage in different microhabitats? (iii) Is there any difference in the bird composition of different vertical strata in different habitats? (iv) Which are the indicator bird species of different habitats in the summer and winter seasons?

By assessing the general patterns of bird assemblage in different habitats, the study will contribute to our understanding of how avian communities are distributed across various habitats within the study area. This information is crucial for habitat conservation and management strategies.

Study area

Jhilmil Jheel Conservation Reserve (JJCR) is a saucer-shaped wetland located in the Rasiyabaad forest range in Haridwar, Uttarakhand (Image 1). It lies between 29.53º–29.83º N and 78.00º–78.25º E with an elevation ranging 200–250 m. It is spread over 37 km^2. It is comprised of various habitats such as grasslands, moist deciduous forests (mixed forest), scrub forest, riverine habitat, plantation, and agriculture field. The texture of the soil varies from sand to clay. It is rich in floral and faunal diversity. JJCR has 24 species of mammals, 20 reptile species, seven species of amphibians, 35 fish species, and 67 species of butterflies (Sinha et al. 2011).

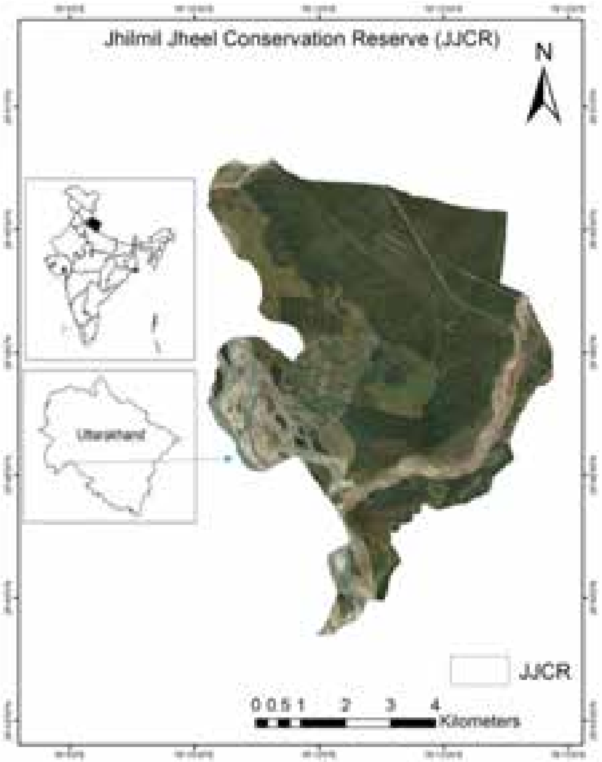

Image 1. Jhilmil Jheel Conservation Reserve, Haridwar, Uttarakhand.

METHODS

Bird sampling

From March 2018 to March 2020, bird sampling was conducted in different habitats of JJCR during both summer (mid-March–June) and winter (November–mid-February) (Bird list in Appendix Table 1). To count the birds in each habitat, the point count method (Bibby et al. 2000) was employed. Point count stations with a fixed width of 50-m radius were placed along existing forest trails in the six habitats: plantation (28), mixed forest (15), scrub forest (12), riverine (25), grassland (21), and agricultural fields (15) (Appendix Table 2). In total, 116 point count stations were utilized for the bird surveys, with a distance of 200 m between each station. Each point count station was visited 20 times, 10 times in summer and 10 times in winter (Appendix Table 3). The sampling effort across the six habitats, namely plantation, mixed deciduous forest, scrub forest, and riverine was 280, 150, 120, 250, 210, and 150 man minutes, resulting in a total effort of 1,160 man-minutes (Appendix Table 3). The surveys took place at 0530–0830 h during the summer and at 0800–1030 h during the winter. The observer recorded all birds seen or heard within a 10-minute period at each point count station, excluding birds in flight. Surveys were not conducted during unfavourable weather conditions. Individual birds were identified using standard field guides (Grimmett et al. 2011).

Data analysis

Richness index and diversity

The data analysis was based on the sum of 20 repeated observations. The survey data was used to calculate the various diversity indices. The richness index was computed as Margalef's richness index (Margalef 1958).

R = (S-1) (1)/Ln(N)

Where: R = Index of species richness.

S = Number of species observed.

N = Number of individuals (all species observed).

Ln = Natural logarithm value.

There are three classifications of Margalef richness index values, namely low species richness (R < 2.5), medium species richness (2.5 > R < 4) and high species richness (R > 4).

Bird species diversity in both seasons was computed using Shannon-Weiner index (Shannon & Weaver 1963) as follows:

$$(H) = -\sum_{k=1}^{s}(P_i * ln\, P_i)$$

H = Species diversity

Pi = Proportion of abundance of species i

S = Total number of species in the habitat

Rank abundance

Once abundance data for each species had been collected, it was organized by listing each species and its corresponding count. Then, the species were ranked in descending order of abundance, from the most common to the rarest. On the graph, the rank of each species was represented on the x-axis, with the most abundant species being assigned rank 1, the next rank 2, and so forth. The abundance of each species was represented on the y-axis and was expressed as the raw number of individuals or as relative abundance, which is the proportion of each species' individuals to the total. To construct the curve, data points were plotted on the graph, with the rank of each species on the x-axis and its abundance on the y-axis. Finally, the plotted points are connected with a line to create the rank abundance curve.

Resource Selection Function

RSF was calculated following Jain & Balakrishnan (2011):

- Proportional use of habitat by species = number of individuals of species found in habitat /total number of individuals of species sampled

- Proportional availability of habitat = average surface area contributed by habitat / total area available (summed across all habitats)
- Resource selection function = Proportion used / Proportion available
- The standardisation is carried out as follows:

$$b_{h,s} = w_{h,s} / \sum_{h=1 \; to \; H} (w_{h,s})$$

for s = 1 to S, where S is the total number of species and H is the total number of habitats.

Based on RSF, birds were classified into habitat specialists if bird species were specifically preferring one or two habitats, habitat generalists if they were present in more than two habitats and human commensal, i.e., the birds which live in close proximity to human habitation (Pal et al. 2019).

Based on our field observations, birds were classified into different microhabitats, based on their perching and feeding height into vertical strata such as upper canopy, middle canopy, lower canopy, understorey, and ground-dwelling birds. Bird species which were either waterbirds or water-dependent were categorized as 'aquatic', while those which are adapted to air were categorized as 'aerial'. The diversity of different vertical strata was calculated through Shannon-Wiener diversity. PERMANOVA test (Anderson 2001) was performed to assess the difference in bird community assemblage in different strata in different seasons and habitats.

Indicator species analysis was done in R software using the package Indval, which measures the importance of habitat for a particular bird species. The indicator value index is the product of two components, called 'A' and 'B' (Dufrêne & Legendre 1997; Cáceres & Legendre 2009). Component 'A' is a sample estimate of the probability that the surveyed site belongs to the target site group, given the fact that the species has been found. This conditional probability is called the specificity or positive predictive value of the species as an indicator of the site group. Component 'B' is a sample estimate of the probability of finding the species in sites belonging to the site group. This second conditional probability is called the fidelity or sensitivity of the species as an indicator of the target site group. This method combines the faithfulness of occurrence of the species in a habitat with its abundance in that habitat and the occurrence and abundance of the species in other habitats. As such, it provides a measure of the importance of that habitat to the species. Indicator value lies between 0 and 1, where 1 means 100% indicator of a particular habitat.

RESULTS

Richness index and diversity

A total of 170 bird species were encountered during the survey period, which constitutes 23.94% of the total number of species (710) reported from the state of Uttarakhand (Mohan & Sondhi 2024). The available data reports a total of 387 bird species for the region around JJCR.

In total, 110 and 131 bird species were recorded in the study area during the summer and winter seasons, respectively. The overall Margalef richness index was observed to be 17.7371, which shows that JJCR has high species richness. Rarefaction curves by habitat and season are mentioned in the Appendix Figures 1a,b. Family Muscicapidae had the highest bird diversity, followed by Accipitridae and Cuculidae. The diversity of bird species was found to be 3.8 and 3.9 in the summer and winter seasons, respectively (Appendix Table 4).

Rank abundance curves (RAD)

Rank abundance curves are useful tools to characterize and understand the structure of ecological communities. The shape and distribution of the curve provide valuable insights into the dynamics, health, and stability of the ecosystem, as well as the forces driving species abundance and diversity. They yield significant insights into two fundamental components of biodiversity: species richness, which denotes the total number of species, and species evenness, which reflects the relative abundance of those species. There are various RAD curves: 1) A log normal distribution indicates a balanced community where most species have moderate abundance, while a smaller number are either very abundant or very rare. This is typical of diverse ecosystems. 2) A geometric series is characterized by a few highly abundant species and many rare species. This pattern is often found in environments with strong competition or disturbance. 3) The broken stick model illustrates a hypothetical scenario where resources are perfectly distributed among all species, resulting in an even abundance. However, this idealized pattern is seldom found in real-world ecosystems.

There is less dominance and moderate evenness of individuals within each species in the bird community assemblage in the summer season within the study area (Figure 1a). Whereas, in the community assemblage in the winter season, there was dominance of a few species (Figure 1b), followed by even distribution of individuals of other species.

Resource selection function

Resource election function (RSF) helps to understand how animals choose habitats based on resource availability. Proportional availability of plantation, mixed deciduous forest, scrub forest, riverine habitat, grassland, and agriculture field-human settlement are 0.39%, 0.13%, 0.07%, 0.18%, 0.16%, and 0.07% respectively (Figure 2).

A total of 20 bird species had 100% selection for riverine habitat during summer, and 30 during winter. In the grassland, 10 and 13 species had 100% RSF during the summer and winter, four (4) and 13 bird species in summer and winter, respectively. Two and six bird species had 100% RSF for mixed forest in summer and winter, respectively. Ten species had 100% RSF for scrub forest in summer, and seven had 100% RSF in winter. Two species had 100% RSF for the agriculture field-human settlement in both summer and winter. Riverine habitat had the highest RSF. So, in total, 48 bird species had 100% selection for a particular habitat in summer (Table 1a) and 71 bird species had 100% selection for a particular habitat in winter (Table 1b).

Habitat specialist and generalist

Birds were grouped into specialists or generalists based on their sighting in a particular habitat or multiple habitats (Figure 3a). It was found that there are more habitat specialists (103) than generalists (63) bird species in JJCR, and four were commensals. The abundance of habitat generalist birds is more than that of habitat specialists (Figure 3b). The bird community was dominated by specialists (60.59%), followed by generalists (37.06%), while human commensal species constituted only 2.35% of the total recorded species. In contrast to species richness, total abundance was highest for generalists, followed by specialists, whereas human commensals showed the lowest abundance. This indicates that although specialists form the majority in terms of species number, generalists dominate numerically in the community. Riverine habitat supported the highest number of habitat specialists

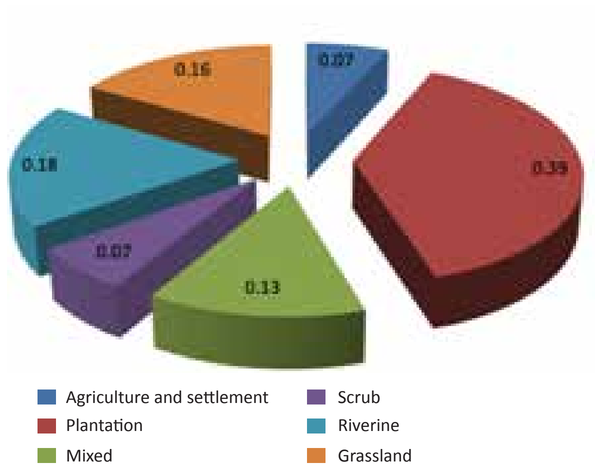

Figure 2. Proportional availability (%) of habitats of Jhilmil Jheel Conservation Reserve.

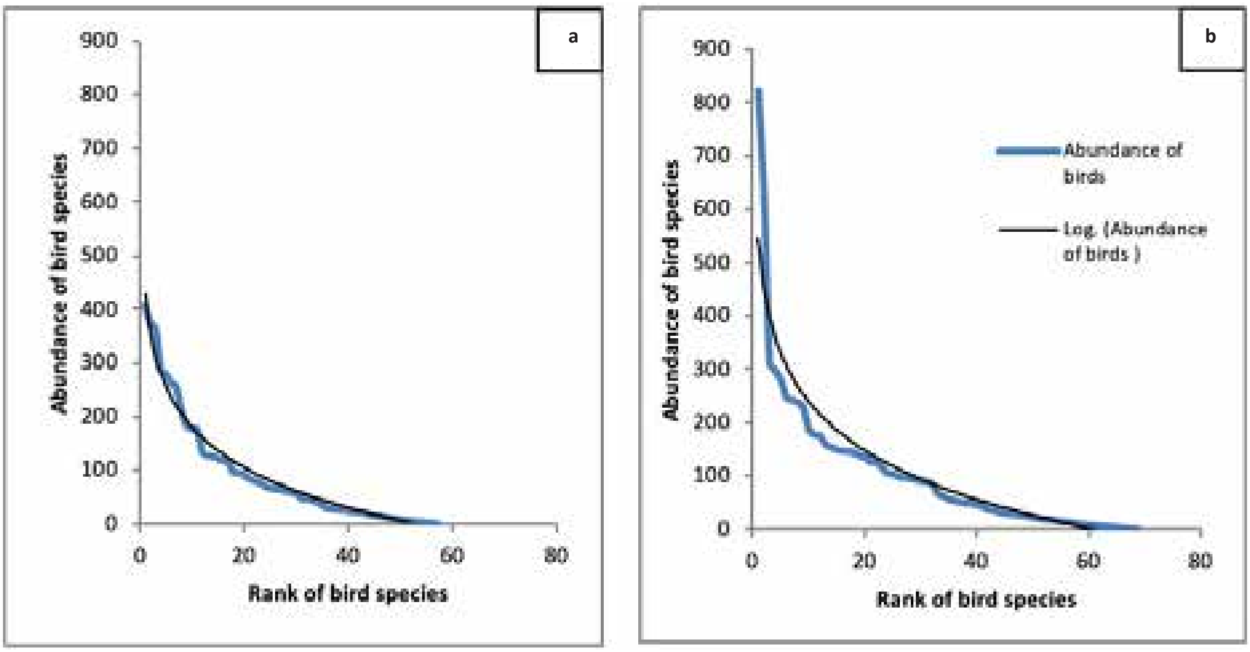

Figure 1. Rank abundance curve: a—summer | b—winter season

Table 1a. Resource selection function during summer season (Proportion of selection for a particular habitat by a bird species).

Bird species	Agriculture	Grassland	Mixed Forest	Plantation	Riverine	Scrub Forest
Ashy-crowned Sparrow-Lark	0.00	0.00	0.00	0.00	1.00	0.00
Ashy Prinia	0.13	0.26	0.17	0.00	0.14	0.31
Asian Koel	0.21	0.00	0.26	0.12	0.13	0.28
Indian Pied Starling	0.43	0.57	0.00	0.00	0.00	0.00
Barn Swallow	0.00	0.73	0.27	0.00	0.00	0.00
Bay-backed Shrike	0.00	0.00	0.00	0.00	0.00	1.00
Baya Weaver	0.10	0.02	0.76	0.00	0.00	0.12
Black-breasted Weaver	0.00	1.00	0.00	0.00	0.00	0.00
Black-chinned Babbler	0.00	0.00	0.59	0.05	0.00	0.36
Black Drongo	0.00	0.12	0.00	0.33	0.29	0.26
Black Francolin	0.00	0.40	0.00	0.00	0.60	0.00
Black-hooded Oriole	0.00	0.00	0.12	0.83	0.05	0.00
Black Kite	0.00	0.00	0.00	0.00	1.00	0.00
Blue tailed Bee-eater	0.00	0.00	0.74	0.00	0.00	0.26
Brahminy Starling	0.00	0.00	0.23	0.00	0.00	0.77
Bristled Grassbird	0.00	1.00	0.00	0.00	0.00	0.00
Brown-headed Barbet	0.00	0.00	0.00	0.83	0.00	0.17
Cattle Egret	0.50	0.10	0.00	0.31	0.08	0.00
Changeable-Hawk Eagle	0.00	0.00	0.00	0.15	0.00	0.85
Chestnut-bellied Nuthatch	0.00	0.00	0.00	0.00	0.00	1.00
Chestnut-shouldered Petronia	0.00	0.00	0.64	0.04	0.03	0.29
Common Cuckoo	0.00	0.00	0.00	1.00	0.00	0.00
Common-Hawk Cuckoo	0.00	0.00	0.47	0.53	0.00	0.00
Common Iora	0.00	0.00	0.38	0.02	0.00	0.60
Common Kingfisher	0.00	0.53	0.00	0.00	0.47	0.00
Common Myna	0.10	0.20	0.00	0.46	0.15	0.09
Common Stonechat	0.00	0.92	0.00	0.00	0.08	0.00
Common Tailorbird	0.00	0.00	0.31	0.02	0.10	0.57
Coppersmith Barbet	0.00	0.00	0.18	0.15	0.00	0.67
Crested Lark	0.00	0.00	0.00	0.00	1.00	0.00
Crested Serpent-Eagle	0.00	0.00	0.67	0.33	0.00	0.00
Drongo Cuckoo	0.00	0.00	0.00	1.00	0.00	0.00
Eurasian Collared-Dove	0.00	0.00	0.35	0.00	0.33	0.32
Great Cormorant	0.00	0.00	0.00	0.00	1.00	0.00
Green Bee-eater	0.08	0.09	0.08	0.00	0.24	0.50
Grey-bellied Cuckoo	0.00	0.69	0.00	0.00	0.31	0.00
Grey-breasted Prinia	0.00	0.00	0.47	0.03	0.00	0.51
Grey Bushchat	0.28	0.72	0.00	0.00	0.00	0.00
Grey Francolin	0.00	0.36	0.00	0.00	0.64	0.00
Grey Heron	0.00	0.00	0.00	0.00	1.00	0.00
Grey-hooded Warbler	0.00	0.00	0.00	1.00	0.00	0.00
Gray Wagtail	0.00	0.00	0.00	0.00	1.00	0.00
Himalayan Griffon	0.00	0.00	0.00	0.00	0.00	1.00
House Crow	0.39	0.10	0.00	0.00	0.51	0.00

Bird species	Agriculture	Grassland	Mixed Forest	Plantation	Riverine	Scrub Forest
House Sparrow	1.00	0.00	0.00	0.00	0.00	0.00
Indian Cuckoo	0.13	0.00	0.22	0.38	0.00	0.27
Indian Grey Hornbill	0.00	0.00	0.38	0.45	0.17	0.00
Indian Paradise- Flycatcher	0.00	0.00	0.28	0.72	0.00	0.00
Indian Peafowl	0.00	0.03	0.47	0.02	0.00	0.48
Indian Pitta	0.00	0.00	0.45	0.34	0.00	0.21
Indian Robin	0.00	0.00	0.00	0.00	0.03	0.97
Indian Roller	0.00	0.02	0.30	0.11	0.35	0.22
Intermediate Egret	0.00	0.00	0.00	0.00	1.00	0.00
Pied Cuckoo	0.00	0.00	0.00	0.00	0.00	1.00
Jungle Babbler	0.00	0.00	0.41	0.32	0.00	0.26
Jungle Myna	0.00	0.00	1.00	0.00	0.00	0.00
Jungle Owlet	0.00	0.00	0.00	1.00	0.00	0.00
Large-billed Crow	0.00	0.16	0.15	0.03	0.66	0.00
Laughing Dove	0.00	0.23	0.00	0.00	0.00	0.77
Lesser Goldenback	0.00	0.00	0.00	0.19	0.00	0.81
Lesser Whitethroat	0.00	0.00	0.00	0.00	0.00	1.00
Little Cormorant	0.00	0.00	0.00	0.00	1.00	0.00
Little Egret	0.00	0.00	0.00	0.00	1.00	0.00
Little-ringed Plover	0.00	0.00	0.00	0.00	1.00	0.00
Little Tern	0.00	0.00	0.00	0.00	1.00	0.00
Long-tailed Shrike	0.00	0.00	0.00	0.00	0.00	1.00
Oriental Honey- buzzard	0.00	0.00	1.00	0.00	0.00	0.00
Oriental Magpie-Robin	0.00	0.03	0.19	0.31	0.05	0.42
Oriental Skylark	0.00	0.89	0.00	0.00	0.11	0.00
Oriental White-eye	0.00	0.00	0.38	0.13	0.00	0.49
Paddyfield Pipit	0.00	0.99	0.00	0.00	0.01	0.00
Pale-billed Flowerpecker	0.00	0.00	0.00	0.00	0.00	1.00
Pied Bushchat	0.39	0.55	0.00	0.00	0.00	0.06
Pied Kingfisher	0.00	0.00	0.00	0.00	1.00	0.00
Plain Prinia	0.15	0.35	0.00	0.04	0.08	0.39
Plum-headed Parakeet	0.00	0.00	0.57	0.00	0.00	0.43
Pond Heron	0.94	0.00	0.00	0.00	0.06	0.00
Purple Sunbird	0.00	0.01	0.20	0.07	0.10	0.62
Red Junglefowl	0.00	0.00	0.63	0.06	0.00	0.31
Red-naped Ibis	0.00	0.00	0.00	0.00	1.00	0.00
Red-vented Bulbul	0.18	0.07	0.28	0.08	0.04	0.36
Red-wattled Lapwing	0.08	0.69	0.00	0.00	0.24	0.00
Red-whiskered Bulbul	0.14	0.10	0.29	0.11	0.00	0.36
Blyth's Reed Warbler	0.00	0.00	0.00	0.00	1.00	0.00
River Lapwing	0.00	0.05	0.00	0.00	0.95	0.00
River Tern	0.00	0.00	0.00	0.00	1.00	0.00
Rock Pigeon	1.00	0.00	0.00	0.00	0.00	0.00
Rose-ringed Parakeet	0.13	0.00	0.65	0.19	0.00	0.03
Ruddy Shelduck	0.00	0.00	0.00	0.00	1.00	0.00

Bird species	Agriculture	Grassland	Mixed Forest	Plantation	Riverine	Scrub Forest
Rufous Treepie	0.28	0.00	0.49	0.23	0.00	0.00
Sarus Crane	0.46	0.00	0.00	0.00	0.54	0.00
Shikra	0.00	0.00	0.00	0.42	0.00	0.58
Short-toed Snake-eagle	0.00	1.00	0.00	0.00	0.00	0.00
Small Minivet	0.00	0.00	0.34	0.04	0.00	0.63
Small Pratincole	0.00	0.00	0.00	0.00	1.00	0.00
Indian Spot-billed Duck	0.00	0.00	0.00	0.00	1.00	0.00
Spotted Dove	0.09	0.01	0.23	0.08	0.04	0.55
Streak-throated Woodpecker	0.00	0.00	0.00	0.00	0.00	1.00
Striated Babbler	0.00	1.00	0.00	0.00	0.00	0.00
Striated Grassbird	0.00	1.00	0.00	0.00	0.00	0.00
Tawny-bellied Babbler	0.00	0.00	0.00	0.00	0.00	1.00
White-bellied Drongo	0.00	0.00	0.00	0.13	0.87	0.00
White-browed Wagtail	0.00	0.00	0.00	0.00	1.00	0.00
White-eyed Buzzard	0.00	0.00	0.00	0.00	0.00	1.00
White-tailed Stonechat	0.00	1.00	0.00	0.00	0.00	0.00
White-throated Kingfisher	0.00	0.45	0.00	0.07	0.48	0.00
White Wagtail	0.00	0.00	0.00	0.00	1.00	0.00
Yellow-bellied Prinia	0.00	1.00	0.00	0.00	0.00	0.00
Yellow-wattled Lapwing	0.00	1.00	0.00	0.00	0.00	0.00
Zitting Cisticola	0.00	1.00	0.00	0.00	0.00	0.00

(51 species), followed by scrub forest and plantation. Scrub forest (48 species), mixed forest (47 species), and plantation (46 species) showed higher numbers of generalists. Grassland had a relatively balanced composition of specialists (31 species) and generalists (34 species). Agriculture fields showed the lowest number of specialists (5 species) but relatively higher generalists (22 species). Human commensals were recorded in very low numbers across all habitats (0–4 species), with slightly higher representation in agricultural fields.

Some of the most abundant generalist birds in JJCR are Baya Weaver *Ploceus philippinus*, Jungle Babbler *Turdoides striata*, Red-vented Bulbul *Pycnonotus cafer*, Rose-ringed Parakeet *Psittacula krameria*, and Spotted Dove *Spilopelia chinensis*. House Crow *Corvus splendens*, Rock Pigeon *Columba livia*, House Sparrow *Passer domesticus*, and Common Myna *Acridotheres tristis* are human commensals. Riverine habitat supported the maximum number of habitat specialists as it is the transition between terrestrial and wetland environments, having unique riparian vegetation and the river-created habitats such as water-edge and sandbars, sandbar scrub, river-edge forests, leading to more diversity of birds (Figure 3c).

Several birds in JJCR are habitat specialists or near habitat specialists, found more or less restricted to their habitats, making the conservation of each habitat vital for the long-term sustenance of this IBA. The JJCR has many grassland birds such as Common Stonechat *Saxicola rubicola*, White-tailed Stonechat *Saxicola leucurus*, Red Avadavat *Amandava amandava*, Zitting Cisticola *Cisticola juncidis*, Sarus Crane *Grus Antigone*, Yellow-bellied Prinia *Prinia flaviventris*, Bristled Grassbird *Chaetornis striata*, and Striated Grassbird *Megalurus palustris*. Among these White-tailed Stonechat, Yellow-bellied Prinia, Striated Grassbird, and Bristled Grassbird are considered grassland bird specialists.

Bristled Grassbird and Sarus Crane are 'Vulnerable'. Notable waterbirds in the area include the River Lapwing *Vanellus duvaucelii*, River Tern *Sterna aurantia*, Black-bellied Tern *Sterna acuticauda*, and Little Tern *Sternula albifrons*, while water-dependent species encompass the Pied Kingfisher *Ceryle rudis*, Stork-billed Kingfisher *Pelargopsis capensis*, and Great Thick-knee *Esacus recurvirostris,* with the River Lapwing and River Tern classified as 'Near Threatened' and the Black-bellied Tern as 'Endangered' by the IUCN Red List for Threatened Species. Some of the prominent scrub habitat specialists

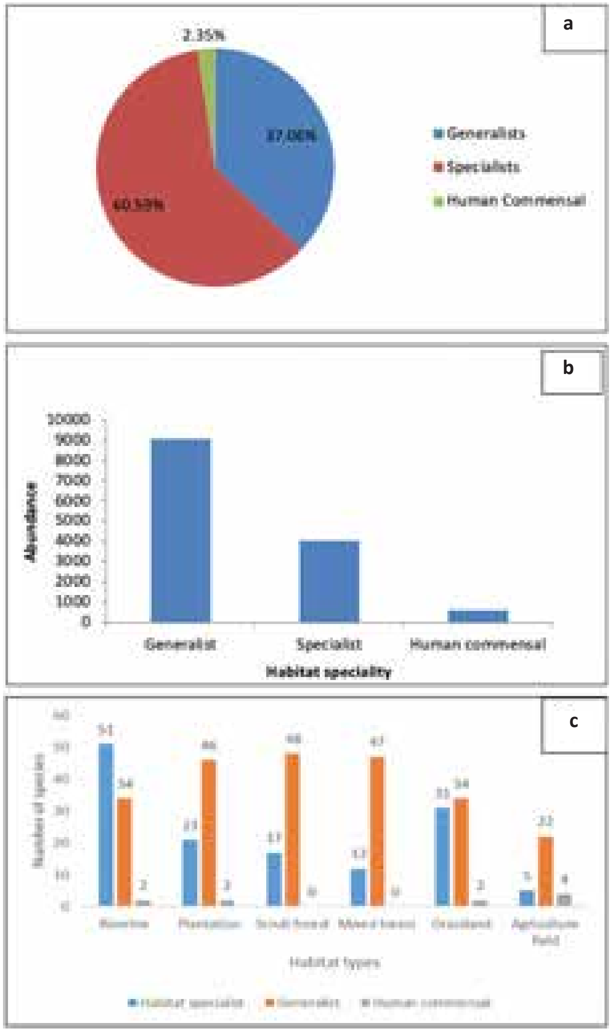

Figure 3. a—Proportion (%) of specialist-generalist birds' species in JJCR | b—Abundance of habitat specialist-generalist birds' species in JJCR | c—Number of habitat specialist-generalist in every habitat.

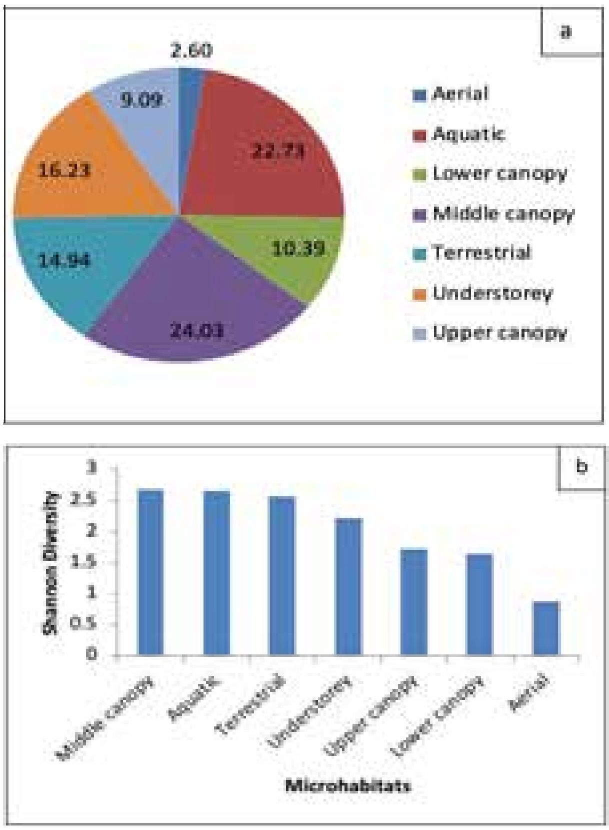

Figure 4. a—Species encountered (%) in different microhabitats | b—Shannon-Wiener diversity of birds in different microhabitats.

are Black Francolin *Francolinus francolinus* and Grey Francolin *Ortygornis pondicerianus*. In plantations of Eucalyptus and Teak, a few birds favouring open woodland habitats were more frequent, such as Black-hooded Oriole *Oriolus xanthornus* and Black Bulbul *Hypsipetes leucocephalus*. Prominent bird species of mixed deciduous forests are Red Junglefowl *Gallus gallus* and Grey Hornbill *Ocyceros birostris*. Sarus Cranes are one of the notable species found in agricultural fields.

Bird composition in different vertical strata (microhabitats)

The middle canopy had the highest proportion of bird species and the highest Shannon diversity in JJCR, and the upper canopy had the lowest number of bird species as compared to other vertical strata (Figure 4a,b). There is a noticeable increase in bird species in the middle canopy in winter (Figure 5). PERMANOVA result showed a significant difference in bird composition in different vertical strata (microhabitats) in different seasons (p = 0.0001). The bird composition significantly differed across vertical strata in different habitats in the summer (p = 0.0001) and winter seasons (p = 0.0001) (Appendix Table 5).

Indicator species

Indicator values of all bird species were computed for every habitat type, and those species with statistically significant values (P < 0.001) were considered as suitable indicators for a particular habitat. High indicator values reflect high species abundance and prevalence within a landcover type (Hayes 2020). In the summer season, out of 110 species, 60 species were identified as indicator species. Riverine habitat had 15 indicator species, mixed deciduous forest—12, plantation—12, grassland—11 indicator species, scrub forest—seven indicator species, and agriculture field-human settlement—three indicator species (Table 2a). In the winter season, out of 131 species, 64 were identified as indicator species for

Table 1b. Resource selection function during winter season (Proportion of selection for a particular habitat by a bird species, 100% selection for a particular habitat is represented by value 1).

Bird species	Agriculture	Grassland	mixed Forest	Plantation	Riverine	Scrub forest
Ashy Drongo	0.00	1.00	0.00	0.00	0.00	0.00
Ashy Prinia	0.00	0.00	0.03	0.00	0.14	0.83
Asian Brown Flycatcher	0.00	0.00	0.86	0.14	0.00	0.00
Indian Pied Starling	0.00	1.00	0.00	0.00	0.00	0.00
Bank Myna	0.00	0.00	0.00	0.00	1.00	0.00
Bar-headed Goose	0.00	0.00	0.00	0.00	1.00	0.00
Barn Swallow	0.00	0.06	0.54	0.00	0.40	0.00
Bay-backed Shrike	0.00	0.00	0.00	0.00	0.00	1.00
Black-bellied Tern	0.00	0.00	0.00	0.00	1.00	0.00
Black Bulbul	0.00	0.00	0.00	1.00	0.00	0.00
Black Drongo	0.00	0.14	0.04	0.23	0.13	0.46
Black-hooded Oriole	0.00	0.00	0.36	0.62	0.03	0.00
Black-naped Monarch	0.00	0.00	0.00	1.00	0.00	0.00
Brahminy Starling	0.00	0.00	0.00	0.00	1.00	0.00
Bronze Drongo	0.00	1.00	0.00	0.00	0.00	0.00
Brown-headed Barbet	0.00	0.00	0.22	0.37	0.00	0.41
Brown Rock Chat	0.53	0.47	0.00	0.00	0.00	0.00
Cattle Egret	0.94	0.04	0.00	0.00	0.03	0.00
Chestnut-bellied Rockthrush	0.00	0.00	0.00	1.00	0.00	0.00
Cinereous Vulture	0.00	0.00	0.00	0.00	1.00	0.00
Citrine Wagtail	0.00	0.24	0.00	0.00	0.76	0.00
Common Greenshank	0.00	0.00	0.00	0.00	1.00	0.00
Common Kingfisher	0.00	0.27	0.00	0.00	0.73	0.00
Common Myna	0.35	0.05	0.00	0.57	0.03	0.00
Common Sandpiper	0.00	0.00	0.00	0.00	1.00	0.00
Common Stonechat	0.00	0.92	0.00	0.00	0.08	0.00
Common Tailorbird	0.30	0.00	0.33	0.00	0.15	0.23
Crested Serpent-eagle	0.00	0.09	0.34	0.23	0.33	0.00
Crimson Sunbird	0.00	0.00	0.41	0.00	0.00	0.59
Egyptian Vulture	0.00	0.00	0.00	0.00	1.00	0.00
Eurasian Collared-dove	0.00	0.00	0.00	0.00	1.00	0.00
Eurasian Sparrowhawk	0.00	0.00	1.00	0.00	0.00	0.00
Gadwall	0.00	0.00	0.00	0.00	1.00	0.00
Golden-fronted Leafbird	0.00	0.00	1.00	0.00	0.00	0.00
Goosander	0.00	0.00	0.00	0.00	1.00	0.00
Great Barbet	0.00	0.00	0.00	0.00	0.00	1.00
Great Cormorant	0.00	0.00	0.00	0.00	1.00	0.00
Great Egret	0.00	0.00	0.00	0.00	1.00	0.00
Great Tit	0.00	0.00	0.46	0.37	0.00	0.17
Greater Coucal	0.20	0.00	0.00	0.00	0.00	0.80

Bird species	Agriculture	Grassland	mixed Forest	Plantation	Riverine	Scrub forest
Green Bee-eater	0.00	0.00	0.71	0.10	0.00	0.19
Greenish warbler	0.00	0.02	0.10	0.24	0.04	0.61
Grey Bushchat	0.00	0.00	0.00	0.00	0.00	1.00
Grey-headed Canary-Flycatcher	0.00	0.00	0.00	1.00	0.00	0.00
Grey-hooded Warbler	0.00	0.00	1.00	0.00	0.00	0.00
Gray Wagtail	0.52	0.09	0.00	0.00	0.38	0.00
Himalayan Bulbul	0.00	0.02	0.11	0.13	0.00	0.74
Himalayan Griffon	0.00	0.00	0.00	0.00	1.00	0.00
House Crow	0.25	0.00	0.00	0.37	0.38	0.00
House Sparrow	1.00	0.00	0.00	0.00	0.00	0.00
Humes Warbler	0.01	0.00	0.25	0.22	0.20	0.31
Indian Grey Hornbill	0.00	0.00	0.78	0.00	0.00	0.22
Indian Peafowl	0.00	0.05	0.30	0.00	0.00	0.65
Indian Robin	0.00	0.00	0.00	0.00	0.00	1.00
Indian Roller	0.00	0.50	0.00	0.01	0.49	0.00
Indian Silverbill	0.00	0.11	0.00	0.00	0.00	0.89
Intermediate Egret	0.00	0.00	0.00	0.00	1.00	0.00
Jungle Babbler	0.05	0.00	0.26	0.25	0.00	0.44
Jungle Owlet	0.00	0.00	0.27	0.73	0.00	0.00
Large-billed Crow	0.00	0.23	0.11	0.38	0.13	0.16
Laughing Dove	0.00	1.00	0.00	0.00	0.00	0.00
Lemon-rumped Warbler	0.00	0.00	0.00	1.00	0.00	0.00
Lesser Goldenback	0.00	0.00	0.00	0.25	0.00	0.75
Lesser Whistling Duck	0.00	0.00	0.00	0.00	1.00	0.00
Lesser Whitethroat	0.00	0.00	0.23	0.00	0.00	0.77
Little Cormorant	0.00	0.00	0.00	0.00	1.00	0.00
Little Egret	0.00	0.00	0.00	0.00	1.00	0.00
Little-ringed Plover	0.00	0.00	0.00	0.00	1.00	0.00
Little Stint	0.00	0.00	0.00	0.00	1.00	0.00
Long-tailed Shrike	0.00	1.00	0.00	0.00	0.00	0.00
Maroon Oriole	0.00	0.00	0.00	1.00	0.00	0.00
Northern Pintail	0.00	0.00	0.00	0.00	1.00	0.00
Oriental Magpie-robin	0.00	0.00	0.34	0.15	0.00	0.51
Oriental Pied hornbill	0.00	0.00	1.00	0.00	0.00	0.00
Oriental Skylark	0.00	0.39	0.00	0.00	0.61	0.00
Oriental White-eye	0.00	0.00	0.42	0.02	0.00	0.57
Osprey	0.00	0.00	0.00	0.00	1.00	0.00
Paddyfield Pipit	0.00	0.72	0.00	0.00	0.28	0.00
Pallas Gull	0.00	0.00	0.00	0.00	1.00	0.00
Pied Bushchat	0.40	0.56	0.00	0.00	0.04	0.00

Bird species	Agriculture	Grassland	mixed Forest	Plantation	Riverine	Scrub forest
Pied Kingfisher	0.00	0.07	0.00	0.00	0.93	0.00
Plain Martin	0.00	0.00	0.00	0.00	1.00	0.00
Plain Prinia	0.07	0.13	0.02	0.00	0.02	0.76
Plum-headed Parakeet	0.00	0.00	0.45	0.10	0.05	0.41
Pond Heron	0.45	0.07	0.00	0.07	0.41	0.00
Purple Sunbird	0.00	0.00	0.28	0.01	0.00	0.71
Red Avadavat	0.00	1.00	0.00	0.00	0.00	0.00
Red-breasted Flycatcher	0.00	0.00	0.37	0.00	0.00	0.63
Red-crested Pochard	0.00	0.00	0.00	0.00	1.00	0.00
Red Junglefowl	0.00	0.00	0.65	0.00	0.00	0.35
Red-naped Ibis	0.00	0.51	0.00	0.49	0.00	0.00
Red-vented Bulbul	0.03	0.07	0.21	0.04	0.03	0.61
Red-wattled Lapwing	0.09	0.89	0.00	0.02	0.00	0.00
Red-whiskered Bulbul	0.10	0.02	0.35	0.00	0.00	0.54
River Lapwing	0.00	0.39	0.00	0.00	0.61	0.00
River Tern	0.00	0.09	0.00	0.00	0.91	0.00
Rock Pigeon	1.00	0.00	0.00	0.00	0.00	0.00
Rose-ringed Parakeet	0.25	0.00	0.23	0.42	0.08	0.03
Ruddy Shelduck	0.01	0.01	0.00	0.00	0.98	0.00
Rufous-gorgeted Flycatcher	0.00	0.00	1.00	0.00	0.00	0.00
Rufous Treepie	0.11	0.00	0.27	0.16	0.16	0.30
Rusty-cheeked Scimitar-Babbler	0.00	0.00	0.00	1.00	0.00	0.00
Sarus Crane	0.48	0.52	0.00	0.00	0.00	0.00
Shikra	0.00	0.00	0.00	1.00	0.00	0.00
Sirkeer Malkoha	0.00	0.00	0.00	0.00	1.00	0.00

Bird species	Agriculture	Grassland	mixed Forest	Plantation	Riverine	Scrub forest
Slender-billed Vulture	0.00	0.00	0.00	0.00	1.00	0.00
Small Minivet	0.00	0.00	0.00	0.00	0.00	1.00
Small Niltava	0.00	0.00	1.00	0.00	0.00	0.00
Small Pratincole	0.00	0.00	0.00	0.00	1.00	0.00
Spangled Drongo	0.00	0.01	0.11	0.46	0.00	0.42
Spotted Dove	0.36	0.00	0.08	0.04	0.00	0.52
Stork-billed Kingfisher	0.00	0.00	0.00	0.00	1.00	0.00
Striated Grassbird	0.00	1.00	0.00	0.00	0.00	0.00
Taiga Flycatcher	0.00	0.00	0.00	1.00	0.00	0.00
Temminck Stint	0.00	0.00	0.00	0.00	1.00	0.00
Thick-billed Flowerpecker	0.00	0.00	0.00	1.00	0.00	0.00
Tickell's Blue Flycatcher	0.00	0.00	0.00	1.00	0.00	0.00
Tickell's Thrush	0.00	1.00	0.00	0.00	0.00	0.00
Velvet-fronted Nuthatch	0.00	0.00	0.00	1.00	0.00	0.00
Verditer Flycatcher	0.00	0.00	0.00	0.00	0.00	1.00
White-browed Wagtail	0.00	0.00	0.00	0.00	1.00	0.00
White-rumped Vulture	0.00	1.00	0.00	0.00	0.00	0.00
White-tailed Stonechat	0.00	1.00	0.00	0.00	0.00	0.00
White-throated Fantail	0.00	0.09	0.05	0.26	0.14	0.46
White-throated Kingfisher	0.00	0.51	0.00	0.00	0.49	0.00
White Wagtail	0.00	0.00	0.00	0.03	0.97	0.00
Woolly-necked Stork	0.00	0.00	0.00	1.00	0.00	0.00
Yellow-bellied Prinia	0.00	1.00	0.00	0.00	0.00	0.00
Yellow-footed Green-Pigeon	0.00	0.00	0.00	0.00	0.00	1.00
Yellow-wattled Lapwing	0.00	1.00	0.00	0.00	0.00	0.00
Yellow-breasted Greenfinch	0.00	1.00	0.00	0.00	0.00	0.00

different habitats. Grassland had 10 indicator species, plantation—12, riverine—16, agriculture field-human settlement—three, mixed—seven, and scrub forest—16 indicator species (Table 2b).

Habitat-wise detailed description

Agriculture field and human settlement: Rock Pigeon and House Sparrow were significantly associated with agriculture and human settlement in both seasons. Rock Pigeon had the highest indicator value (57%) during summer, whereas Cattle Egret had the highest Indicator value (64.9%) during winter.

Grassland: Paddyfield Pipit *Anthus rufulus*, Common Stonechat, Red-wattled Lapwing *Vanellus indicus*, Pied Buschat *Saxicola caprata*, and Yellow-bellied Prinia were strongly associated with grasslands in summer. Species such as Common Stonechat, Red-wattled Lapwing, Paddyfield Pipit, and White-tailed Stonechat were strongly associated with grassland during the winter season. Paddyfield Pipit had the highest indicator value (96.9%) in summer, whereas Common Stonechat had the highest indicator value of 88.8% during winter.

Mixed deciduous forest: Baya Weaver, Red Junglefowl, Rose-ringed Parakeet, Black-chinned Babbler *Stachyris pyrrhops*, Indian Peafowl *Pavo cristatus*, Blue-tailed Bee-eater *Merops philippinus*, and Chestnut-shouldered Petronia *Gymnoris xanthocollis* were strongly associated with mixed deciduous forest during summer, while Red Junglefowl, Oriental White-eye *Zosterops palpebrosus*, and Indian Grey Hornbill were strongly associated during the winter season. Baya Weaver had the highest Indicator value (91.4%) during

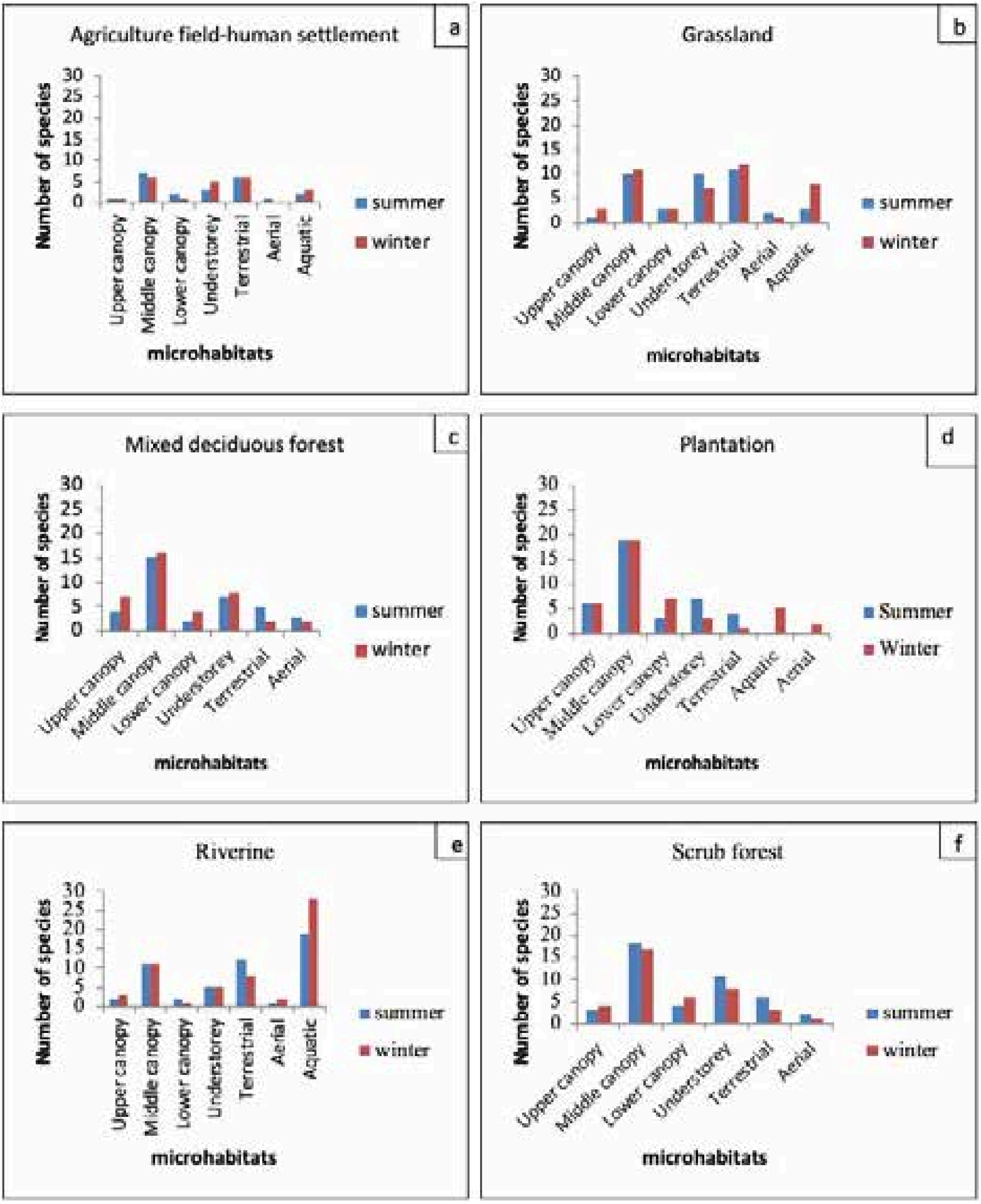

Figure 5. Vertical strata in every habitat: a—Agriculture fields-human settlements | b—Grassland | c—Mixed deciduous forest | d—Plantation | e—Riverine habitat | f—Scrub Forest.

summer and Red Junglefowl had the highest Indicator value of 70% during winter.

Riverine habitat: River Lapwing, River Tern, Little Egret *Egretta garzetta*, and Little Cormorant *Microcarbo niger* had a strong association during summer and birds, namely Little Cormorant, White Wagtail *Motacilla alba*,

Table 2a. Indicator bird species in different habitats in summer season.

	A	B	Indicator value	P value	Significance codes
Agriculture and settlement					
Rock Pigeon	1	0.3333	0.577	0.0002	***
House Sparrow	1	0.2667	0.516	0.0006	***
Pond Heron	0.9091	0.2	0.426	0.0075	**
Grassland					
Paddyfield Pipit	0.9868	0.9524	0.969	0.0001	***
Common Stonechat	0.9237	0.619	0.756	0.0001	***
Red-wattled Lapwing	0.7163	0.7619	0.739	0.0001	***
Pied Bushchat	0.6593	0.6667	0.663	0.0001	***
Yellow-bellied Prinia	1	0.381	0.617	0.0001	***
Oriental Skylark	0.8972	0.3333	0.547	0.0001	***
Striated Grassbird	1	0.2381	0.488	0.0015	**
Zitting Cisticola	1	0.2381	0.488	0.0015	**
Striated Babbler	1	0.1429	0.378	0.0162	*
Yellow-wattled Lapwing	1	0.1429	0.378	0.0128	*
Grey Bushchat	0.8108	0.1429	0.34	0.0453	*
Mixed deciduous forest					
Baya Weaver	0.8347	1	0.914	0.0001	***
Red Junglefowl	0.6767	0.9333	0.795	0.0001	***
Rose-ringed Parakeet	0.6235	0.9333	0.763	0.0001	***
Black-chinned Babbler	0.6486	0.8	0.72	0.0001	***
Indian Peafowl	0.5469	0.8	0.661	0.0001	***
Blue-tailed Bee-eater	0.8077	0.5333	0.656	0.0001	***
Chestnut-shouldered Petronia	0.6893	0.5333	0.606	0.0001	***
Red-vented Bulbul	0.3347	1	0.578	0.0003	***
Rufous Treepie	0.4802	0.4667	0.473	0.0051	**
Oriental White-eye	0.4158	0.4667	0.44	0.017	*
Grey-breasted Prinia	0.5499	0.3333	0.428	0.0081	**
Jungle Myna	1	0.1333	0.365	0.0447	*
Plantation					
Black-hooded Oriole	0.8928	0.9643	0.928	0.0001	***
Indian Paradise-flycatcher	0.8069	0.6786	0.74	0.0001	***
Oriental Magpie-robin	0.4737	0.8571	0.637	0.0001	***
Indian Pitta	0.4856	0.8214	0.632	0.0001	***
Common Myna	0.6393	0.5357	0.585	0.0006	***
Jungle Babbler	0.4683	0.6071	0.533	0.002	**
Brown-headed Barbet	0.9205	0.2857	0.513	0.0018	**
Black Drongo	0.5058	0.5	0.503	0.002	**
Common Hawk-cuckoo	0.641	0.3571	0.478	0.0032	**
Indian Grey Hornbill	0.5855	0.3571	0.457	0.0059	**
Jungle Owlet	1	0.1786	0.423	0.0068	**
Indian Cuckoo	0.5687	0.25	0.377	0.032	*
Riverine					
River Lapwing	0.942	0.92	0.931	0.0001	***
River Tern	1	0.64	0.8	0.0001	***
Little Egret	1	0.6	0.775	0.0001	***

	A	B	Indicator value	P value	Significance codes
Little Cormorant	1	0.52	0.721	0.0001	***
House Crow	0.5904	0.6	0.595	0.0004	***
Spot-billed Duck	1	0.24	0.49	0.0007	***
Little-ringed Plover	1	0.2	0.447	0.0036	**
Ruddy Shelduck	1	0.2	0.447	0.0024	**
White-browed Wagtail	1	0.2	0.447	0.0048	**
Pied Kingfisher	1	0.16	0.4	0.0121	*
White-bellied Drongo	0.7706	0.2	0.393	0.0156	*
Large-billed Crow	0.622	0.24	0.386	0.0293	*
Grey Heron	1	0.12	0.346	0.0377	*
Gray Wagtail	1	0.12	0.346	0.0432	*
Small Pratincole	1	0.12	0.346	0.0408	*
Scrub forest					
Indian Robin	0.96	0.58	0.75	0.0001	***
Purple Sunbird	0.5079	1.00	0.713	0.0001	***
Spotted Dove	0.4453	1.00	0.667	0.0001	***
Green Bee-eater	0.4531	0.9167	0.645	0.0001	***
Common Tailorbird	0.4693	0.6667	0.559	0.0003	***
Common Iora	0.4966	0.5833	0.538	0.0005	***
Laughing Dove	0.7241	0.25	0.425	0.0059	**

A—Specificity | B—Fidelity
Significant codes: 0 '***' | 0.001 '**' | 0.01 '*' | 0.05 '.' | 0.1 ' ' | 1

Citrine Wagtail *Motacilla citreola*, and Pied Kingfisher have a strong association during the winter season. River Lapwing had the highest indicator value 93.1% during the summer season and Little Cormorant had the highest Indicator value of 77.5% during winter.

Plantation: Black-hooded Oriole, Indian Paradise-Flycatcher *Terpsiphone paradisi*, Oriental Magpie-Robin *Copsychus saularis*, and Indian Pitta *Pitta brachyura* had a strong association with the plantation during summer, while Black-hooded Oriole, Black Bulbul, Rose-ringed Parakeet, Taiga Flycatcher *Ficedula albicilla*, and Spangled Drongo *Dicrurus bracteatus* had a strong association during the winter season. Black-hooded Oriole had a strong association with the plantation, with an indicator value of 92.8% and 81.9% during summer and winter, respectively.

Scrub forest: Indian Robin *Copsychus fulicatus*, Purple Sunbird *Cinnyris asiaticus*, Spotted Dove *Spilopelia chinensis*, and Green Bee-eater *Merops orientalis* were strongly associated with scrub forest during summer, while Lesser Whitethroat *Curruca curruca*, Indian Robin, Plain Prinia *Prinia inornata*, Spotted Dove, and Purple Sunbird were strongly associated during the winter season. Indian Robin had the highest indicator value (75%) during the summer season and Lesser Whitethroat had the highest Indicator value of 83.5% during the winter season.

DISCUSSION

The current study demonstrates that JJCR has a high species richness and diversity of bird species. The JJCR is home to a variety of habitat types that support numerous bird species. Therefore, the significance and importance of the conservation reserve for birdlife conservation is extensive. The favourable environmental conditions may have contributed to the greater species richness and diversity in JJCR. More number of bird species were found in the winter season because of the arrival of many winter visitors.

We provide here a quantitative demonstration of habitat selection in the natural assemblage of bird species using a resource selection function based on proportional use and availability. Using RSF, we found 48 bird species had 100% selection for a particular habitat in summer, and 71 bird species had 100% selection for a particular habitat in winter. There is more RSF in winter because of the presence of many winter visitors. The riverine habitat had the highest RSF, possibly because

Table 2b. Indicator bird species in different habitats in winter season.

	A	B	Indicator value	P value	Significance codes
Agriculture and settlement					
Cattle Egret	0.9023	0.4667	0.649	0.0001	***
House Sparrow	1	0.3333	0.577	0.0001	***
Rock Pigeon	1	0.2	0.447	0.0047	**
Grassland					
Common Stonechat	0.9194	0.8571	0.888	0.0001	***
Red-wattled Lapwing	0.901	0.7619	0.829	0.0001	***
Paddyfield Pipit	0.736	0.9048	0.816	0.0001	***
White-tailed Stonechat	1	0.619	0.787	0.0001	***
Pied Bushchat	0.6696	0.4762	0.565	0.0002	***
Indian Roller	0.5043	0.381	0.438	0.0105	*
Indian Pied Starling	1	0.1905	0.436	0.0035	**
White-throated Kingfisher	0.5263	0.3333	0.419	0.0124	*
Yellow-bellied Prinia	1	0.1429	0.378	0.0142	*
Yellow-wattled Lapwing	1	0.1429	0.378	0.0198	*
Mixed deciduous forest					
Red Junglefowl	0.7368	0.6667	0.701	0.0001	***
Oriental White-eye	0.5021	0.8667	0.66	0.0002	***
Indian Grey Hornbill	0.8438	0.4667	0.627	0.0001	***
Red-whiskered Bulbul	0.4462	0.6667	0.545	0.0009	***
Humes Warbler	0.2558	0.8667	0.471	0.0258	*
Plum-headed Parakeet	0.4866	0.3333	0.403	0.0252	*
Crimson Sunbird	0.507	0.2667	0.368	0.0308	*
Plantation					
Black-hooded Oriole	0.7231	0.9286	0.819	0.0001	***
Black Bulbul	1	0.5357	0.732	0.0001	***
Rose-ringed Parakeet	0.6016	0.7143	0.656	0.0002	***
Taiga Flycatcher	1	0.4286	0.655	0.0001	***
Spangled Drongo	0.6497	0.6429	0.646	0.0001	***
Common Myna	0.7851	0.3214	0.502	0.0017	**
Grey-headed Canary Flycatcher	1	0.2143	0.463	0.0027	**
Jungle Owlet	0.8108	0.25	0.45	0.0043	**
White-throated Fantail	0.4334	0.4643	0.449	0.01	**
Large-billed Crow	0.5384	0.3571	0.438	0.0224	*
Jungle Babbler	0.4063	0.4643	0.434	0.0304	*
House Crow	0.5744	0.3214	0.43	0.0251	*
Riverine					
Little Cormorant	1	0.6	0.775	0.0001	***
White Wagtail	0.9522	0.6	0.756	0.0001	***
Citrine Wagtail	0.7489	0.68	0.714	0.0001	***
Pied Kingfisher	0.9216	0.52	0.692	0.0001	***
Ruddy Shelduck	0.9795	0.32	0.56	0.0009	***
River Lapwing	0.592	0.52	0.555	0.0016	**

	A	B	Indicator value	P value	Significance codes
Gray Wagtail	0.466	0.48	0.473	0.0066	**
Eurasian Collared-Dove	1	0.2	0.447	0.0045	**
Temminck Stint	1	0.2	0.447	0.0047	**
White-browed Wagtail	1	0.2	0.447	0.0031	**
Brahminy Starling	1	0.16	0.4	0.0162	*
Goosander	1	0.16	0.4	0.0143	*
Little Egret	1	0.16	0.4	0.0149	*
Little-ringed Plover	1	0.16	0.4	0.0128	*
Red-crested Pochard	1	0.16	0.4	0.0139	*
River Tern	0.9023	0.16	0.38	0.021	*
Scrub forest					
Lesser Whitethroat	0.6966	1	0.835	0.0001	***
Indian Robin	1	0.5833	0.764	0.0001	***
Plain Prinia	0.7343	0.75	0.742	0.0001	***
Spotted Dove	0.5063	0.8333	0.65	0.0001	***
Purple Sunbird	0.6187	0.6667	0.642	0.0001	***
Small Minivet	1	0.3333	0.577	0.0001	***
Ashy Prinia	0.7937	0.4167	0.575	0.0001	***
Red-vented Bulbul	0.5178	0.5833	0.55	0.0263	*
Greenish Warbler	0.463	0.5833	0.52	0.0021	**
Yellow-footed Green-Pigeon	1	0.25	0.5	0.0009	***
Indian Silverbill	0.8596	0.25	0.464	0.0022	**
Oriental Magpie-Robin	0.3736	0.5	0.432	0.0193	*
Indian Peafowl	0.5571	0.3333	0.431	0.0103	*
Red-breasted Flycatcher	0.5294	0.3333	0.42	0.0103	*
Lesser Goldenback	0.5568	0.25	0.373	0.0438	*
Greater Coucal	0.8333	0.1667	0.373	0.0186	*

A—Specificity | B—Fidelity
Significant codes: 0 '***' | 0.001 '**' | 0.01 '*' | 0.05 '.' | 0.1 '' | 1.

of the presence of many microhabitats attracting winter migrant waterbirds. Within the bird community, some are generalists, and some are specialists in specific habitats. A larger number of habitat specialist bird species could be because of habitat heterogeneity (Surasinghe & Alwis 2010), while generalist birds were more abundant as they can adapt to a variety of environmental conditions and utilize a variety of resources. The dominance of specialists in species richness suggests that the study area supports diverse and structurally complex habitats capable of meeting specific ecological requirements. Specialist species are often sensitive to habitat alteration; therefore, their higher proportion indicates relatively good habitat quality and ecological integrity.

However, the greater abundance of generalists reflects their ecological flexibility and competitive advantage in heterogeneous or moderately disturbed landscapes. The riverine habitat emerged as a critical refuge for specialist species, likely due to the availability of diverse microhabitats and consistent water resources. A low number of human commensals indicates that avian community composition is largely influenced by natural habitat characteristics, including vegetation structure, canopy stratification, and availability of natural food resources.

The JJCR is rich in bird species, and vertical stratification is possibly one of the key factors for promoting diversity, and the underlying concept has also been stated in other studies on stratification by Bernard (2001); Molleman et al. (2006), and Oliveira & Scheffers (2019). Vertical stratification has been associated with major shifts in biotic communities, emphasizing the great variety of niches and high species co-existence possible in tropical forests at small scales (Brown 1981; Scheffers et al. 2017; Mottl et al. 2020). It is also important to determine the most important strata that are used by the forest bird community (Peh et al. 2006). The middle canopy had the highest proportion of bird species in JJCR. This is also supported by other studies (Jayson & Mathew 2003; Dinanti et al. 2018) showing similar results in Western Ghats, India and West Java, Indonesia. Upper canopy had the lowest number of bird species as compared to other vertical strata, which could be due to unfavourable conditions, i.e. physical (rain, wind, heat, openness) and biological factors (predators), and is energetically adverse for behaviours like feeding, breeding, or roosting (Turton & Siegenthaler 2004). There was seasonal variation in birds of different vertical strata, possibly because of the arrival of many summer and winter visitors in their respective seasons.

The indicator bird species also represented birds belonging to various strata of the forests, i.e., upper canopy, middle canopy, lower canopy, understory, terrestrial and aquatic. The bird species, namely Paddyfield Pipit, Red-wattled Lapwing, Common Stonechat, White-tailed Stonechat, and Yellow-bellied Prinia, showed strong association with the grassland habitat as indicator species. Paddyfield Pipit, Red-wattled Lapwing, Common Stonechat, and Yellow-bellied Prinia (Manakadan 2014; Madge et al. 2020) are commonly found in grasslands, and White-tailed Stonechat is an obligate grassland bird (Roberts 1992; Baral 2001, 2004). They can be monitored to understand the effect of management in grasslands. Subtropical grasslands in the Indian subcontinent are of international significance for biodiversity and are regarded as the most threatened habitat in the Indian subcontinent, and many grassland birds are also threatened (Grimmett et al. 1998). Lesser White Throat, Indian Robin, and Purple Sunbird were identified as indicator species of scrub forest in JJCR. Lesser White throat (Aymí & Gargallo 2021), Indian Robin (Collar & Bonan 2020), and Purple Sunbird (Cheke & Mann 2020) are usually found in scrub habitats and thus can be monitored easily. Black-hooded Oriole, Black Bulbul, and Indian Paradise-Flycatcher were obtained as indicator species in plantations in JJCR. Black-hooded Oriole (Walther & Jones 2020) and Indian Paradise-Flycatcher (Moeliker et al. 2020) are found in plantations and can be used as monitor species in this habitat. House Sparrow and Rock Pigeon were reported as the indicator species of agriculture and human settlements in JJCR. House Sparrow and Rock Pigeon are human commensals and thus can be easily seen in and near human settlements (Leveau & Leveau 2016). The lack of forest birds in agricultural fields and human settlements could be attributed to pesticide usage, chemical fertilizers, incompatible agricultural practices, and semi-natural habitats. Rising levels of pesticides in agricultural fields have negative impacts on invertebrate populations, which in turn leads to the decline of the farmland bird population (Boatman et al. 2004; Hallmann et al. 2014; Stanton et al. 2018). Unsustainable agricultural practices pose threats to many forest-dependent birds (Naidoo 2004). Some of the factors responsible for degradation in agricultural fields include changes in cropping species and patterns, and the removal of semi-natural habitats (Sundar & Kittur 2013; Redhead et al. 2018). Forest specialist birds are sensitive to monoculture agricultural lands, and changes in vegetation characteristics can impact bird assemblages (Schulze & Riedl 2008; Maas et al. 2009). The intensification and expansion of agriculture threaten biodiversity (Laurance et al. 2013). There has been a long history of disturbance in the mixed deciduous forests of the Shiwalik region. Forests in these regions are under pressure from an influx of people, expanding human habitation, lopping, and grazing (Gautam et al. 2016). Baya Weaver, Red Junglefowl, and Indian Grey Hornbill can be used as indicator species for monitoring the mixed deciduous forest. Baya Weavers were observed engaging in nesting activities within these forests, using *Zizyphus mauritiana* trees for their nests. Moreover, the high indicator value of Red Junglefowl (Palei et al. 2016) and Indian Grey Hornbill (Balasubramanian et al. 2005) within deciduous forests is obvious, as, they are typically found within this habitat. Among the indicator bird species from riverine habitats, River Lapwing, and River Tern are species of conservation concern. River Lapwing is a near threatened, and River Tern is vulnerable.

Our results provide important baseline information for selecting which species to monitor as indicator species for different habitats. The present study also states the importance of vertical stratification as the ability of species to respond to canopy characteristics may, therefore, be useful in predicting the effects of forest management on bird communities (Hinsley et al. 2009). Such studies are useful in the broader context of increasing anthropogenic pressure on tropical ecosystems and call for action to prevent biodiversity loss (Barlow et al. 2018). Monitoring the spatial and temporal changes of biodiversity is one of the prerequisites for effective integration of biodiversity conservation in forest management planning. This study demonstrates a significant link between the bird species and the habitat. The indicator bird species, including the threatened and habitat specialists, have definite preferences for long-term monitoring of a particular habitat. All the habitats, including plantations, have their own importance for birds. Understanding the link between indicator species and habitat is important for habitat-specific management. Potential indicator species reflect the on-site ecological conditions. The analysis is based on data from six habitats representing different vegetation compositions, so the determined indicator species can be used as bio-indicators for future monitoring of the management of each habitat.

CONCLUSION

Regular monitoring of bird populations, along with awareness programs focused on bird and habitat conservation, is essential. Despite its small size, the study area supports a remarkably rich and diverse avian community. Ongoing habitat management practices should integrate measures for the conservation of key bird species. The identified indicator species provide a valuable baseline for future monitoring efforts. Understanding the population trends and dynamics of these species can serve as an effective tool for assessing habitat and forest conditions and for refining management and conservation strategies. Caveat of the study—Though there is a possibility of non-detection of certain bird species in a particular habitat, resulting in 100% selection of certain habitats, most of the birds show multiple habitat selection through RSF analysis in the present study.

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Appendix Table 1. Bird species list at Jhilmil Jheel Conservation Reserve.

	Bird species	Scientific name	Family
1	Black Kite	*Milvus migrans*	Accipitridae
2	Changeable Hawk-Eagle	*Nisaetus cirrhatus*	Accipitridae
3	Cinereous Vulture	*Aegypius monachus*	Accipitridae
4	Crested Serpent-Eagle	*Spilornis cheela*	Accipitridae
5	Egyptian Vulture	*Neophron percnopterus*	Accipitridae
6	Eurasian Sparrowhawk	*Accipiter nisus*	Accipitridae
7	Himalayan Griffon	*Gyps himalayensis*	Accipitridae
8	Oriental Honey-buzzard	*Pernis ptilorhynchus*	Accipitridae
9	Shikra	*Tachyspiza badia*	Accipitridae
10	Short-toed Snake-Eagle	*Circaetus gallicus*	Accipitridae
11	Slender-billed Vulture	*Gyps tenuirostris*	Accipitridae
12	White-eyed Buzzard	*Butastur teesa*	Accipitridae
13	White-rumped Vulture	*Gyps bengalensis*	Accipitridae
14	Blyth's Reed Warbler	*Acrocephalus dumetorum*	Acrocephalidae
15	Common Iora	*Aegithina tiphia*	Aegithinidae
16	Ashy-crowned Sparrow-lark	*Eremopterix griseus*	Alaudidae
17	Crested Lark	*Galerida cristata*	Alaudidae
18	Oriental Skylark	*Alauda gulgula*	Alaudidae
19	Common Kingfisher	*Alcedo atthis*	Alcedinidae
20	Pied Kingfisher	*Ceryle rudis*	Alcedinidae
21	Stork-billed Kingfisher	*Pelargopsis capensis*	Alcedinidae
22	White-throated Kingfisher	*Halcyon smyrnensis*	Alcedinidae
23	Bar-headed Goose	*Anser indicus*	Anatidae
24	Gadwall	*Mareca strepera*	Anatidae
25	Goosander	*Mergus Merganser*	Anatidae
26	Indian Spot-billed Duck	*Anas poecilorhyncha*	Anatidae
27	Lesser Whistling-duck	*Dendrocygna javanica*	Anatidae
28	Northern Pintail	*Anas acuta*	Anatidae
29	Red-crested Pochard	*Netta rufina*	Anatidae
30	Ruddy Shelduck	*Tadorna ferruginea*	Anatidae
31	Cattle Egret	*Ardea coromanda*	Ardeidae
32	Great Egret	*Ardea alba*	Ardeidae
33	Grey Heron	*Ardea cinerea*	Ardeidae
34	Indian Pond-Heron	*Ardeola grayii*	Ardeidae
35	Intermediate Egret	*Ardea intermedia*	Ardeidae
36	Little Egret	*Egretta garzetta*	Ardeidae
37	Indian Grey Hornbill	*Ocyceros birostris*	Bucerotidae
38	Oriental Pied-Hornbill	*Anthracoceros albirostris*	Bucerotidae
39	Small Minivet	*Pericrocotus cinnamomeus*	Campehagidae
40	Little Ringed Plover	*Charadrius dubius*	Charadriidae
41	Red-wattled Lapwing	*Vanellus indicus*	Charadriidae

	Bird species	Scientific name	Family
42	River Lapwing	*Vanellus duvaucelii*	Charadriidae
43	Yellow-wattled Lapwing	*Vanellus malabaricus*	Charadriidae
44	Golden-fronted Leafbird	*Chloropsis aurifrons*	Chloropseidae
45	Woolly-necked Stork	*Ciconia episcopus*	Ciconiidae
46	Ashy Prinia	*Prinia socialis*	Cisticolidae
47	Common Tailorbird	*Orthotomus sutorius*	Cisticolidae
48	Grey-breasted Prinia	*Prinia hodgsonii*	Cisticolidae
49	Plain Prinia	*Prinia inornata*	Cisticolidae
50	Yellow-bellied Prinia	*Prinia flaviventris*	Cisticolidae
51	Zitting Cisticola	*Cisticola juncidis*	Cisticolidae
52	Eurasian Collared-dove	*Streptopelia decaocto*	Columbidae
53	Laughing Dove	*Spilopelia senegalensis*	Columbidae
54	Rock Pigeon	*Columba livia*	Columbidae
55	Spotted Dove	*Spilopelia chinensis*	Columbidae
56	Yellow-footed Green-pigeon	*Treron phoenicopterus*	Columbidae
57	Indian Roller	*Coracias benghalensis*	Coraciidae
58	House Crow	*Corvus splendens*	Corvidae
59	Large-billed Crow	*Corvus macrorhynchos*	Corvidae
60	Rufous Treepie	*Dendrocitta vagabunda*	Corvidae
61	Asian Koel	*Eudynamys scolopaceus*	Cuculidae
62	Common Cuckoo	*Cuculus canorus*	Cuculidae
63	Common Hawk-cuckoo	*Hierococcyx varius*	Cuculidae
64	Gray-bellied Cuckoo	*Cacomantis passerinus*	Cuculidae
65	Greater Coucal	*Centropus sinensis*	Cuculidae
66	Indian Cuckoo	*Cuculus micropterus*	Cuculidae
67	Pied Cuckoo	*Clamator jacobinus*	Cuculidae
68	Sirkeer Malkoha	*Taccocua leschenaultii*	Cuculidae
69	Square-tailed Drongo-cuckoo	*Surniculus lugubris*	Cuculidae
70	Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	Dicaeidae
71	Thick-billed Flowerpecker	*Dicaeum agile*	Dicaeidae
72	Ashy Drongo	*Dicrurus leucophaeus*	Dicruridae
73	Black Drongo	*Dicrurus macrocercus*	Dicruridae
74	Bronzed Drongo	*Dicrurus aeneus*	Dicruridae
75	Spangled Drongo	*Dicrurus hottentottus*	Dicruridae
76	White-bellied Drongo	*Dicrurus caerulescens*	Dicruridae
77	Indian Silverbill	*Euodice malabarica*	Estrildidae
78	Red Avadavat	*Amandava amandava*	Estrildidae
79	Yellow-breasted Greenfinch	*Chloris spinoides*	Fringillidae

	Bird species	Scientific name	Family
80	Small Pratincole	*Glareola lactea*	Glareolidae
81	Sarus Crane	*Antigone antigone*	Gruidae
82	Barn Swallow	*Hirundo rustica*	Hirundinidae
83	Plain Martin	*Riparia chinensis*	Hirundinidae
84	Bay-backed Shrike	*Lanius vittatus*	Laniidae
85	Long-tailed Shrike	*Lanius schach*	Laniidae
86	Black-bellied Tern	*Sterna acuticauda*	Laridae
87	Little Tern	*Sternula albifrons*	Laridae
88	Pallas's Gull	*Ichthyaetus ichthyaetus*	Laridae
89	River Tern	*Sterna aurantia*	Laridae
90	Jungle Babbler	*Argya striata*	Leiothrichidae
91	Striated Babbler	*Argya earlei*	Leiothrichidae
92	Bristled Grassbird	*Schoenicola striatus*	Locustellidae
93	Striated Grassbird	*Cincloramphus palustris*	Locustellidae
94	Brown-headed Barbet	*Psilopogon zeylanicus*	Megalaimidae
95	Coppersmith Barbet	*Psilopogon haemacephalus*	Megalaimidae
96	Great Barbet	*Psilopogon virens*	Megalaimidae
97	Asian Green Bee-eater	*Merops orientalis*	Meropidae
98	Blue-tailed Bee-eater	*Merops philippinus*	Meropidae
99	Black-naped Monarch	*Hypothymis azurea*	Monarchidae
100	Indian Paradise-flycatcher	*Terpsiphone paradisi*	Monarchidae
101	Citrine Wagtail	*Motacilla citreola*	Motacillidae
102	Grey Wagtail	*Motacilla cinerea*	Motacillidae
103	Paddyfield Pipit	*Anthus rufulus*	Motacillidae
104	White Wagtail	*Motacilla alba*	Motacillidae
105	White-browed Wagtail	*Motacilla maderaspatensis*	Motacillidae
106	Asian Brown Flycatcher	*Muscicapa dauurica*	Muscicapidae
107	Brown Rock Chat	*Oenanthe fusca*	Muscicapidae
108	Chestnut-bellied Rock-thrush	*Monticola rufiventris*	Muscicapidae
109	Common Stonechat	*Saxicola maurus*	Muscicapidae
110	Grey Bushchat	*Saxicola ferreus*	Muscicapidae
111	Indian Robin	*Copsychus fulicatus*	Muscicapidae
112	Oriental Magpie-robin	*Copsychus saularis*	Muscicapidae
113	Pied Bushchat	*Saxicola caprata*	Muscicapidae
114	Red-breasted Flycatcher	*Ficedula parva*	Muscicapidae
115	Rufous-gorgeted Flycatcher	*Ficedula strophiata*	Muscicapidae
116	Small Niltava	*Niltava macgrigoriae*	Muscicapidae
117	Taiga Flycatcher	*Ficedula albicilla*	Muscicapidae
118	Tickell's Blue Flycatcher	*Cyornis tickelliae*	Muscicapidae
119	Verditer Flycatcher	*Eumyias thalassinus*	Muscicapidae
120	White-tailed Stonechat	*Saxicola leucurus*	Muscicapidae
121	Crimson Sunbird	*Aethopyga siparaja*	Nectariniidae

	Bird species	Scientific name	Family
122	Purple Sunbird	*Cinnyris asiaticus*	Nectariniidae
123	Black-hooded Oriole	*Oriolus xanthornus*	Oriolidae
124	Maroon Oriole	*Oriolus traillii*	Oriolidae
125	Osprey	*Pandion haliaetus*	Pandionidae
126	Great Tit	*Parus major*	Paridae
127	Chestnut-shouldered Petronia	*Gymnoris xanthocollis*	Passeridae
128	House Sparrow	*Passer domesticus*	Passeridae
129	Great Cormorant	*Phalacrocorax carbo*	Phalacrocoracidae
130	Little Cormorant	*Microcarbo niger*	Phalacrocoracidae
131	Black Francolin	*Francolinus francolinus*	Phasianidae
132	Grey Francolin	*Francolinus pondicerianus*	Phasianidae
133	Indian Peafowl	*Pavo cristatus*	Phasianidae
134	Red Junglefowl	*Gallus gallus*	Phasianidae
135	Greenish Warbler	*Phylloscopus trochiloides*	Phylloscopidae
136	Grey-hooded Warbler	*Phylloscopus xanthoschistos*	Phylloscopidae
137	Hume's Warbler	*Phylloscopus humei*	Phylloscopidae
138	Lemon-rumped Warbler	*Phylloscopus chloronotus*	Phylloscopidae
139	Lesser Goldenbacked Woodpecker	*Dinopium benghalense*	Picidae
140	Streak-throated Woodpecker	*Picus xanthopygaeus*	Picidae
141	Indian Pitta	*Pitta brachyura*	Pittidae
142	Baya Weaver	*Ploceus philippinus*	Ploceidae
143	Black-breasted Weaver	*Ploceus benghalensis*	Ploceidae
144	Plum-headed Parakeet	*Psittacula cyanocephala*	Psittaculidae
145	Rose-ringed Parakeet	*Psittacula krameri*	Psittaculidae

	Bird species	Scientific name	Family
146	Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae
147	Himalayan Bulbul	*Pycnonotus leucogenys*	Pycnonotidae
148	Red-vented Bulbul	*Pycnonotus cafer*	Pycnonotidae
149	Red-whiskered Bulbul	*Pycnonotus jocosus*	Pycnonotidae
150	White-throated Fantail	*Rhipidura albicollis*	Rhipiduridae
151	Common Greenshank	*Tringa nebularia*	Scolopacidae
152	Common Sandpiper	*Actitis hypoleucos*	Scolopacidae
153	Little Stint	*Calidris minuta*	Scolopacidae
154	Temminck's Stint	*Calidris temminckii*	Scolopacidae
155	Chestnut-bellied Nuthatch	*Sitta cinnamoventris*	Sittidae
156	Velvet-fronted Nuthatch	*Sitta frontalis*	Sittidae
157	Grey-headed Canary-Flycatcher	*Culicicapa ceylonensis*	Stenostiridae
158	Jungle Owlet	*Glaucidium radiatum*	Strigidae
159	Bank Myna	*Acridotheres ginginianus*	Sturnidae
160	Brahminy Starling	*Sturnia pagodarum*	Sturnidae
161	Common Myna	*Acridotheres tristis*	Sturnidae
162	Indian Pied Starling	*Gracupica contra*	Sturnidae
163	Jungle Myna	*Acridotheres fuscus*	Sturnidae
164	Lesser Whitethroat	*Curruca curruca*	Sylviidae
165	Red-naped Ibis	*Pseudibis papillosa*	Threskiornithidae
166	Black-chinned Babbler	*Cyanoderma pyrrhops*	Timaliidae
167	Rusty-cheeked Scimitar-babbler	*Erythrogenys erythrogenys*	Timaliidae
168	Tawny-bellied Babbler	*Dumetia hyperythra*	Timaliidae
169	Tickell's Thrush	*Turdus unicolor*	Turdidae
170	Indian White-eye	*Zosterops palpebrosus*	Zosteropidae

Appendix Table 2. Details of point counts in every habitat at Jhilmil Jheel Conservation Reserve.

Habitat	Area (km²)	No. of point count stations
Plantation	14.59	28
Riverine	6.95	25
Grassland	6.23	21
Mixed forest	5.06	15
Agriculture fields-human settlement	2.55	15
Scrub forest	2.46	12

Appendix Table 3. Details of the efforts in every habitat at Jhilmil Jheel Conservation Reserve.

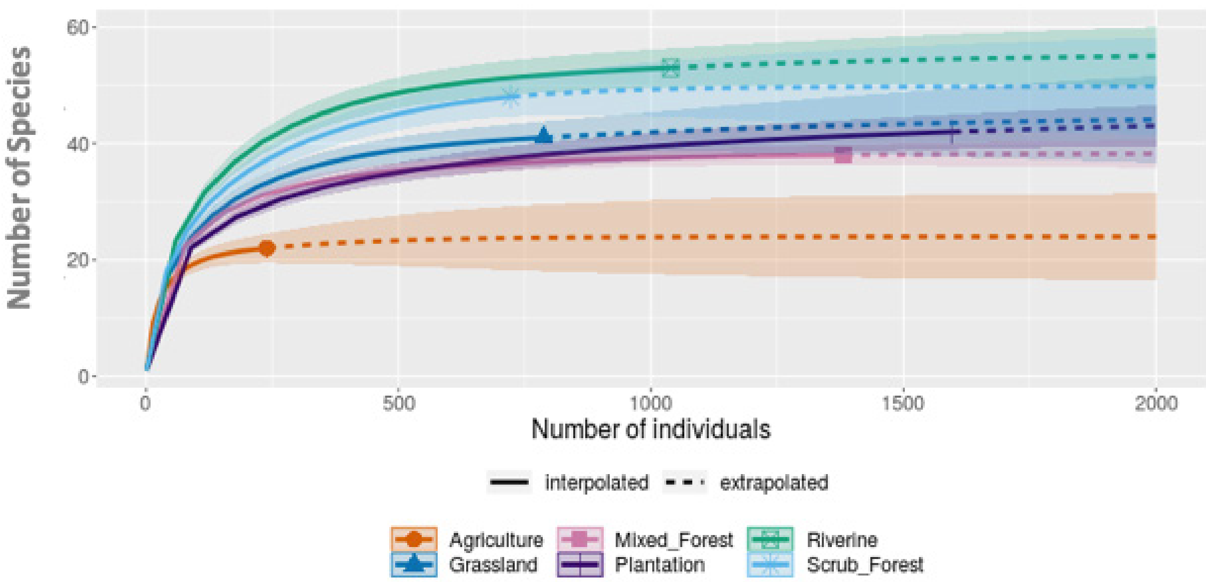
Habitat	No. of Point count	Man-Minutes	Summer (10 replications)	Winter (10 replications)
Plantation	28	280	2800	2800
Mixed deciduous forest	15	150	1500	1500
Scrub forest	12	120	1200	1200
Riverine	25	250	2500	2500
Grassland	21	210	2100	2100
Agriculture field	15	150	1500	1500

Appendix Table 4. Diversity metrics during summer and winter season at Jhilmil Jheel Conservation Reserve.

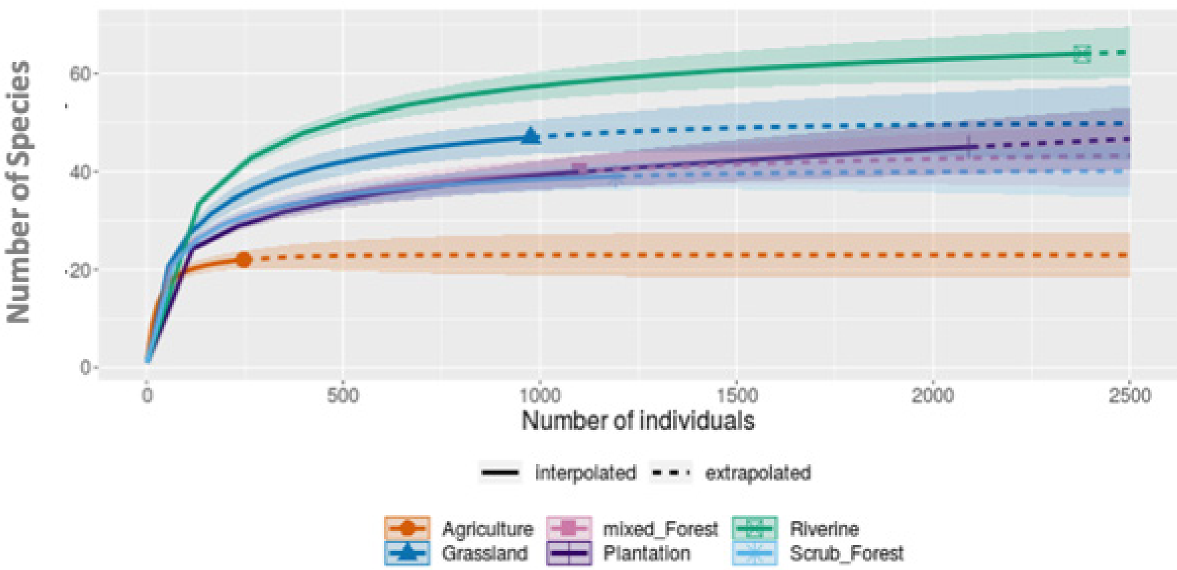
Season	Diversity Metrics	Value	Lower limit	Upper limit
Summer	Shannon_H	3.81	3.78	3.84
	Evenness_e^H/S	0.41	0.40	0.42
Winter	Shannon_H	3.99	3.96	4.02
	Evenness_e^H/S	0.39	0.38	0.40

Appendix Table 5. PERMANOVA of vertical stratification at Jhilmil Jheel Conservation Reserve.

PERMANOVA (summer)		PERMANOVA (winter)
Permutation N:	9999	9999
Total sum of squares:	23.77	31.37
Within-group sum of squares:	10.25	17.22
F:	29.04	18.26
p (same):	0.0001	0.0001



Appendix Figure 1a. Rarefaction curve for summer season.



Appendix Figure 1b. Rarefaction curve for winter season.

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ARTICLE

Herpetofauna of the Chitwan-Annapurna Landscape, Nepal: a comprehensive species checklist including occurrence in protected areas, with suggested conservation recommendations

Santosh Bhattarai [1], Bishal Prasad Neupane [2], Bivek Gautam [3], Prabin Shrestha [4], Ashley R. Olson [5], Fiona Hogan [6] & Wendy Wright [7]

[1,5,6,7] Future Regions Research Centre, Federation University Australia, Gippsland Campus, Churchill 3842, Victoria, Australia.
[1,2,4] Nepal Conservation and Research Center, Ratnanagar-06, Chitwan 44204, Nepal.
[3] Biodiversity Research and Conservation Society, Tarakeshwar-11, Kathmandu, Nepal.
[1] santosh.bhattarai@hotmail.com (corresponding author), [2] bishalneupane667@gmail.com, [3] bivek.gautam2@gmail.com,
[4] beenpra1987@gmail.com, [5] a.olson@federation.edu.au, [6] fiona.hogan@federation.edu.au, [7] wendy.wright@federation.edu.au

Abstract: We present an up-to-date species list of all known amphibians and reptiles of the Chitwan-Annapurna Landscape (CHAL), comprising a total of 140 species that includes 35 amphibian and 105 reptile species, representing 63% of amphibians and 71% of reptiles known from Nepal. Of the six protected areas in the CHAL, Chitwan National Park has the highest species richness of herpetofauna (n=90), followed by Annapurna Conservation Area (n = 73 species), Parsa National Park (n = 58), Shivapuri-Nagarjun National Park (n = 53), Langtang National Park (n = 47) and Manaslu Conservation Area (n = 45). Data from the IUCN Red List shows that the herpetofauna of the CHAL includes four Critically Endangered reptile species, six Endangered species (five reptiles and one amphibian) and eight Vulnerable species (five reptiles and three amphibians). We recommend more inclusive conservation measures to ensure the long-term conservation of the full range of biodiversity in the Chitwan-Annapurna Landscape.

Keywords: Amphibians, biodiversity, connectivity, distribution pattern, endemism, reptiles, species richness, type locality Himalaya.

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Author contribution: SB, BPN, BG and PS conducted field surveys. SB and PS acquired study permit. SB wrote manuscript, revised and submitted. AO, FH, WW reviewed the manuscript.

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INTRODUCTION

Anthropogenic activities have accelerated the loss of global biodiversity, and there are growing concerns that we are experiencing a sixth mass extinction event (Pimm et al. 2014; Chen et al. 2025). Globally, over one million species are at risk of extinction (Tollefson 2019). The Living Planet Report documented that population sizes of wild vertebrates have decreased, on average, by 73% between 1970 and 2020 (WWF 2024).

Amphibians and reptiles are among the vertebrate groups most vulnerable to ongoing environmental change (Cordier et al. 2021). As ectotherms, their physiology, distribution, and survival are linked to climatic conditions, rendering them particularly sensitive to habitat degradation, land-use change, and climate warming (Frishkoff et al. 2015). Globally, 21% of reptile species are threatened with extinction (Cox et al. 2022), while amphibians face even higher risks, with more than 41% of species currently threatened (Luedtke et al. 2023). Despite this vulnerability, herpetofauna remain consistently underrepresented in conservation planning and policy, particularly outside formal protected areas (PAs).

Vertebrate populations in human-dominated landscapes, particularly those outside of PAs, are declining at rates that are, on average, five times higher than inside PAs (Nowakowski et al. 2023). The consequences of losing species and their cascading effects can lead to regional biodiversity collapses (Young et al. 2016; Carné & Vieties 2024). PAs are essential for halting biodiversity loss, but their effectiveness depends on strategic location, management quality, and the specific anthropogenic and environmental pressures they face (Geldmann et al. 2019). In Nepal, conservation outside of the PAs is often not a priority (Gautam et al. 2022; Bhattarai et al. 2025b).

PAs have been established to preserve species, ecosystems, and genetic diversity (MFSC 1988; Bhattarai et al. 2025c). However, they are often not complete ecological units, and in response to the growing challenges of long-term biodiversity conservation (for example, identifying and protecting future climate refugia, and understanding species' range shifts), various governments have established entire conservation landscapes. In Nepal, five such priority landscapes exist. One is the Chitwan-Annapurna Landscape (CHAL), which connects habitats and PAs across the diverse elevational gradients of central Nepal. The CHAL extends from the lowlands of the Terai to the trans-Himalayan region and includes six PAs (MFSC 2015). Since its establishment, the governance and management of the CHAL have been guided by 10-year plans (MFSC 2015). The current 2016–2025 Strategy and Action Plan is now due for renewal, and it has been observed that its focus on the conservation of selected large mammal species such as Greater One-horned Rhinoceros and Bengal Tiger, in the lowlands, and Snow Leopard, in the High Himalayas, is at the expense of the protection of lesser-known species, including amphibians and reptiles.

Geographically, the CHAL is located in central Nepal and includes seven Global 200 priority ecoregions, recognized for high biodiversity (Olson et al. 2001; Olson & Dinerstein 2002). The geographical position of the CHAL, its environmental and biogeographic heterogeneity, supports floral and faunal assemblages comprising elements from both the eastern and western Himalayas (KMTNC 1998; NTNC 2020; Bhattarai et al. 2025b).

Amphibians and reptiles are not typically considered among the priority species for conservation and management (Bhattarai et al. 2017, 2020; Rawat et al. 2020). Exceptions include Gharial *Gavialis gangeticus*, Burmese python *Python bivittatus*, and Golden Monitor Lizard *Varanus flavescens*; these species are listed in Schedule-I as protected priority species in Nepal's National Parks and Wildlife Conservation Act, 1973 (2029 BS).

Knowledge of the herpetofauna of the CHAL remains limited, despite recent field surveys that have resulted in the description of five previously unknown species (Bhattarai et al. 2025a,b) and indications that additional undescribed taxa are likely present. Undescribed species are inherently vulnerable, as they lack formal recognition and are therefore excluded from conservation assessments and management frameworks (Lees & Pimm 2015; Moura & Jetz 2021; Liu et al. 2022; Carné & Vieties 2024; Li et al. 2025). Consequently, many amphibian and reptile species may face extinction before they are formally documented. Strengthening the knowledge base is therefore essential for informing future conservation planning, particularly as Nepal revises its landscape-level conservation strategies under accelerating climate and land-use change. This study addresses a knowledge gap by providing an updated checklist of amphibians and reptiles of the CHAL, including information on species occurrence within PAs and identification of conservation priorities.

METHODS

Study Area

The Chitwan-Annapurna Landscape (CHAL) was conceived in 1999 to maintain north-south ecological connectivity through the range of eco-physiographic zones existing across Nepal's significant elevational range. The CHAL covers 32,090 km^2, almost 22% of Nepal's land area, across 19 districts (Arghakhanchi, Gulmi, Palpa, Baglung, Parbat, Myagdi, Mustang, Syangja, Kaski, Tanahun, Lamjung, Gorkha, Manang, Rasuwa, Nuwakot, Dhading, Nawalparasi, Chitwan, and Makwanpur). It encloses the entire Gandaki river basin and its tributaries namely: Kali Gandaki, Seti, Marsyangdi, Daraundi, Budhi Gandaki, Trishuli, and Narayani/East Rapti. Altitudinally, the CHAL extends from the tropical lowland Terai (200m) through the alpine high mountains to the cold and dry trans-Himalayan region (above 4,000 m) (MFSC 2015). The highest peaks within the CHAL exceed 8,000 m. The CHAL includes six protected areas including four national parks (Langtang, Chitwan, Shivpuri-Nagarjun, and Parsa), and two conservation areas, namely Annapurna and Manaslu (Figure 1).

Compilation of Species List and Threat Status

We compiled a list of all amphibian and reptile species known to be present in the CHAL (Table 1) based on direct field observations and published records (including those of recently described species (Bhattarai et al. 2025a,b).

Direct observations were made during visual encounter surveys (Heyer et al. 1994) at 12 survey locations positioned along elevational and habitat gradients within the CHAL. These survey locations were established by the Government of Nepal and other conservation agencies in 2016 to study the impact of climate change on local fauna and flora across the landscape. Given the complex terrain, transit between the 12 survey locations was often by circuitous routes; and direct observations of herpetofauna observed as we moved through the diverse habitats within the CHAL were also documented (Image 1).

All individuals recorded as direct observations were identified to species level based on morphological

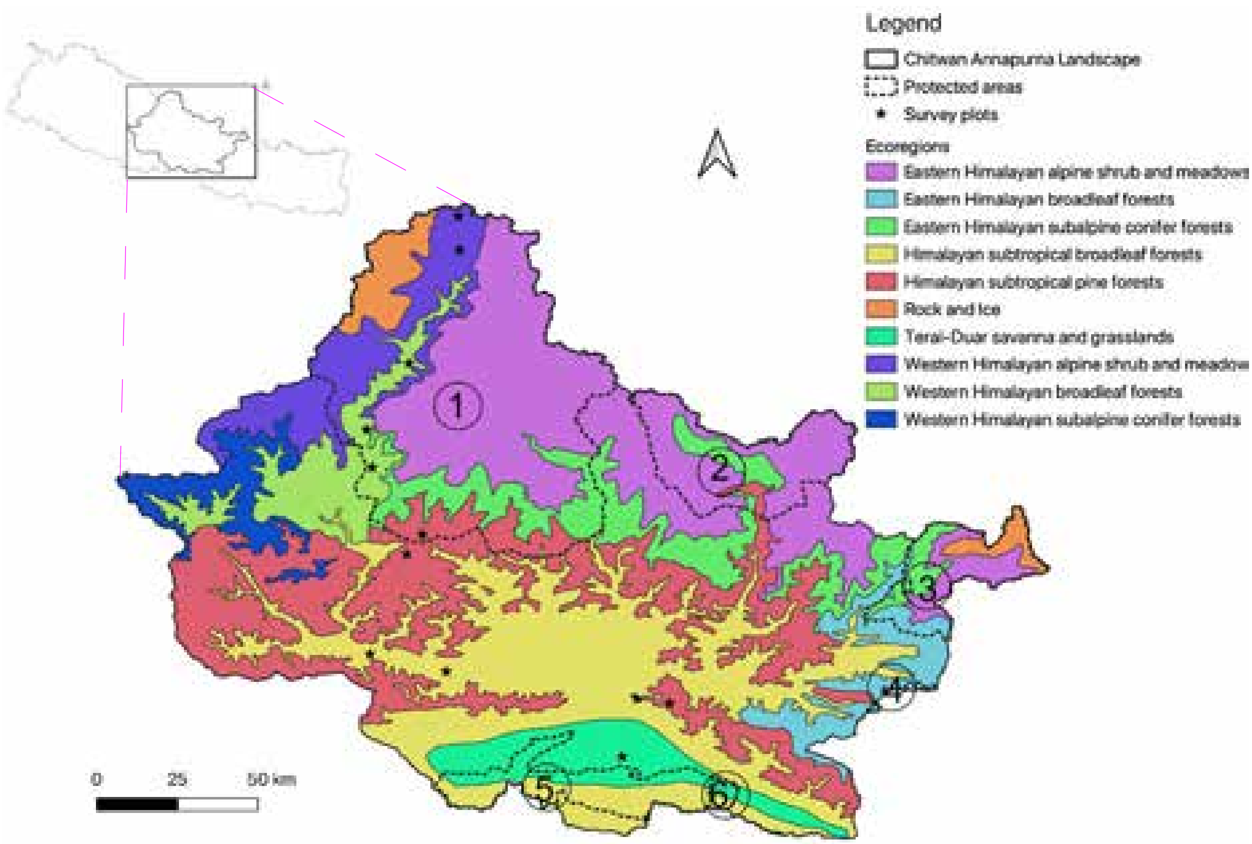

Figure 1. Chitwan-Annapurna Landscape including ecoregions (coloured shading) and protected areas. Dotted lines indicate PA boundaries: 1—Annapurna Conservation Area | 2—Manaslu Conservation Area | 3—Langtang National Park | 4—Shivapuri Nagarjun National Park | 5—Chitwan National Park | 6—Parsa National Park. Inset shows the location of the Chitwan-Annapurna Landscape within Nepal.

characteristics, and photographic documentation, using standard field guides, and taxonomic literature (Smith 1935; Schleich & Kästle 2002; Shah & Tiwari 2004; Whitaker & Captain 2004; Lajmi et al. 2016; Das & Das 2017; David & Vogel 2021; Garg & Biju 2021; Gowande et al. 2021; Khatiwada et al. 2021; Amarasinghe et al. 2022; Vogel et al. 2022; Köhler et al. 2023).

Records contributing to our checklist of the CHAL were also compiled from the following published works: Smith (1951), Swan & Levinton (1962), Kramer (1977), Ouboter (1986), Nanhoe & Ouboter (1987), Zug & Mitchell (1995), Tillack & Grossmann (2001), Schleich & Kästle (2002), Tillack et al. (2003), Shah & Tiwari (2004), Aryal et al. (2010), Pokhrel et al. (2012), Kästle et al. (2013), Pokhrel & Thakuri (2017), Shrestha & Shah (2017), Bhattarai et al. (2018, 2020, 2025c), Pandey et al. (2018), Baral et al. (2020), Gautam et al. (2020), Thapa & Shah (2020), and Baral & Kadariya (2025).

We excluded two amphibian, three lizard, and three snake species reported from the Annapurna Conservation Area by Baral & Kadariya (2025) from Table 1. These species, and the reasons for their exclusion are the skink, *Ablepharus ladacensis*: recent molecular studies (Bragin et al. 2024; Bragin et al. 2025) restrict this species to the western Himalaya of India. Earlier observations of *A. ladacensis* from Nepal are likely to be *A. himalayanus* or a new species yet to be described. Similarly, the agamid lizard, *Japalura major* is currently known to be geographically restricted to the western Himalaya of India and Pakistan (Wang et al. 2019). Consequently, earlier records of *Japalura major* from CHAL need further verification and may represent misidentifications of *J. tricarinata*. Likewise, Nepal Bent-toed Gecko *Cyrtodactylus nepalensis* is known to be distributed in far-western Nepal and reported observations of this species in Annapurna Conservation Area most likely represent *C. chitwanensis,* recently described by Bhattarai et al. (2025a). The frogs *Polypedates himalayensis* and *Zhangixalus smaragdinus* (syn. *Rhacophorus maximus*) are representative species of the eastern Himalaya, with their westernmost known distribution limited to eastern Nepal (Pradhan et al. 2018; Khatiwada et al. 2021). Reports of *P. himalayensis* from the Annapurna Conservation Area are likely to reflect misidentifications of *P. maculatus*. There are no verifiable historical records of *Z. smaragdinus* from CHAL; therefore, this species was excluded from the present checklist. However, there is a report of this species from Arghakhanchi District in western Nepal (Shah & Tiwari 2004).

The snakes—*Trimerusurus albolabris*, *T. erythrurus*, and *T. yunannensis*—have historical unverified records from Nepal and recent taxonomic studies suggest that such historical records represent misidentifications of the congener *T. sepentrionalis* which has its type locality in the CHAL (Sharma et al. 2013; Vogel et al. 2022). The distribution and taxonomy of *Trimerusurus* sp. in Nepal is poorly understood and requires further work, including independent verified confirmation of their presence in Nepal.

For taxonomic nomenclature, Frost (2025) was used for amphibians, and Uetz et al. (2025) was followed for reptiles. However, following the taxonomic revision by Bragin et al. (2024), we treated *Ablepharus capitaneus* rather than *Scincella capitanea*. We followed Jablonski et al. (2026) for *Gloydius* from CHAL, Nepal.

The conservation status of each species listed in Table 1 is reported using the IUCN Red List categories: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) (IUCN 2025). Recently described species which have not yet been listed were treated as not assessed (NA).

RESULTS

Species Richness

We documented a total of 140 herpetofaunal species from the Chitwan–Annapurna Landscape (CHAL), comprising 35 amphibian species and 105 reptile species (Table 1, Image 2–4). Many species previously described in the literature were also observed during field work (indicated by the number '1' in Table 1), however, one species of snake, the Common Slug Snake *Pareas* cf. *monticola* (Image 4F), and four species of gecko, not previously reported as occurring in the area, were observed during our field work. Descriptions of all four geckos have recently been published (Bhattarai 2025a,b).

The 140 species presented in Table 1 account for 63% of Nepal's known amphibian species (Frost 2025) and 71% of the country's reptile species (Uetz et al. 2025). The amphibians included 35 species of frogs and toads and one species of caecilian. Among the recorded amphibians, the family Dicroglossidae was the most speciose, with 16 species, followed by Ranidae (five species), Microhylidae, and Rhacophoridae (four species each), Bufonidae (three species), Megophryidae (two species), and Ichthyophiidae (one species). Among the reptiles, snakes comprised the largest group with 62 species, followed by lizards with 29 species, turtles with

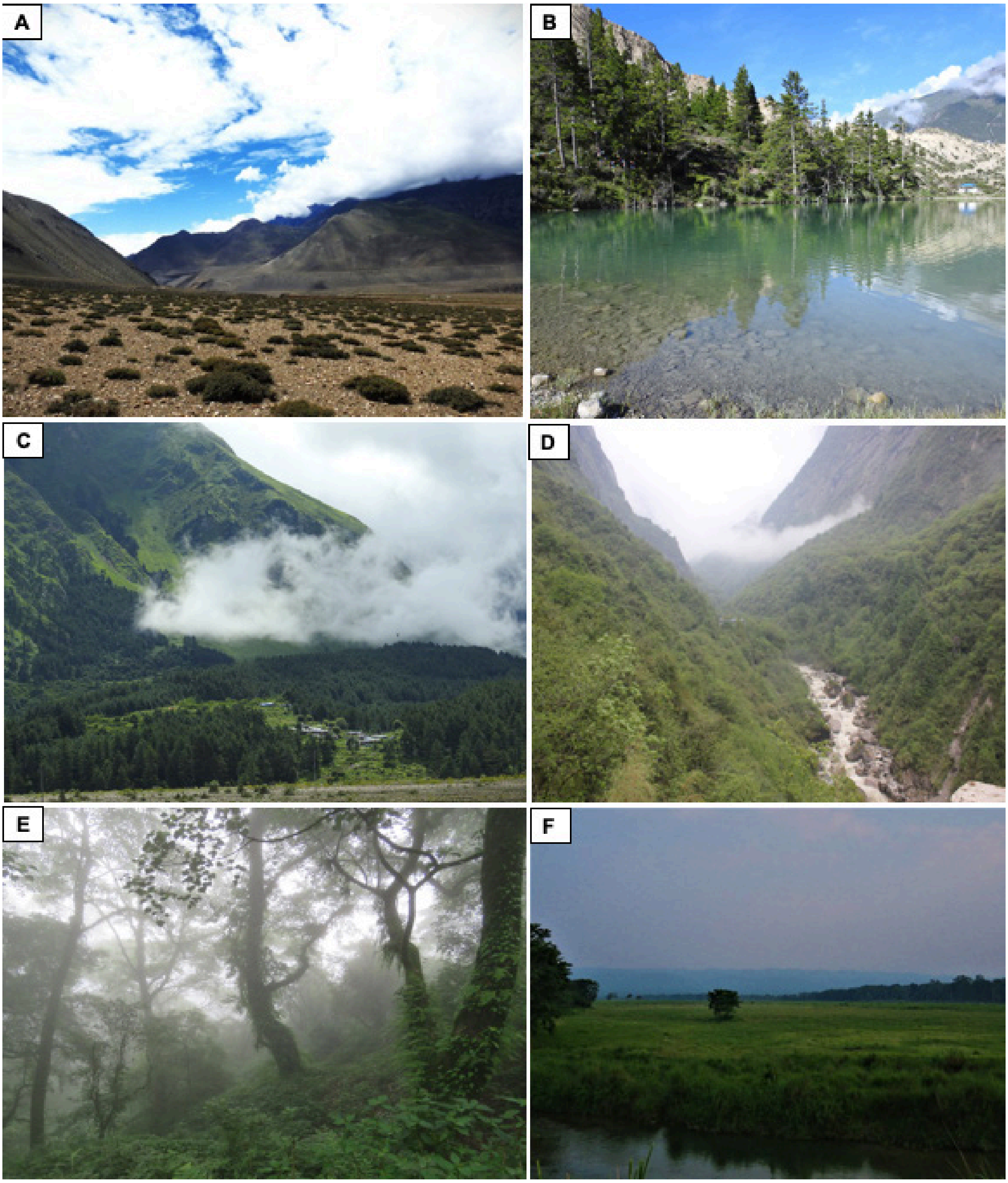

Image 1. Representative habitats of Chitwan-Annapurna Landscape: A—Typical high-altitude habitat from Upper Mustang where *Phrynocephalus theobaldi* occurs | B—Type locality of Mustang Frog, Dhumba Tal | C,D—Typical mid-hills forest habitat in Annapurna Conservation Area | E—Cloud forest habitat of upper Chitwan, type locality of Mahabharat Cascade Frog | F—Grassland habitat of Chitwan National Park. © Santosh Bhattarai.

11 species, and crocodiles with two species. The 29 lizard species comprised seven species of agamids, 10 species of geckos belonging to two families (including four newly described species recorded during field surveys for this study), ten species of skinks, and two species of monitor lizards (Table 1).

Table 1. List of herpetofauna species in Chitwan-Annapurna Landscape (CHAL) with their IUCN Red List status and noting their recorded presence (+) in the six Protected areas of the CHAL.

	Species name	Common name	Red List	ACA	MCA	LNP	SNNP	CNP	PNP	Data sources	Remarks
AMPHIBIANS											
Family: Bufonidae Gray, 1825											
1	*Duttaphrynus himalayanus* (Günther, 1864)	Himalayan Toad	LC	+	+	+	+			1,2,3,4	
2	*Duttaphrynus melanostictus* (Schneider, 1799)	Common Asian Toad	LC	+	+	+	+	+	+	1,2,3,4,5,8	
3	*Firouzophrynus stomaticus* (Lütken, 1864)	Marbled Toad	LC		+			+	+	1,2,3,4,5,8	
Family: Microhylidae Günther, 1858 (1843)											
4	*Microhyla nilphamariensis* Howlader, Nair, Gopalan & Merilä, 2015	Nilphamari Narrow-mouth Frog	LC	+		+	+	+	+	1,5,8	
5	*Uperodon globulosus* (Günther, 1864)	Globular Balloon Frog	LC					+	+	1,2,3,5,8	
6	*Uperodon taprobanicus* (Parker, 1934)	Painted Frog	LC					+	+	1,2,3,5,8	
7	*Uperodon systoma* (Schneider, 1799)	Marbled Balloon Frog	LC						+	1,2,3	
Family: Dicroglossidae Anderson, 1871											
8	*Euphlyctis adolfi* (Gunther, 1860)	Skittering Frog	LC	+		+	+	+	+	1,8	
9	*Fejervarya orissaensis* (Dutta, 1997)	Odisha Cricket Frog	LC					+	+	1,8	
10	*Hoplobatrachus tigerinus* (Daudin, 1802)	Indian Bull Frog	LC	+			+	+	+	1,2,3,5,8	
11	*Minervarya chilapata* Ohler, Deuti, Grosjean, Paul, Ayyaswamy, Ahmed & Dutta, 2009	Chilapata Rainpool Frog	VU					+		1,8,9	
12	*Minervarya nepalensis* (Dubois, 1975)	Nepal Cricket Frog	LC	+	+	+	+	+		1,2,3,4,8	
13	*Minervarya pierrei* (Dubois, 1975)	Pierre's Cricket Frog	LC					+		1,2,3,8	
14	*Minervarya* cf *syhadrensis* (Annandale, 1919)	Syhadra Cricket Frog	LC	+				+	+	1,2,3,4,8	
15	*Minervarya teraiensis* (Dubois, 1984)	Terai Cricket Frog	LC					+	+	1,2,3,8	
16	*Nanorana blanfordii* (Boulenger, 1882)	Blandford's Paa Frog	LC	+	+	+				1,2,3,4	
17	*Nanorana liebigii* (Günther, 1860)	Liebig's Paa Frog	LC	+	+	+	+			1,2,3,4	
18	*Nanorana minica* (Dubois, 1975)	Nepal Paa Frog	LC	+						4	
19	*Nanorana* cf *parkeri* (Stejneger, 1927)	High Himalaya Paa Frog	LC	+	+					1,2,3,4	
20	*Nanorana polunini* (Smith, 1951)	Langtang Paa Frog	LC			+				1,2,3,4	
21	*Nanorana rostandi* (Dubois, 1974)	Mustang Paa Frog	LC	+	+					1,2,3,4	
22	*Ombrana sikimensis* (Jerdon, 1870)	Sikkim Frog	LC	+	+					1,4	
23	*Sphaerotheca maskeyi* (Schleich & Anders, 1998)	Maskey's Burrowing Frog	LC	+				+	+	1,4	
Family: Megophryidae Bonaparte, 1850											
24	*Scutiger boulengeri* (Bedriaga, 1898)	Boulenger's High Altitude Toad	LC	+	+					1,4	
25	*Xenophrys zhangi* (Ye & Fei, 1992)	Zhang's Horned Toad	LC	+	+	+	+			1,4	
Family: Ranidae Batsch, 1796											
26	*Amolops formosus* (Günther, 1876)	Assam Cascade Frog	LC	+	+	+	+			1,2,3,4	
27	*Amolops mahabharatensis* Khatiwada, Shu, Wang, Zhao, Xie & Jiang, 2020	Mahabharat Torrent Frog	VU	+	+	+	+	+	+	1,4	
28	*Amolops monticola* (Anderson, 1871)	Mountain Cascade Frog	EN	+						1,4	
29	*Hylarana chitwanensis* (Das, 1998)	Chitwan Frog	DD					+		8	
30	*Hylarana tytleri* Theobald, 1868	Yellow-striped Frog	LC					+		8	
Family: Rhacophoridae Hoffman, 1932 (1858)											
31	*Chirixalus dudhwaensis* Ray, 1992	Dudhwa Reed Frog	VU					+		8	

	Species name	Common name	Red List	ACA	MCA	LNP	SNNP	CNP	PNP	Data sources	Remarks
32	*Polypedates maculatus* (Gray, 1830)	Common Tree Frog	LC	+	+	+	+	+	+	1,2,3,4,5,8	
33	*Polypedates taeniatus* (Boulenger, 1906)	Six-lined Bush Frog	LC					+		1,2,3,8	
34	*Polypedates zed* (Dubois, 1987)	Narayanghat Whipping Frog	DD							1,2,3,8	From Narayan-ghat
Family: Ichthyophiidae Taylor, 1968											
35	*Ichthyophis sikkimensis* Taylor, 1960	Sikkim Caecilian	LC	+						1, 10	Chitwan, Dhading, Palpa and Kaski districts
REPTILES											
Family: Crocodylidae Cuvier, 1807											
36	*Crocodylus palustris* Lesson, 1831	Mugger Crocodile	VU					+	+	2,3,5,9	
Family: Gavialidae Adams 1854											
37	*Gavialis gangeticus* (Gmelin, 1789)	Gharial	CR					+		2,3,9	
Family: Geoemydidae Theobald 1868											
38	*Batagur dhongoka* (Gray, 1834)	Three-striped Roofed Turtle	CR					+		2,3,9	
39	*Cyclemys gemelli* Fritz, Guicking, Auer, Sommer, Wink & Hundsdörfer, 2008	Assam Leaf Turtle	NT							11	Hetauda
40	*Melanochelys tricarinata* (Blyth, 1856)	Tricarinate Hill Turtle	EN					+	+	2,3,8,12	
41	*Melanochelys trijuga* (Schweigger,1812)	Black Pond Turtle	LC					+	+	2,3,8,12	
42	*Pangshura smithii* (Gray, 1863)	Brown Roofed Turtle	NT					+		2,3,8,12	
43	*Pangshura tecta* (Gray, 1830)	Indian Roofed Turtle	VU					+		2,3,8,12	
44	*Pangshura tentoria* (Gray, 1834)	Indian Tent Turtle	LC					+		2,3,8,12	
Family: Testudinidae Batsch, 178											
45	*Indotestudo elongata* (Blyth, 1854)	Elongated Tortoise	CR					+	+	2,3,5,8,12	
Family: Trionychidae Gray, 1835											
46	*Chitra indica* (Gray 1831)	Narrow-headed Softshell Turtle	EN					+		2,3,8,12	
47	*Lissemys punctata* (Bonnaterre, 1789)	Indian Flapshell Turtle	VU					+	+	2,3,8,12	
48	*Nilssonia gangetica* (Cuvier, 1825)	Gangetic Softshell Turtle	EN					+		2,3,8,12	
49	*Nilssonia hurum* (Gray, 1830)	Peacock Softshell Turtle	EN					+		2,3,8,12	
Family: Agamidae Gray, 1827											
50	*Calotes vultousus* (Harlan, 1825)	Common Garden Lizard	LC	+	+	+	+	+	+	1,8	
51	*Japalura tricarinata* (Blyth, 1853)	Three-keeled Mountain Lizard	LC	+	+	+	+			1,2,3,4, 8	
52	*Japalura variegata* (Gray, 1853)	Variagated Lizard	LC	+			+			1,2,3,4,12	
53	*Laudakia tuberculata* (Gray, 1827)	Rock Lizard	LC	+	+	+		+		1,2,3,4,12	
54	*Phrynocephalus theobaldi* (Blyth, 1863)	Toad-headed Agama	LC	+						1,2,3,4	
55	*Sitana fusca* Schleich & Kästle,1998		CR						+	1,2,3,5,12	
56	*Sitana sivalensis* Schleich, Kästle & Shah, 1998	Sivalik Fan-throated Lizard	LC					+		9	
Family: Eublepharidae Boulenger, 1883											
57	*Eublepharis macularius* (Blyth, 1854)	Common Leopard Gecko	LC							12	Nawalpur
Family: Gekkonidae Gray, 1825											
58	*Cyrtodactylus annapurnaensis* Bhattarai,Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	ACAP Bent-toed Gecko	NA	+						1, 6	

	Species name	Common name	Red List	ACA	MCA	LNP	SNNP	CNP	PNP	Data sources	Remarks
59	*Cyrtodactylus chitwanensis* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	Chitwan Bent-toed Gecko	NA							1,6	Chitwan, Tanahun
60	*Cyrtodactylus karanshahi* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	Karan's Bent-toed Gecko	NA		+					1,6	Gorkha
61	*Cyrtodactylus makwanpurgadhiensis* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Olson, Hogan & Wright, 2025	Makwanpur Gadhi Bent-toed Gecko	NA							1,7	Makwan-pur
62	*Hemidactylus* cf. *kushmorensis* Murray, 1884	Kushmore Gecko	NA	+			+	+	+	1,9	
63	*Hemidactylus flaviviridis* (Rüppell, 1835)	Yellow-bellied House Gecko	LC	+		+	+	+	+	1,2,3,4,5,8, 12	
64	*Hemidactylus frenatus* (Duméril & Bibron, 1836)	Common House Gecko	LC	+			+	+	+	1,2,3,4,5, 8,12	
65	*Hemidactylus garnotii* (Duméril & Bibron, 1836)	Fox Gecko	LC	+		+	+			1,2,3,4	
66	*Hemidactylus platyurus* (Schneider, 1797)	Flat-tailed Gecko					+			1, 4	
Family: Scincidae Gray, 1825											
67	*Ablepharus himalayanus* (Günther, 1864)	Himalayan Ground Skink	LC	+	+	+				1,2,3,4	
68	*Ablepharus mahabharatus* (Eremchenko, Shah & Panfilov, 1998)	Mahabharat Ground Skink	DD				+			1,2,3,	Makwan-pur
69	*Ablepharus capitaneus* (Ouboter, 1986)	Large Ground Skink	LC	+						1,2,3,4	
70	*Ablepharus nepalensis* (Eremchenko & Helfenberger, 1998)	Nepal Ground Skink	DD	+	+	+	+	+		1,2,3,4	
71	*Ablepharus sikimmensis* (Blyth, 1854)	Sikkim Ground Skink	LC	+	+	+	+	+		1,2,3,4	
72	*Eutropis carinata* (Schneider, 1801)	Common Ground Skink	LC	+	+	+	+	+	+	1,2,3,4	
73	*Eutropis macularia* (Blyth, 1853)	Bronze Ground Skink	LC	+				+	+	1,2,3,4	
74	*Eutropis trivittata* (Hardwicke & Gray, 1827)	Striped-ground skink	LC					+	+	1,2,3	
75	*Riopa albopunctata* (Gray, 1846)	White-spotted Supple Skink	LC					+	+	1,2,3	
76	*Sphenomorphus maculatus* (Blyth, 1853)	Spotted Forest Skink	LC	+		+	+	+	+	1,2,3,4,5, 8,12	
Family: Varanidae Merrem, 1820											
77	*Varanus bengalensis* (Daudin, 1802)	Bengal Monitor	NT	+	+	+	+	+	+	1,2,3,5, 8,12	
78	*Varanus flavescens* (Hardwicke & Gray, 1827)	Golden Monitor	EN	+				+	+	1,2,3,4, 5,8, 12	
Family: Erycidae Bonaparte, 1831											
79	*Eryx conicus* (Schneider, 1801)	Common Sand Boa	NT					+	+	1,2,3,5, 8,12	
80	*Eryx johnii* (Russell, 1801)	Red Sand Boa	NT					+	+	1,5,8	
Family: Pythonidae Fitzinger, 1826											
81	*Python bivittatus* Kuhl, 1820	Burmese Python	VU	+	+	+	+	+	+	1,2,3,4,5, 8,12	
Family: Colubridae Oppell, 1811											
82	*Ahaetulla laudankia* Deepak, Narayanan, Sarkar, Dutta & Mohapatra, 2019	Laudanka Vine Snake	LC					+		8,13	
83	*Ahaetulla longirostris* Mirza, Pattekar, Verma, Stuart, Purkayastha, Mohapatra & Patel, 2024	Long-snout Vine Snake	NA					+		1, 8	
84	*Anguiculus rappi* (Günther, 1860)	Himalayan Striped-necked Snake	LC	+	+	+	+			1,2,3,4	

	Species name	Common name	Red List	ACA	MCA	LNP	SNNP	CNP	PNP	Data sources	Remarks
85	*Boiga forsteni* (Duméril, Bibron and Duméril, 1854)	Forsten's Cat Snake	LC						+	1,4	
86	*Boiga stoliczkae* (Wall, 1909)	Tawny Cat Snake	LC	+	+	+	+	+	+	1,2,3,4,8, 12	
87	*Boiga siamensis* (Nutaphand, 1871)	Siamese Cat Snake	LC					+		1, 8, 12,14	
88	*Boiga trigonata* (Schneider, 1802)	Common Cat Snake	LC	+		+	+	+	+	1,2,3,4,5,8, 12,14	
89	*Boiga multifasciata* Blyth, 1861	Many-banded Cat Snake	LC	+	+	+	+			1,2,3,4	
90	*Boiga westermanni* (Reinhardt, 1863)	Indian Egg-eating Snake	LC					+	+	2,3,8	
91	*Chrysopelea ornata* (Shaw, 1802)	Ornate Flying Snake	LC					+		1,2,3,5,8, 12, 14	
92	*Coelognathus helena* (Daudin, 1803)	Common Trinket Snake	LC	+			+	+	+	1,2,3,4,5,8, 12,14	
93	*Coelognathus radiatus* (Boie, 1827)	Copper-headed Trinket Snake	LC	+		+	+	+	+	1,2,3,4,5,8, 12,14	
94	*Dendrelaphis tristis* (Daudin, 1803)	Common Bronze-back Tree Snake	LC	+	+	+	+	+	+	1,2,3,4,5,8, 12,14	
95	*Dendrelaphis proarchos* Wall, 1909	Eastern Bronze-back Tree Snake	NA					+		1, 8	
96	*Elaphe hodgsoni* (Günther, 1860)	Himalayan Trinket Snake	LC	+	+	+	+			1,2,3,4	
97	*Gongylosoma calamaria* (Günther, 1858)	Calamaria Reed Snake	LC					+		8	
98	*Lycodon aulicus* (Linnaeus, 1758)	Common Wolf Snake	LC	+			+	+	+	1,2,3,4,5,8, 12,14	
99	*Lycodon jara* (Shaw, 1802)	Twin-spotted Wolf Snake	LC					+	+	1,2,3,5,8, 12,14	
100	*Lycodon striatus* (Shaw, 1802)	Barred Wolf Snake	LC					+		1,8,12,14	
101	*Oligodon erythrogaster* Boulenger, 1907	Nagarkot Kukri Snake	NT	+	+	+	+			1,2,3,4	
102	*Oligodon kheriensis* Acharji & Ray, 1836	Coral Red Kukri Snake	LC					+		8,14	
103	*Oligodon russelius* (Daudin, 1803)	Russell's Kukri Snake	NA	+				+	+	1,2,3,4,5,8, 12,14	
104	*Oreocryptophis porphyraceus* (Cantor, 1839)	Black-banded Trinket Snake	LC	+		+	+			1,2,3,4	
105	*Ptyas mucosa* (Linnaeus, 1758)	Common Rat Snake	LC	+	+	+	+	+	+	1,2,3,4,5,8, 12,14	
106	*Sibynophis collaris* (Gray, 1853)	Collared Black-headed Snake	LC	+	+	+	+			1,2,3,4	
107	*Sibynophis sagittarius* (Cantor, 1839)	Cantor's Black-headed Snake	LC					+	+	1,2,3,4	
Family: Homalopsidae Bonaparte, 1845											
108	*Enhydris enhydris* (Schneider, 1799)	Rainbow Water Snake	LC					+		2,3,8,14	
109	*Ferania sieboldii* (Schlegel, 1837)	Siebold's Water Snake	LC					+		2,3,8,14	
Family: Psammophidae Bourgeois, 1968											
110	*Psammophis condanarus* Merrem, 1820	Common Sand Snake	LC					+		8	
Family: Psammodynastidae Das, Greenbaum, Brecko, Pauwels, Ruane, Pirro & Merilä, 2024											
111	*Psammodynastes pulverulentus* (Boie, 1827)	Common Mock Viper	LC					+		8,14	
Family: Natricidae Bonaparte, 1838											
112	*Amphiesma stolatum* (Linnaeus, 1758)	Striped Keelback Snake	LC	+	+	+	+	+	+	1,2,3,4,5,8, 12,14	
113	*Atretium schistosum* (Daudin, 1803)	Olive Keelback Snake	LC							1,8	Nawalpur
114	*Fowlea piscator* (Schneider, 1799)	Checkered Keelback Snake	LC	+	+	+	+	+	+	1,2,3,4,5,8, 12,14	
115	*Fowlea sanctijohannis* (Boulenger, 1890)	St. John's Keelback Snake	LC	+	+					1,4	

	Species name	Common name	Red List	ACA	MCA	LNP	SNNP	CNP	PNP	Data sources	Remarks
116	*Herpetoreas platyceps* (Blyth, 1854)	Mountain Keelback Snake	LC	+	+	+	+	+		1,2,3,4,8	
117	*Rhabdophis helleri* Schmidt, 1925	Red-necked Keelback Snake	NA	+	+	+	+	+		1,2,3,4,8	
118	*Rhabdophis himalayanus* (Günther, 1864)	Himalayan Keelback Snake	LC	+	+	+	+			1,2,3,4	
119	*Trachischium laeve* Peracca, 1904	Olive Worm-eating Snake	LC	+	+	+	+			1,2,3,4	
120	*Trachischium tenuiceps* (Blyth, 1854)	Yellow-bellied Worm-eating Snake	DD	+	+	+	+			1,2,3	
121	*Xenochrophis cerasogaster* (Cantor, 1839)	Painted Keelback Snake	VU					+		8	
Family: Pseudoxenodontinae McDowell, 1987											
122	*Pseudoxenodon macrops* (Blyth, 1855)	False Cobra	LC	+		+	+			1,2,3,4	
Family: Pareidae Romer, 1956											
123	*Pareas monticola* (Cantor, 1839)	Common Slug Snake	LC							1	Chitwan
Family: Elapidae F. Boie, 1827											
124	*Bungarus caeruleus* (Schneider, 1801)	Common Krait	LC					+	+	1,2,3,5, 8,12, 14	
125	*Bungarus fasciatus* (Schneider, 1801)	Banded Krait	LC					+	+	1,2,3,5, 8,12, 14	
126	*Bungarus lividus* Cantor, 1839	Lesser Black Krait	LC					+	+	1,2,3,4,5, 8,12, 14	
127	*Bungarus niger* Wall, 1908	Greater Black Krait	LC	+						2,3,4, 15	
128	*Naja kaouthia* Lesson, 1831	Monocled Cobra	LC	+		+	+	+	+	1,2,3,4,8	
129	*Naja naja* (Linnaeus, 1758)	Common Cobra	LC					+	+	1,2,3,5,8, 12, 14	
130	*Ophiophagus hannah* (Cantor, 1836)	King Cobra	VU	+	+	+	+	+	+	1,2,3,4,5, 8, 12, 14	
131	*Sinomicrurus macclellandi* (Reinhardt, 1844)	MacClelland's Coral Snake	LC	+			+	+		1,2,3,4,5, 8,12	
Family: Typhopidae Merrem, 1820											
132	*Argyrophis diardii* (Schlegel, 1839)	Diard's Blind Snake	LC					+	+	14	
133	*Indotyphlops braminus* (Daudin, 1803)	Common Blind Snake	LC	+			+	+	+	1,2,3,4,5,8, 12, 14	
Family: Viperidae Oppel, 1811											
134	*Gloydius nepalensis* Jablonski, Tillack, Mahlow-Tillack, Petzold, Wilzo, Das, Idrees, Baniya, Masroor & Hofmann, 2026	Himalayan Pit Viper	LC	+	+					1,2,3,4	
135	*Ovophis monticola* (Günther, 1864)	Mountain Pit Viper	LC	+	+	+	+			1,2,3,4	
136	*Protobothrops himalayanus* Pan, Chettri, Yang, Jiang, Wang, Zhang & Vogel, 2013	Habu Pit Viper	LC	+	+					1,4	
137	*Daboia russelii* (Shaw & Noddor, 1797)	Russell's Viper	LC					+	+	1,2,3,5,8, 12, 14	
138	*Trimeresurus salazar* Mirza, Bhosale, Phansalkar, Sawant, Gowande & Patel, 2020	Salazar Pit Viper	NA					+	+	1,8	
139	*Trimeresurus septentrionalis* Kramer, 1977	Nepal Pit Viper	LC	+	+	+	+			1,2,3,4,5,8, 12	
140	*Trimeresurus tibetanus* Huang, 1982	Tibetan Pit Viper	LC			+				16	

ACA—Annapurna Conservation Area Project | MCA—Manaslu Conservation Area Project | LNP—Langtang National Park | SNNP—Shivapuri-Nagarjun National Park | CNP—Chitwan National Park | PNP—Parsa National Park. IUCN Status: LC—Least Concern | DD—Data Deficient | NT—Near Threatened | VU—Vulnerable | EN—Endangered | CR—Critically Endangered. Data Sources: 1—This study | 2—Schleich & Kastle (2002) | 3—Shah & Tiwari (2004) | 4—Baral & Kadariya (2025) | 5—Bhattarai et al. (2018) | 6—Bhattarai et al. (2025a) | 7—Bhattarai et al. (2025b) | 8—Bhattarai et al. (2025c) | 9—Gautam & Bhattarai (2022) | 10—Thapa & Shah (2020) | 11—Rai (2025) | 12—Bhattarai et al. (2020) | 13—Rawat et al. (2020) | 14—Pandey et al. (2018) | 15—Tillack & Grossmann (2001) | 16—Tillack et al. (2003).

IUCN Red List Status

The IUCN status of all species recorded in the CHAL is noted in Table 1. Of the total amphibian species recorded, four are classified as globally threatened. The Mountain Cascade Frog *Amolops monticola* is listed as EN, while the Chilapata Rain-pool Frog *Minervarya chilapata*, Mahabharat Cascade Frog *Amolops mahabharatensis*, and Dudhwa Reed Frog *Chirixalus dudhwaensis* are categorized as VU (IUCN 2025). In addition, 28 species are listed as LC. Two species, namely Narayanghat Whipping Frog *Polypedates zed*, and Chitwan Frog *Hylarana chitwanensis* are listed as DD.

Among the reptiles, four species, namely Gharial *Gavialis gangeticus*, Three-striped Roofed Turtle *Batagur dhongoka*, Elongated Tortoise *Indotestudo elongata*, and Dark Sitana *Sitana fusca*, are listed as Critically Endangered (CR), whereas five species, namely Tri-carinate Hill Turtle *Melanochelys tricarinata*, Narrow-headed Soft-shell Turtle *Chitra indica*, Gangetic Soft-shell Turtle *Nilssonia gangetica*, Peacock Soft-shell turtle *Nilssonia hurum*, and Golden Monitor Lizard *Varanus flavescens*, are categorized as EN. Five species, namely, Mugger Crocodile *Crocodylus palustris*, Indian Roofed Turtle *Pangshura tecta*, Indian Flap-shell Turtle *Lissemys punctata*, Burmese Python *Python bivittatus*, and Painted Keelback *Xenochrophis cerasogaster*, are listed as VU. Five species are listed as NT, 72 species are listed as LC, three species are listed as DD.

Type Localities of Herpetofauna in Chitwan-Annapurna Landscape

Among the 140 known herpetofauna species in CHAL, 16 species (Table 2) (seven amphibians and nine reptiles) were described from the CHAL and have type localities within the CHAL. Of these, four species of amphibians, namely Maskey's Burrowing Frog *Sphaerotheca maskeyi*, Chitwan Frog *Hylarana chitwanensis*, Mustang Frog *Nanorana rostandi*, and Langtang Frog *Nanorana polunini*, have type localities within the protected area system, whereas three species, namely Mahabharat Torrent Frog *Amolops mahabharatensis*, Narayanghat Whipping Frog *Polyepedates zed*, and Nepal Cricket Frog *Minervarya nepalensis*, were described from areas outside of the Protected Area system. Similarly, of the nine reptiles which have type localities in the CHAL, only three, namely ACAP Bent-toed Gecko *Cyrtodactylus annapurnaensis*, Nepali Pit-Viper *Gloydius nepalensis* and Karan's Bent-toed Gecko *Cyrtodactylus karanshahi*, are described from locations within the PAs (Table 2).

Protected Area Coverage

Information about the known presence of each species in each of the six PAs of the CHAL is provided in Table 1. Chitwan National Park supports the largest number of records (90) of herpetofauna species, followed by the Annapurna Conservation Area (73), Parsa National Park (58), Shivapuri–Nagarjun National Park (53), Langtang National Park (47), and Manaslu Conservation Area (45) (Table 1). However, many species were documented from locations outside of the protected area system. For example, the recently described Chitwan Bent-toed Gecko *Cyrtodactylus chitwanensis* was recorded from Chitwan and Tanahun districts beyond the boundaries of the PAs (Bhattarai et al. 2025a). Similarly, the ACAP Bent-toed Gecko *Cyrtodactylus annapurnaensis* was also observed in the hills on the northern side of Fewa Lake in Pokhara; and in Bahundanda, Lumjung near the Annapurna Conservation Area, but outside its border. The Common Leopard Gecko *Eublepharis macularius*, Olive Keelback *Atretium schistosum*, and Forsten's Cat Snake *Boiga forsteni* have been reported from Nawalparasi District, and the Common Slug Snake *Pareas monticola* was recorded from the Gairibari–Shaktikhor area in Chitwan District. No records for these species are reported from within the PA network in CHAL.

Elevation range of species

The distribution of amphibians and reptiles in CHAL can be categorized into three major groups, namely lowland species, mid-elevation species and Himalayan species (Figure 2). The lowland species include amphibian species such as Burrowing frogs *Uperodon* spp., Dudhwa Reed Frog *Chirixalus dudhwaensis*, and Chitwan Frog *Hylarana chitwanensis*, Yellow-striped Frog *Hylarana tytleri*, Terai Bush Frog *Polypedates taeniatus*, and reptiles specifically turtles, crocodiles and the agamid lizard of the genus *Sitana* sp. The amphibian species exclusively occupying the mid hills are cascade frogs of the genus *Amolops*, Sikkim Frog *Ombrana sikimensis* and Zhang's Horned Frog *Xenophrys zhangi.* However, we recorded individuals of the Mahabharat Cascade Frog *Amolops mahabharatensis* at low elevation streams in Jugedi, Chitwan, and Tanahun. Reptiles such as forest lizards of the genus *Japalura*, Rock Lizard *Laudakia tuberculata*, Large Ground Skink *Ablepharus capitaneus*, Black-banded Trinket Snake *Oreocryptophis porphyraceus*, False Cobra *Pseudoxenodon macrops*, Himalayan Trinket Snake *Elaphe hodgsoni*, and Mountain Pit-viper *Ovophis monticola* are also considered mid-hill species. The high elevation Himalayan endemics include

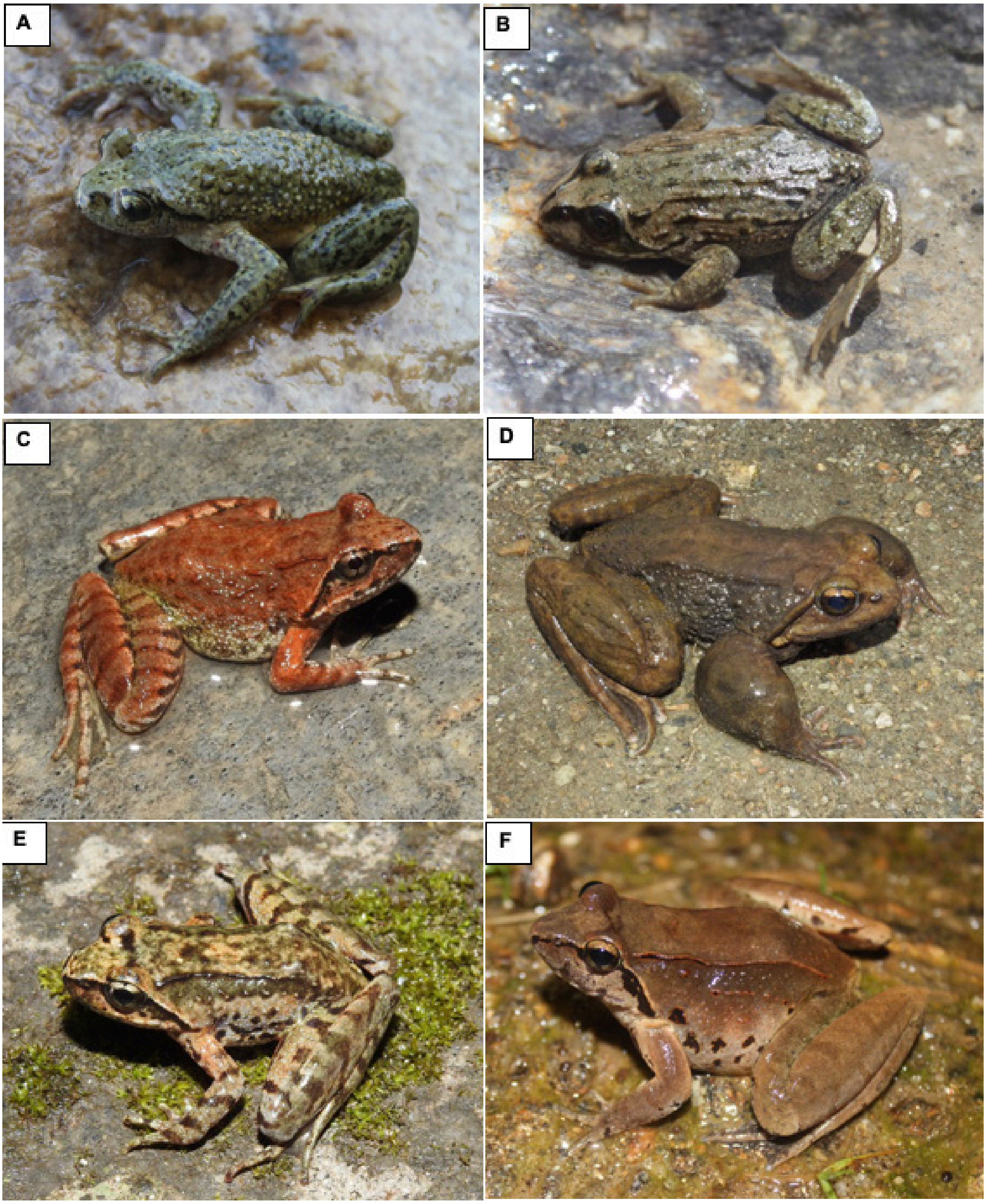

Image 2. Some amphibian species from CHAL: A—Boulenger's High Altitude Toad *Scutiger boulengeri* | B—High Himalaya Paa Frog *Nanorana* cf. *parkeri* | C—Mustang Frog *Nanorana rostandi* | D—Liebig's Paa Frog *Nanorana leibigii* | E—Blandford's Paa Frog *Nanorana blandfordii* | F—Langtang Frog *Nanorana polunini*. © Santosh Bhattarai.

Image 2. Some amphibian species from CHAL: G—Assam Cascade Frog *Amolops formosus* | H—Mounatin Cascade Frog *Amolops monticola* | I—Mahabharat Cascade Frog *Amolops mahabharatensis* | J—Nepal Cricket Frog *Minervarya nepalensis* | K—Sikkim Frog *Ombrana sikimensis* | L—Chitwan Frog *Hylarana chitwanensis*. © Santosh Bhattarai.

amphibians such as high Himalayan frogs of the genus *Nanorana*, lazy-toads of the genus *Scutiger*, and reptiles such as Toad-headed Agama *Phrynocephalus theobaldi* and Nepali Pit-viper *Gloydius nepalensis*.

DISCUSSION

This study provides a much-needed update regarding the current understanding of the richness of herpetofauna in the CHAL, with records of 35 amphibian and 105 reptile species. The high diversity of herpetofauna in the CHAL is likely due to its geographical position, which facilitates faunal and floral exchange between the species assemblages of the eastern and western Himalaya (KMTNC 1998; NTNC 2020; Bhattarai et al. 2025b).

Field surveys yielded a notable record of the Mountain Cascade Frog *Amolops monticola* from the Annapurna Conservation Area (Image 2H). Baral & Kadariya (2025) also reported the occurrence of *A. monticola* from the Annapurna Conservation Area. These specimens, observed from CHAL, exhibit morphological differences compared to true *A. monticola,* and are from locations approximately 455 km from the type locality in Darjeeling, India. Therefore, we recommend further integrative taxonomic studies to confirm the species identity as several cryptic species within the *monticola* group have been described in recent years. Patel et al. (2021) redefined the distribution of *A. monticola* to the lower Himalayan range of Darjeeling and south Sikkim, India; accordingly, the most recent IUCN assessment lists

Table 2. Type localities of herpetofauna within the Chitwan-Annapurna Landscape. The asterisk (*) indicates species described from outside of the PAs.

Taxa	Family	Common name	Scientific name	Type locality	Elevation (m)
Amphibians					
Frog	Dicroglossidae	Nepal Cricket Frog	*Minervarya nepalensis* (Dubois, 1975)	*Godavari (= Godawari), Central Nepal	1,560
Frog	Dicroglossidae	Langtang Frog	*Nanorana polunini* (Smith, 1951)	Langtang Village	3,353
Frog	Dicroglossidae	Mustang Frog	*Nanorana rostandi* (Dubois, 1974)	Lac Kutsab Terna Tal (= Dhumba Tal/ Lake), Jomsom, Mustang	2,900
Frog	Dicroglossidae	Maskey's Burrowing Frog	*Sphaerotheca maskeyi* (Schleich & Anders, 1998)	Chitwan National Park	300
Frog	Ranidae	Mahabharat Torrent Frog	*Amolops mahabharatensis* Khatiwada, Shu, Wang, Zhao, Xie & Jiang, 2020	*Hattibang, Chitwan	775
Frog	Ranidae	Chitwan Frog	*Hylarana chitwanensis* (Das, 1998)	Chitwan National Park	300
Frog	Rhacophridae	Narayanghat Whipping Frog	*Polypedates zed* (Dubois, 1987)	*Narayanghat, Chitwan	310
Reptiles					
Gecko	Gekkonidae	Annapurna Bent-toed Gecko	*Cyrtodactylus annapurnaensis* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	Lwang, Annapurna Conservation Area	1,450
Gecko	Gekkonidae	Chitwan Bent-toed Gecko	*Cyrtodactylus chitwanensis* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	*Bandipur, Tanahun	1,050
Gecko	Gekkonidae	Karan's Bent-toed Gecko	*Cyrtodactylus karanshahi* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	Philim, Manaslu Conservation Area	1,590
Gecko	Gekkonidae	Makwanpurgadhi Bent-toed Gecko	*Cyrtodactylus makwanpurgadhiensis* Bhattarai, Gautam, Neupane, Khandekar, Thackeray, Agarwal, Tillack, Olson, Hogan & Wright, 2025	*Makwanpurgadhi, Makwanpur, Bagmati Province	1,050
Skink	Scincidae	Mahabharat Skink	*Ablepharus mahabharatus* (Eremchenko, Shah & Pankilov, 1998)	*Bhaise-Daman, Makwanpur	950
Skink	Scincidae	Nepal skink	*Ablepharus nepalensis* (Eremchenko & Helfenberger, 1998)	*Suikhet-Naudanda, Kaski	1,500
Skink	Scincidae	Large Ground Skink	*Ablepharus capitaneus* (Ouboter, 1986)	*Dhampus, Annapurna region	1,850
Snake	Viperidae	Nepal Pit Viper	*Trimerusurus sepentrionalis* Krammer, 1977	*Hyangchya (=Hemja), Kaski	1,500
Snake	Viperidae	Nepali Pit Viper	*Gloydius nepalensis* Jablonski, Tillack, Mahlow-Tillack, Petzold, Wilzo, Das, Idrees, Baniya, Masroor, Hofmann, 2026	Kalopani, Mustang	2,500

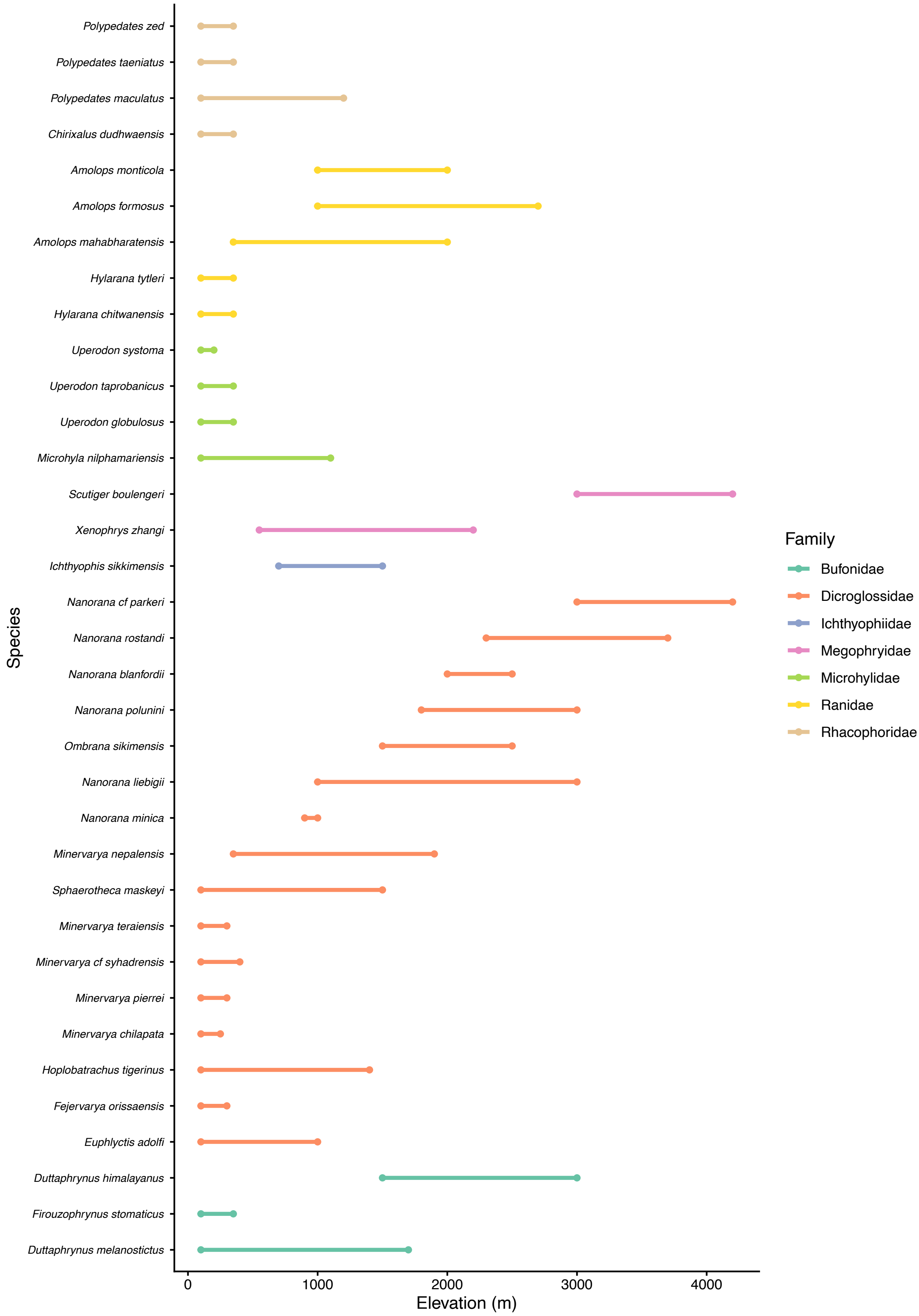

Figure 2. Elevational distribution of amphibians in the CHAL region (elevation in m).

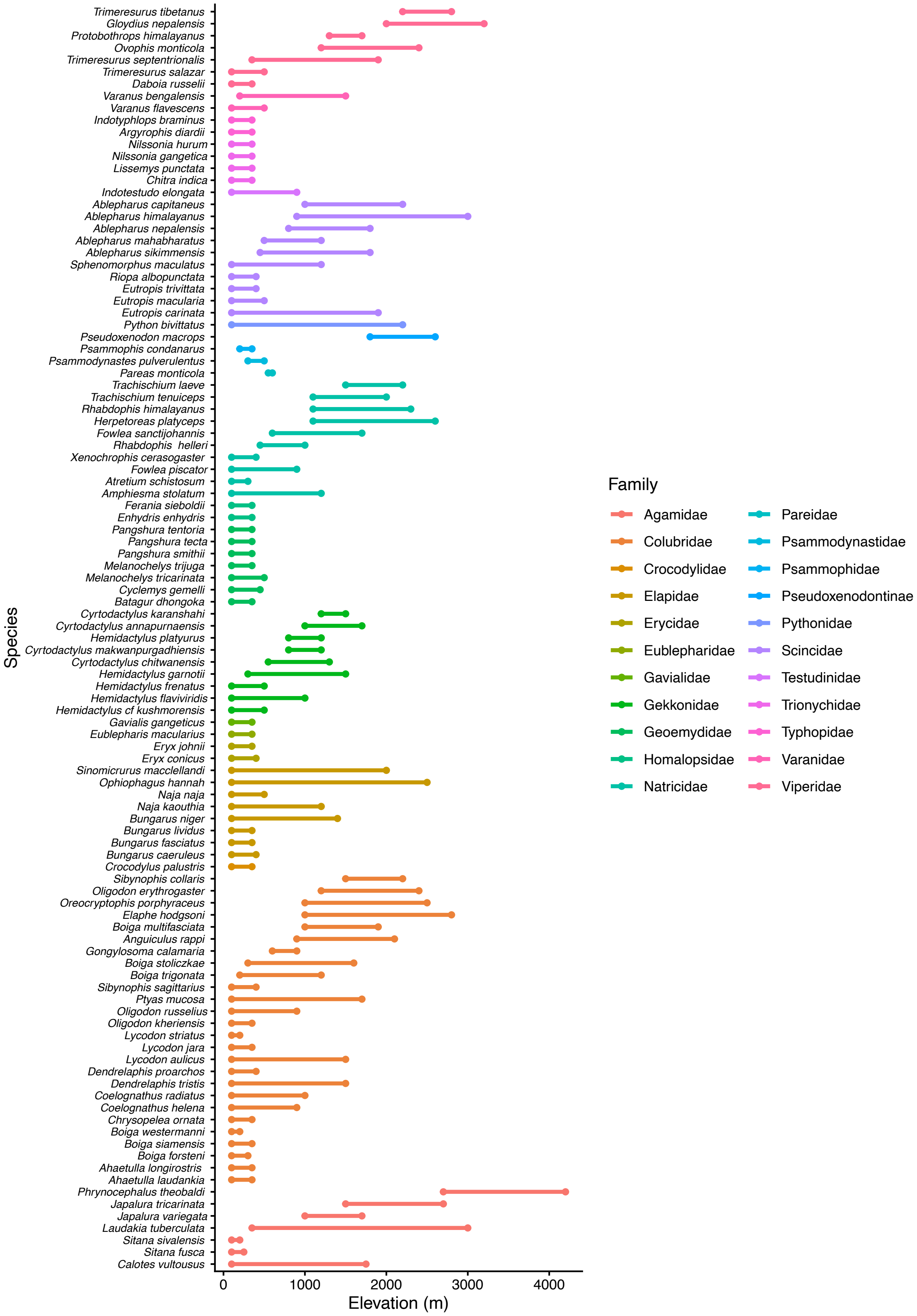

Figure 2 cont.. Elevational distribution of reptiles in the CHAL region (elevation in m).

Image 3. Some representative lizards from Chitwan-Annapurna Landscape: A—Toad-headed Agama *Phrynocephalus theobaldi* | B—Gravid female of Tricarinate Forest Agama *Japalura tricarinata* | C—Large Ground Skink *Ablepharus capitanius* | D—Mahabharat Skink *Ablepharus* mahabharatus | E—Chitwan Bent-toed Gecko *Cyrtodactylus chitwanensis* | F—ACAP Bent-toed Gecko *Cyrtodactylus annapurnaensis*. © Santosh Bhattarai.

Image 4. Some snake species from Chitwan Annapurna Landscape: A—Nepali Pit Viper *Gloydius nepalensis* | B—Mountain Pit Viper *Ovophis monticola* killed by villagers in Kaule, Chitwan | C—Nepal Pit Viper *Trimerusurus sepentrionalis* | D—Himalayan Habu Pit Viper *Protobothrops himalayanus* | E—False Cobra *Pseudoxenodon macrops* | F—Common Slug Snake *Pareas* cf. *monticola*. © Santosh Bhattarai.

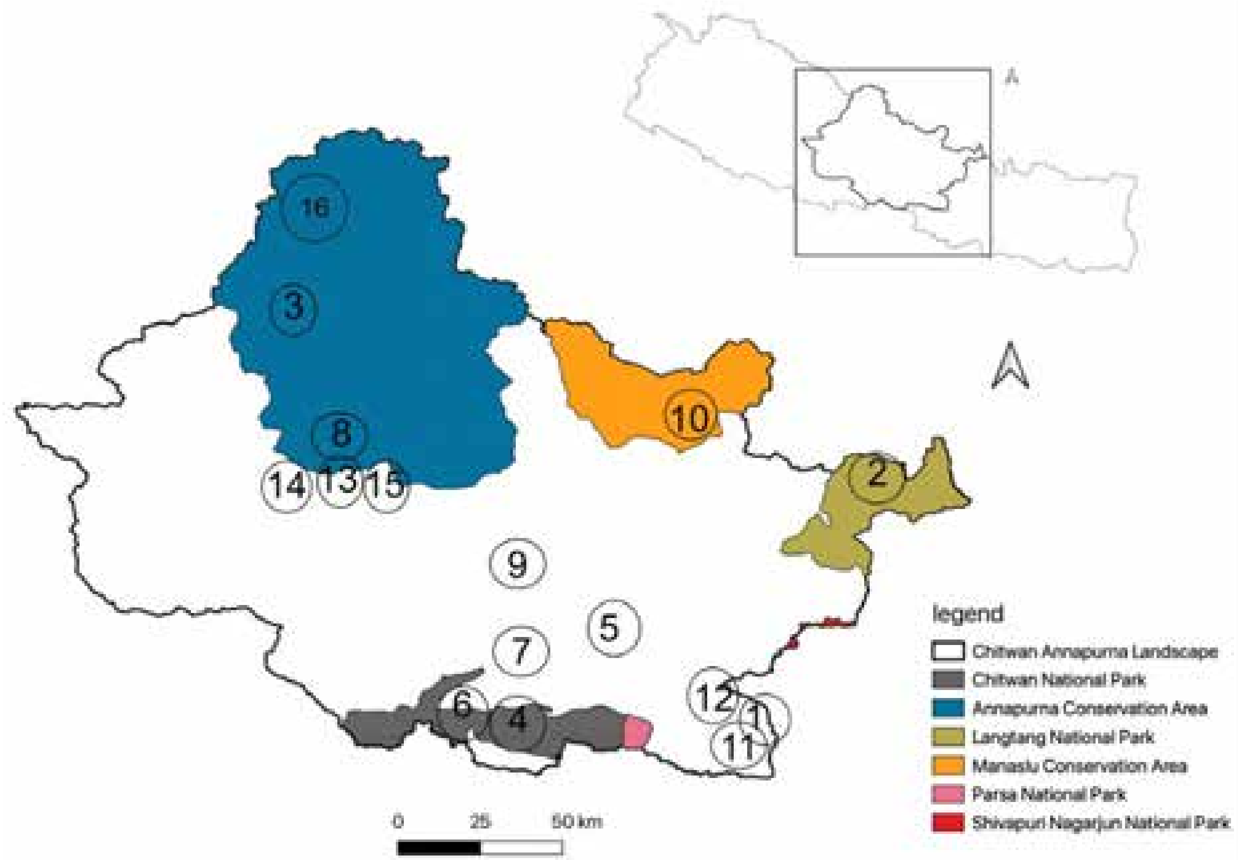

Figure 3. Type localities of amphibians and reptiles within and outside of protected areas in CHAL. The numbers in the circle refers to the species: 1—*Minervarya nepalensis* | 2—*Nanorana polunini* | 3—*Nanorana rostandi* | 4—*Sphaerotheca maskeyi* | 5—*Amolops mahabharatensis* | 6—*Hylarana chitwanensis* | 7—*Polypedates zed* | 8—*Cyrtodactylus annapurnaensis* | 9—*Cyrtodactylus chitwanensis* | 10—*Cyrtodactylus karanshahi* | 11—*Cyrtodactylus makwanpurgadhiensis* | 12—*Ablepharus mahabharatus* | 13—*Ablepharus nepalensis* | 14—*Ablepharus capitaneus* | 15—*Trimerusurus sepentrionalis* | | 16—*Gloydius nepalensis*.

its occurrence as "presence uncertain" in Nepal (IUCN SSC Amphibian Specialist Group 2023).

Rai et al. (2021) reported the Common Slug Snake *Pareas monticola* from Ilam as a new country record for Nepal. Our field surveys extend the known range of this species approximately 450 km west to the northern hills of Chitwan near Shaktikhor, representing the westernmost record of *P. monticola* within Nepal (Image 4F).

CHAL as a notable Type Locality Hotspot for Herpetofauna

The CHAL represents the type locality for 16 species of herpetofauna (Table 2). These type localities, distributed across a range of biogeographic zones from the lowlands to the high Himalaya, highlight the landscape's ecological heterogeneity and its role as a faunal and floral exchange for species which originate from both the western and eastern Himalaya (KMTNC 1998; NTNC 2020; Bhattarai et al. 2025b). Additionally, several of these type localities occur outside the protected area network (Table 2, Figure 3) and are increasingly affected by anthropogenic pressures and climate change (Pandit 2013; Paudel et al. 2018; Kattel 2022; Hofmann et al. 2024). Populations from type localities provide critical reference material for taxonomic comparisons with congeners and for resolving species boundaries. Conserving these sites is therefore essential not only for safeguarding original populations but also for advancing our understanding of large-scale biodiversity patterns and their underlying evolutionary and ecological processes (Agarwal et al. 2014; Hofmann et al. 2024).

Conservation Gaps

The CHAL spans several of Nepal's biogeographic regions from the lowland (Terai) to the high plateau of the trans-Himalaya region. Most conservation and research activities in Nepal are focused either in the lowland protected areas, where large, charismatic species such as tiger and rhinoceros occur, or in the parts of the trans-Himalayan region which support snow leopard populations (Rawat et al. 2020; Bist et al. 2021). The lower Himalayas, especially the Siwalik Mountain range, are under-surveyed (Bhattarai et al. 2020, 2025b; Gautam et al. 2022). This geologically fragile and unstable mountain ecosystem has high biodiversity significance and deserves a stronger conservation focus (Lamichhane et al. 2021; Subedi et al. 2021).

The overarching document for wildlife and biodiversity conservation in Nepal is the National Parks and Wildlife Conservation Act (1973). Schedule-I of this Act identifies high priority species for conservation. Only three reptiles, namely Burmese Python *Python bivittatus*, Gharial *Gavialis gangeticus*, and Golden Monitor Lizard *Varanus flavescens* are listed. No amphibian species is included in the schedule. There are no species-specific national conservation strategies for any herpetofauna except for Gharial (Bhattarai et al. 2018; DNPWC 2018).

Our records show that there are several critically endangered, and several more endangered reptile and amphibian species present in the CHAL. These species would benefit from consideration in future conservation policy and planning.

Legally, Nepal's environmental impact assessment (EIA) system requires a biodiversity assessment prior to any large development project. Again, amphibians and reptiles are overlooked in many EIA documents. As amphibians and reptiles are very sensitive to local environmental changes, the omission of these species from EIAs risks the extirpation of populations of amphibians and reptiles known from Nepal and may also result in the extinction of some species before they are formally described or documented in Nepal.

Conservation and Research Priorities

Our results show that most herpetofauna species documented in the CHAL are recorded from protected areas, with a further bias towards those PAs which are most accessible. This is most likely due to the concentration of research activity in such areas. More remote protected areas such as Manaslu Conservation Area should be prioritized for future research and conservation activities, since there are clear gains to be made in such places. For example, a recent short herpetological survey in Manaslu Conservation Area led to the description of a new gecko species *Cyrtodactylus karanshahi* (Bhattarai et al. 2025a). Nepal shares common species between India and China, but after the advent and application of molecular techniques in neighbouring countries the taxonomy of several species and groups has undergone substantial changes. Taxonomic studies which integrate morphology, ecology, biogeography, and molecular techniques should be encouraged in Nepal to allow for a better understanding of species distributions and endemicity. Notably, reports of species such as *Ablepharus* sp., *Japalura* sp., *Polypedates* sp., and *Trimeresurus* sp. present in the CHAL, flags a requirement for a dedicated research effort including molecular techniques to explore evolutionary histories (Wang et al. 2019; Khatiwada et al. 2021; Vogel et al. 2022; Vences et al. 2024; Bragin et al. 2025; Malhotra et al. 2025) and taxonomic ambiguities.

CONCLUSIONS

This study highlights the remarkable diversity of amphibians and reptiles in the Chitwan–Annapurna Landscape including 140 species emphasizing the landscape's significance for herpetofauna conservation in the country. The species richness is highest within protected areas, particularly those that are more accessible, underscoring a strong research bias and suggesting that herpetofauna diversity in remote areas remains underestimated. Our findings demonstrate that targeted surveys in underexplored areas can yield substantial conservation gains, including the discovery of new species. Integrative taxonomic approaches combining morphological, ecological, biogeographical, and molecular data are urgently needed to resolve taxonomic uncertainties and improve understanding of species distributions and endemicity. Expanding research beyond well-studied protected areas will be essential for effective, landscape-scale conservation planning in the Chitwan–Annapurna Landscape.

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Author details: Santosh Bhattarai is a conservation biologist, with a focus on Himalayan amphibians and reptiles. His work integrates systematics, biogeography, and ecology to advance the understanding and conservation of herpetofauna in Nepal. Bishal Prasad Neupane is a fellow at the Nepal Conservation and Research Center, with a primary focus on the conservation of Nepal's herpetofauna. His work emphasizes outreach and education to promote awareness and protection of amphibians and reptiles. He also serves as a member of the IUCN Amphibian Specialist Group. Bivek Gautam is a herpetologist. His recent work examines the impacts of wildfires on amphibian populations, combining satellite-based fire analysis with ecological field surveys and community engagement. His research interests include molecular phylogeny, fire ecology, acoustics, modeling, and the conservation of Himalayan amphibians. Mr. Prabin Shrestha is a conservation biologist, primarily works on pangolin conservation and other lesser-known species. His current works include restore and manage degraded watershed. Dr. Ashley R. Olson is an ecologist. His interests include biogeography, species interactions, movement ecology, human-wildlife conflict, and the use of emergent technologies in ecological research. Dr. Fiona Hogan is an associate professor and a molecular ecologist at Federation University Australia. Her research focuses on non-invasive molecular approach to filling knowledge gaps to improve future management of wildlife and natural resources. Dr. Wendy Wright is a professor of conservation biology and Dean of Gradate Research School at Federation University Australia. Her research themes include wildlife conservation, disturbance ecology, conservation in highly modified environments and ecological anthropology.

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ARTICLE

Dietary assessment of tadpoles of selected rhacophorid frogs (*Polypedates*, *Rhacophorus*, *Zhangixalus*) (Amphibia: Anura: Rhacophoridae) of Kangchup, Manipur, India

Yumkham Shelina Devi [1] & Saibal Sengupta [2]

[1,2] Department of Zoology, Assam Don Bosco University, Guwahati, Assam 782402, India.
[1] shelinayumkhamr7@gmail.com, [2] saibal.sengupta@dbuniversity.ac.in (corresponding author)

Abstract: Tadpoles are an abundant and diverse component of many freshwater ecosystems, yet little is known about their trophic status and feeding ecology compared to many other consumer groups. This study used gut content analysis to examine the diet patterns of four rhacophorid tadpole species (*Polypedates mutus*, *P. braueri*, *Rhacophorus bipunctatus*, and *Zhangixalus burmanus*) collected from ephemeral pools in Manipur, India. The food spectrum of tadpoles included mostly phytoplankton (diatoms, desmids, algae), followed by zooplankton (crustaceans, rotifers, insects). It was observed that *Phormidium* and *Surirella* were the primary sources of food for *P. mutus*, whereas *Navicula* and *Netrium* were consumed in large quantities by the other three species. Members of the class Bacillariophyceae (*Melosira* sp., *Navicula* sp., *Synedra* sp.) and Zygnematophyceae (*Netrium* sp.) were consistently present in the gut of all the tadpoles examined. These findings suggest that *Netrium* sp. and *Navicula* sp. represent key dietary components within the ecological niche occupied by the species, highlighting their significant role in the trophic dynamics of the habitat. Trophic niche width and overlap were also analysed between the species. Important insights into the ecological dynamics and conservation of tropical amphibian populations and communities can be acquired from studying the diet of amphibian tadpoles.

Keywords: Diet, dietary flexibility, ephemeral pools, feeding ecology, gut analyses, herbivory, microalgae, niche overlap, niche width, zooplankton.

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Author details: Yumkham Shelina Devi is a PhD scholar in the Department of Zoology, Assam Don Bosco University, Guwahati, Assam, India. Her research focuses on tadpole taxonomy and ecology. Saibal Sengupta is a professor in the Department of Zoology, Assam Don Bosco University, whose research interests include amphibian ecology, conservation biology, and aquatic ecology.

Author contribution: YSD conducted the field surveys, analyzed the data, and prepared the original manuscript draft. SS supervised the study, provided guidance throughout the research work, and reviewed and proofread the manuscript.

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INTRODUCTION

Tadpoles live in freshwater habitats and are remarkably diverse, occurring in both lotic and lentic ecosystems throughout tropical regions (Inger et al. 1986; Whiles et al. 2006). They play a variety of ecological roles in their ecosystems, have a wide range of microhabitats, and show considerable morphological variation (Altig & Johnston 1989). Saidapur (1989) also highlighted that many Indian anuran species co-breed and use a range of lentic and lotic water bodies, including rivers, streams, ephemeral ponds, wet grounds, temporary puddles, and permanent ponds following the south-west monsoon rains.

A fundamental aspect of tadpole biology involves understanding food and feeding techniques. Since amphibians' diets reflect the availability of food of optimum size, it is generally believed that they are feeding opportunists (Asrafuzzaman et al. 2018). It is crucial to understand the tadpole's diet and feeding habits as the early stages of an amphibian's life depend on the availability of food in their natural environment (Diaz–Paniagua 1985; Inger 1986). Dietary data for anuran larvae have only been published in the last 30 years (Khare & Sahu 1984; Ao & Khare 1986; Sekar 1990; Saidapur 2001; Sinha et al. 2001; Khongwir et al. 2003). The feeding ecology of tadpoles has been poorly studied despite their diversity and abundance in various kinds of freshwater habitats (Altig et al. 2007).

According to Duellman & Trueb (1994), tadpoles are regarded as specialized filter-feeder herbivores since they eat a wide range of algae during their development period (Wickramasinghe et al. 2007). Tadpoles may additionally consume microscopic organisms, fungi, and protozoa that are present in their environment, making them omnivores (Altig & Johnston 1989). Further study shows that tadpoles are more carnivorous than previously believed (Petranka et al. 1998) or that they are nonselective consumers (Seale 1980) with little dietary differentiation (Kupferberg 1997). Despite their high diversity and abundance across a wide range of freshwater habitats, the feeding ecology of tadpoles remains poorly understood and inadequately explored (Altig et al. 2007).

The tadpoles of India, especially those from the northeastern region, are very poorly documented. A great deal of studies on amphibians have focused on the Western Ghats, a biodiversity hotspot, with little research done in other parts of India (Aravind & Gururaja 2011). In the present study, the diet of tadpoles of four Rhacophorids (*Polypedates mutus*, *P. braueri*, *Rhacophorus bipunctatus*, *Zhangixalus burmanus*) of Gosner stage 32–36 (Gosner 1960), were investigated based on the hypothesis that species that dwell in the same microhabitat must share similar food resources. By documenting the food items consumed during their developmental stages, it was aimed to gain insights into their feeding behaviour and to quantify niche width and niche overlap amongst tadpoles to assess the extent of resource partitioning.

MATERIALS AND METHODS

Sample collection

Tadpoles were collected from ephemeral pools during the month of June–September (2023–2024) from 1100 h to 1600 h from the foothills of Kangchup, Manipur (24.859° N, 93.810° E) located in Imphal–west District by visual encounter survey using dip-net (1 × 1 m). Pools were sampled for approximately 15 minutes. Dip-net sweeps were performed systematically along the margins and open water of each pool to ensure representative sampling. Collected tadpoles (N = 10 for each species of Gosner stage 32–36) were euthanised using tricaine methane sulphonate (5 g/L MS-222). After which, they were preserved in 10% formalin immediately after collection to prevent the complete digestion of food particles they had consumed. Tadpoles were deposited in the laboratory of Assam Don Bosco University.

Identification

The identification of tadpoles was based on the morphology observed, which includes colour pattern, pigmentation, body shape, position of the spiracles, vent tube, eyes, nostrils, and morphometric relations (Inger 1986; Sahu 1994; Grosjean 2001; Malkmus et al. 2002). Further, tadpoles were matched with syntopic adults based on partial sequences of the mitochondrial 16S rRNA gene.

Gut analyses

The entire length of the alimentary canal of each tadpole was removed through a longitudinal incision from mouth to anus. The gut contents were collected on a Petri plate and were stored in 10% formalin. Each sample was analysed in six replicates on glass slides using a Leica DMLS2 light microscope at 10× magnification, and when necessary, 40× magnification was used. The food items were quantified as the number of individuals per field of view over 10 observations per slide, and classified to the lowest possible taxonomic level following Needham

& Needham (1962), van der Valk (2012), and Thorp et al. (2014).

Data analyses

The items ingested by tadpoles were expressed as proportional utilization (% PU) and occurrence frequency (% OF). Further, prey-specific abundance (%) was calculated following Costello (1990) and the modified model of Amundsen et al. (1996).

The Shannon-Wiener index (H') was used to determine diet diversity for all four species, and Levins' measure (B) to determine the niche width for different types of food items consumed (Krebs 1999). Niche overlap was calculated following Pianka (1973). Venn diagrams showing the shared and unique food items between the taxonomically related pairs were created using R software (version 4.4.3).

RESULTS

Around 23 different food items were identified from *Polypedates mutus* tadpoles, 14 food items from *Polypedates braueri*, 13 from *Zhangixalus burmanus*, and 15 from *Rhacophorus bipunctatus*. The total amount of food items ingested by tadpoles varied markedly. Of the four species studied, *P. mutus* consumed different food items but in smaller amounts, while *R. bipunctatus* preferred limited food items but in larger amounts.

Five food items were consistently present in the diets of all four species examined: *Melosira* (diatoms), *Navicula* (diatoms), *Synedra* (diatoms), *Netrium* (desmids), and *Phormidium* (blue-green algae). In addition to these, *Meridion* (diatoms), *Gomphonema* (diatoms), *Diatoma* (diatoms), *Closterium* (desmids), and *Dileptus* (protozoans) were commonly found in the diets of *R. bipunctatus* and *Z. burmanus*. While, *Gyrosigma* (diatoms), *Ophiocytium* (green algae), *Oscillatoria* (blue-green algae), *Monostyla* (rotifers) and *Euglena* (protozoans) were commonly present in the diet of *P. mutus* and *P. braueri* (Table 1). Rotaria (16.66%), Cyclops (16.66%), and *Penium* sp. (14.28%) were the rare food items.

Certain prey items were species specific: *Euastrum* (desmids) was only consumed by *Z. burmanus*. Likewise, *Achnanthes* (diatoms), *Cocconeis* (diatoms), *Eunotia* (diatoms) and egg parasites were unique to *R. bipunctatus*; *Penium* (desmids), *Rotaria* (rotifers), Cyclops (crustaceans), and *Spirulina* (blue-green algae) to *P. mutus*; *Epithemia* (diatoms), *Amphora* (diatoms), *Surirella* (diatoms), *Pediastrum* (green algae), *Mougeotia* (green algae), *Microspora* (green algae), *Euchlanis* (rotifers), *Coelosphaerium* (blue-green algae), *Selenastrum* (green algae), and *Crucigenia* (green algae) to *P. braueri*.

The most dominant food items in the gut of *P. mutus* tadpoles were *Phormidium* sp. (39.9%) and *Surirella* sp. (25.4%); *Navicula* sp. (47.4%) and *Netrium* sp. (17.8%) in *P. braueri*; *Navicula* sp. (37.2%) and *Netrium* sp. (27.8%) in *Z. burmanus*; *Navicula* sp. (55.5%) and *Netrium* sp. (27.6%) in *R. bipunctatus*, respectively (Figure 1). Two genera, namely *Navicula* sp. and *Netrium* sp., dominated the food spectrum.

Tadpoles of *P. mutus* consumed *Synedra* sp., *Phormidium* sp., *Navicula* sp. and *Coelosphaerium* sp., with an occurrence frequency of 100% in their diet (Table 2). The least occurring food items were *Melosira* sp., *Epithemia* sp., *Gyrosigma* sp., Cyclops, *Netrium* sp., and *Rotaria* (16.66%). In the congeneric species *P. braueri*, *Meridion* sp., *Netrium* sp., *Melosira* sp., *Synedra*

Table 1. Food items identified from the intestine of anuran tadpoles: PM—*Polypedates mutus* | PB—*Polypedates braueri* | RB—*Rhacophorus bipunctatus* | ZB—*Zhangixalus burmanus* | +—present | -—absent.

Class	Genus	PM	PB	ZB	RB
Bacillariophycea	*Melosira* sp.	+	+	+	+
	Navicula sp.	+	+	+	+
	Synedra sp.	+	+	+	+
	Meridion sp.	+	-	+	+
	Gomphonema sp.	-	+	+	+
	Diatoma sp.	-	-	+	+
	Achnanthes sp.	-	-	-	+
	Gyrosigma sp.	+	+	-	+
	Cocconeis sp.	-	-	-	+
	Eunotia sp.	-	-	-	+
	Epithemia sp.	-	+	-	-
	Amphora sp.	-	+	-	-
	Surirella sp.		+		
Zygnematophyceae	*Netrium* sp.	+	+	+	+
	Closterium sp.	-	-	+	+
	Euastrum sp.	-	-	+	-
	Penium sp.	+	-	-	-
	Ophiocytium sp.	+	+	-	-
	Mougeotia sp.	-	+	-	-
Cyanophyceae	*Phormidium* sp.	+	+	+	+
	Spirulina sp.	+	-	-	-
	Oscillatoria sp.	+	+	-	-
	Microspora sp.	-	+	-	-
Monogononta	*Monostyla* sp.	+	+	+	-
	Euchlanis sp.	-	+	-	-
	Rotaria sp.	+	-	-	-
Litostomatea	*Dileptus* sp.	+	-	+	+
Euglenophyceae	*Euglena* sp.	+	+	+	-
Chlorophyceae	*Pediastrum* sp.	-	+	-	-
	Coelosphaerium sp.	-	+	-	-
	Selenastrum sp.	-	+	-	-
	Crucigenia sp.	-	+	-	-
Crustacea	*Cyclops* sp.	+	-	-	-
Insecta	Eggs of parasites	-	-	-	+
	Miscellaneous invertebrates	-	+	+	-

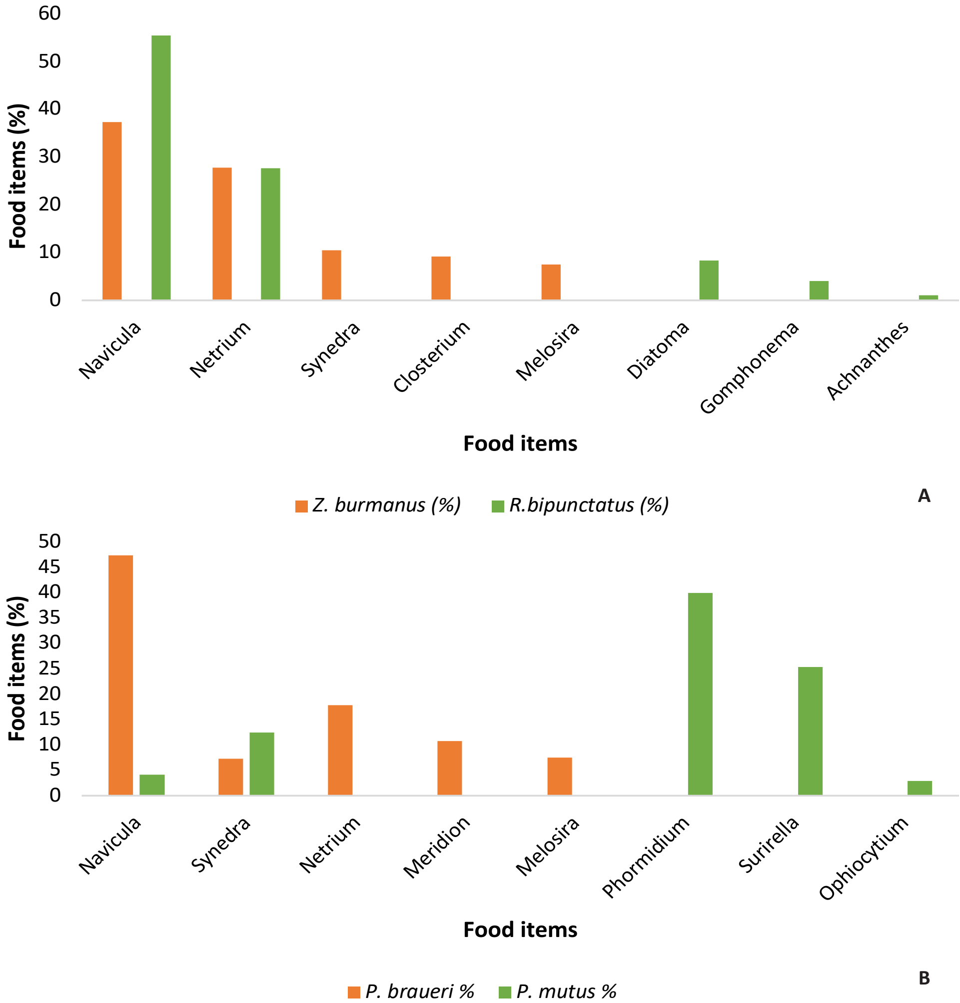

Figure 1. Five most abundant food items of each species of taxonomically related pairs and of the congenerics: A—*Zhangixalus burmanus* and *Rhacophorus bipunctatus* | B—*Polypedates mutus* and *P. braueri*.

sp., *Navicula* sp., and *Phormidium* sp. were ingested by the tadpoles, with a 100% occurrence frequency in their diet (Table 3). The least occurring food items of this species were *Penium* sp. and *Oscillatoria* sp. (14.28%).

Tadpoles of *R. bipunctatus* consumed *Navicula* sp., *Netrium* sp., *Gomphonema* sp., *Achnanthes* sp., *Diatoma* sp., *Melosira* sp., and *Cocconeis* sp. with an occurrence frequency of 100% in their diet (Table 4). The least occurring food items were *Synedra* sp. (0.46%) and *Gyrosigma* sp. (0.22%). While, in the congeneric species *Z. burmanus*, most of the food items were ingested by the tadpoles with an occurrence frequency of 100% and 75% except for *Euglena* sp. with 25% occurrence frequency (Table 5).

Phormidium sp. showed the highest Pi value (39.84) among all the food items ingested by *P. mutus* tadpoles, suggesting that it is both frequently consumed and a highly dominant component. *Navicula* sp. also exhibited the highest Pi value (47.37) in the diet of *P. braueri* tadpoles, indicating that it is a significant dietary component. It was observed that members of *Navicula* sp. dominated the food spectrum of *R. bipunctatus* (Pi: 55.49) and *Z. burmanus* (Pi: 37.23).

The analysis revealed a high trophic niche overlap value (0.92) between the tadpoles *R. bipunctatus* and *Z. burmanus*, suggesting potential competition for shared food resources. In contrast, the low overlap value between *P. braueri* and *P. mutus* (0.18) suggests minimal trophic overlap and reduced competition, indicating clear resource partitioning despite their congeneric and sympatric occurrence (Figure 2).

Niche width was found to be the lowest in *P. mutus* tadpoles (0.27) indicating that the species has a narrow ecological niche while niche width was highest in *Z. burmanus* (1.81) suggesting a wide range of ecological niche among the four tadpole species examined.

Table 2. Proportional utilization, occurrence frequency and prey-specific dominance of different food items in the tadpoles of *Polypedates mutus*.

Polypedates mutus	Proportional utilization	Occurrence frequency (%)	Prey specific dominance pi (%)
Microspora sp.	0.009	66.666	1.340
Synedra sp.	0.124	100	12.388
Phormidium sp.	0.398	100	39.843
Rotifers	0.005	50	1.052
Melosira sp.	0.009	16.666	5.797
Navicula sp.	0.041	100	4.129
Epithemia sp.	0.002	16.666	1.538
Gomphonema sp.	0.012	33.333	4.347
Miscellaneous invertebrates	0.015	83.333	1.827
Gyrosigma sp.	0.002	16.666	1.538
Pediastrum sp.	0.003	33.333	1.056
Cyclops	0.001	16.666	0.813
Mougeotia sp.	0.004	33.333	1.212
Amphora sp.	0.001	16.666	0.769
Coelosphaerium sp.	0.022	100	2.232
Oscillatoria sp.	0.008	50	1.690
Selenastrum sp.	0.011	66.666	1.672
Netrium sp.	0.017	16.666	11.538
Ophiocytium sp.	0.029	83.333	3.363
Rotaria sp.	0.001	16.666	0.729
Surirella sp.	0.253	66.666	35.303
Euglena sp.	0.019	66.666	2.643
Crucigenia sp.	0.008	33.333	2.027

Rhacophorus bipunctatus tadpoles have moderately narrow niche width (1.08) and *P. braueri* has an intermediate (1.37) niche width (Table 6).

DISCUSSION

The present study revealed that the food diversity of four tadpole species includes various microalgae, mainly from three classes namely, Bacillariophyceae, Zygnematophyceae, and Cyanophyceae. Bacillariophyceae have been identified as the most commonly ingested food item in the diets of various lentic tadpoles (Rossa-Feres et al. 2004; Echeverría et al. 2007; Bionda et al. 2012; Huckembeck et al. 2016; Mohapatra et al. 2017; Rout et al. 2018), suggesting that high diatom concentrations in tadpole intestinal contents could be considered a widespread occurrence. Sengupta et al. (2013) observed seven different food items in the gut of five species of tadpoles of Basistha stream in Assam, India with diatoms (class Bacillariophyceae) being the most abundant food items consumed by tadpoles, which was also observed in this study.

Table 3. Proportional utilization, occurrence frequency and prey-specific dominance of different food items in the tadpoles of *Polypedates braueri*.

Polypedates braueri	Proportional utilization	Occurrence frequency (%)	Prey specific dominance pi (%)
Meridion sp.	0.108	100	10.807
Netrium sp.	0.178	100	17.794
Melosira sp.	0.075	100	7.532
Synedra sp.	0.073	100	7.314
Penium sp.	0.001	14.285	0.917
Spirulina sp.	0.009	85.714	1.168
Navicula sp.	0.474	100	47.379
Monostyla sp.	0.004	42.850	1.142
Phormidium sp.	0.036	100	3.602
Oscillatoria sp.	0.001	14.285	0.917
Dileptus sp.	0.009	42.850	2.244
Euglena sp.	0.003	42.850	0.810
Ophiocytium sp.	0.018	71.428	2.387
Gyrosigma sp.	0.007	42.850	1.601

Table 4. Proportional utilization, occurrence frequency and prey-specific dominance of different food items in the tadpoles of *Rhacophorus bipunctatus*.

Rhacophorus bipunctatus	Proportional utilization	Occurrence frequency (%)	Prey specific dominance pi (%)
Navicula sp.	0.555	100	55.493
Netrium sp.	0.276	100	27.638
Dileptus sp.	0.003	71.428	0.422
Synedra sp.	0.001	28.571	0.464
Gomphonema sp.	0.041	100	4.085
Achnanthes sp.	0.010	100	1.021
Gyrosigma sp.	0.001	28.571	0.219
Diatoma sp.	0.084	100	8.387
Melosira sp.	0.006	100	0.588
Meridion sp.	0.007	85.714	0.785
Cocconeis sp.	0.006	100	0.649
Closterium sp.	0.002	57.142	0.449
Phormidium sp.	0.002	71.428	0.308
Eggs of parasites	0.003	85.714	0.320
Eunotia sp.	0.003	42.850	0.595

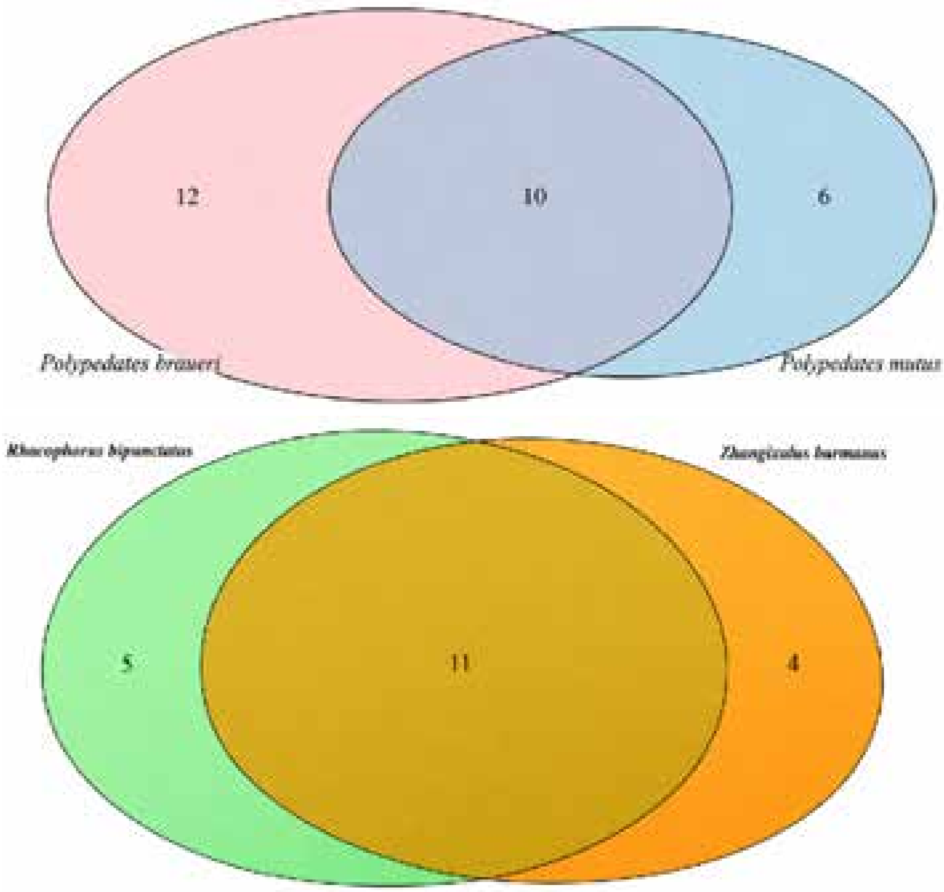

Figure 2. Venn diagram showing shared and unique food items between: a—*Polypedates braueri* and *P. mutus* | b—*Rhacophorus bipunctatus* and *Zhangixalus burmanus*. The overlapping region represents food items consumed by both species, and the non-overlapping region represents species-specific items.

Sinha et al. (2001) conducted qualitative analyses of the food spectrum of five species of anuran tadpoles (*Bufo melanostictus*, *Rhacophorus maximus*, *Amolops afghanus*, *Rana danieli*, and *Euphlyctis cyanophlyctis*) from Arunachal Pradesh, India. They found that diatoms and Chlorophyta were present in all five species. In the present study, diatoms were consumed by all four tadpoles' species, whereas green algae and crustaceans were consumed exclusively by *P. braueri* tadpoles. In accordance with studies conducted by Sinha et al. (2001) and Lalremsanga et al. (2013), the predominant prey category in the diets of *P. maculatus* tadpoles was found to be members of the class Bacillariophyceae. This study also revealed similar findings.

Rotifers, crustaceans, protozoans, and other miscellaneous invertebrates have also been documented in the diets of other species (Candioti 2005; Dutra & Callisto 2005; Heinen & Abdella 2005; Pfennig et al. 2006; Sousa Filho et al. 2007; Wickramasinghe et al. 2007). In the present study, the diets of the examined tadpoles were also found to contain these groups. Additionally, the consumption of eggs of the parasitic worm by *R. bipunctatus* tadpoles demonstrates dietary flexibility, shifting from herbivory to omnivory, as observed by Jacobson et al. (2019) in *Triprion petasatus*. The high nutritional value of invertebrates, particularly in terms of protein and energy, is noteworthy (Bowen et al. 1995). Heinen & Abdella (2005) also suggested that tadpoles require animal food items during their developmental stage for faster growth.

Apart from a large amount of debris ingested accidentally, gut content analysis revealed that the tadpoles' diet consisted primarily of desmids and diatoms, which does not align with the findings of Lajmanovich (2000) and Rossa-Feres et al. (2004), where diatoms and microalgae were the most predominant food items. Bacillariophyceae members are more convenient to eat than filamentous algae, and they may be the richest source of food in their environment (Kupferberg 1997).

Table 5. Proportional utilization, occurrence frequency and prey-specific dominance of different food items in the tadpoles of *Zhangixalus burmanus*.

Zhangixalus burmanus	Proportional utilization	Occurrence frequency (%)	Prey specific dominance pI (%)
Melosira sp.	0.074	100	7.470
Navicula sp.	0.372	100	37.235
Netrium sp.	0.278	100	27.794
Closterium sp.	0.092	100	9.214
Phormidium sp.	0.025	100	2.568
Synedra sp.	0.104	100	10.423
Meridion sp.	0.006	75	0.778
Euastrum sp.	0.019	100	1.888
Monostyla sp.	0.006	100	0.604
Gomphonema sp.	0.007	100	0.755
Diatoma sp.	0.007	100	0.755
Dileptus sp.	0.005	75	0.715
Euglena sp.	0.001	25	0.327

Table 6. Niche width (B) and Shannon-Weiner diversity index (H') of the diet of tadpoles in the ephemeral pools of Kangchup, Manipur, India.

Species	B	H'
Polypedates mutus	0.27	1.89
Polypedates braueri	1.37	1.66
Zhangixalus burmanus	1.81	1.71
Rhacophorus bipunctatus	1.08	1.25

Tadpoles live in microhabitats where they can readily access resources and food (Inger et al. 1986; Horat & Semlitsch 1994). As adaptive omnivores rather than specialized feeders, tadpoles are unlikely to differentiate themselves by food partitioning (Hoff et al. 1999). Considering that food conditions vary depending on habitat, anuran larval dietary patterns should correspond to its distribution pattern; a species may have evolved to be more successful with the nutrient conditions that exist in its ideal habitat, or a species may select the habitat where its appropriate food is abundant (Iwai & Kagaya 2005). Understanding the dietary and feeding habits of tadpoles is crucial because the early stages of an amphibian's existence depend on the food resources in their environment (Sinha et al. 2001).

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ARTICLE

Eastern range record of the semiaquatic freshwater earthworm *Glyphidrilus gangeticus* Gates, 1958 (Clitellata: Crassiclitellata: Almidae) from West Bengal, India, with a brief key to the Indian species of the genus

M. Nurul Hasan [1], John Warren Reynolds [2], Hasko F. Nesemann [3], Shyamasree Ghosh [4] & Chandra Kanta Mandal [5]

[1,5] Zoological Survey of India (Ministry of Environment, Forest and Climate Change, Government of India), FPS Building, Indian Museum Campus, 27 JL Nehru Road, Kolkata, West Bengal 700016, India.
[2] Oligochaetology Laboratory, Kitchener, Ontario, N2A 4E1 Canada and New Brunswick Museum, Saint John, New Brunswick, E2K 1E5, Canada.
[3] Im Obergarten 9, D-65719 Hofheim am Taunus, Hesse, Germany.
[4] School of Biological Sciences, National Institute of Science Education and Research (NISER), Bhubaneswar, Odisha, India.
[4] Homi Bhabha National Institute, Training School Complex , Anushakti Nagar, Mumbai 400094, India.
[1] nhasan.mld@gmail.com (corresponding author), [2] john.w.reynolds1941@gmail.com, [3] hnesemann2000@yahoo.co.in, [4] shyamasree_b@yahoo.com, [5] mandalsucker@gmail.com

Abstract: The semi-aquatic earthworm genus *Glyphidrilus* is poorly documented in West Bengal, India, with only one species previously recorded. To fill this distribution gap, we surveyed riverbanks of the Mahananda River (West Bengal) and Ganga River (Bihar). Earthworms were collected by hand sorting from wet soil and mud during low-water conditions in 2021 and 2024, preserved in 4% formalin, and identified using morphological characters under a stereomicroscope. We report the first record of *Glyphidrilus gangeticus* Gates, 1958 from West Bengal, extending its known range eastward from Uttar Pradesh and Bihar. Additionally, we provide a revised identification key to all seven Indian species of *Glyphidrilus* (*annandalei*, *elegans*, *fluviatilis*, *gangeticus*, *papillatus*, *spelaeotes*, and *tuberosus*) based on literature and newly examined material. This discovery increases the number of *Glyphidrilus* species known from West Bengal to two and highlights the need for further surveys of semi-aquatic habitats in the Gangetic plains. The improved key will aid future biodiversity assessments and conservation planning.

Keywords: Almidae, first record, freshwater biodiversity, Ganga River, identification key, Mahananda River, semiaquatic earthworms.

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Author details: M. Nurul Hasan, Ph.D. research scholar, is working on the annelid fauna of India with special emphasis on taxonomy and biodiversity studies. He is affiliated with the Zoological Survey of India (Ministry of Environment, Forest and Climate Change, Government of India), West Bengal. John Warren Reynolds, Ph.D., LL.B., is director of the Oligochaetology Laboratory, Kitchener, Canada, and research associate at the University of New Brunswick, Saint John, Canada. His specialization is the taxonomy, systematics, and biogeography of the Oligochaeta. Hasko F. Nesemann, Ph.D., is an independent researcher affiliated with Im Obergarten 9, Germany. His research interests include freshwater biodiversity, aquatic ecology, and annelid taxonomy. Shyamasree Ghosh, Ph.D., is working in the capacity of scientific officer at the School of Biological Sciences (SBS), National Institute of Science Education and Research, Bhubaneswar, Odisha, India, under the Homi Bhabha National Institute, Mumbai. Her research activities involve molecular biology and biodiversity sciences. Chandra Kanta Mandal, Ph.D., scientist, is an expert on the annelid fauna of India and is affiliated with the Zoological Survey of India (Ministry of Environment, Forest and Climate Change, Government of India), West Bengal.

Author contribution: MNH, JWR and CKM: conceptualization, investigation and writing – original draft. MNH, JWR, CKM and SG: data curation, monitoring and validation. MNH, JWR, CKM and SG: visualization. MNH, JWR, CKM, SG and HN: writing, reviewing and editing. All authors contributed to the article and approved the submitted version.

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INTRODUCTION

There are approximately 5,739 species and subspecies of megadrile earthworms worldwide (Marchán et al. 2022; Mısırlıoğlu et al. 2023; Reynolds & Wetzel 2025). At present, India has 457 species under 10 families – Almidae, Acanthodrilidae, Benhamiidae, Eudrilidae, Lumbricidae, Moniligastridae, Megascolecidae, Ocnerodrilidae, Octochaetidae, and Rhinodrilidae (Balakrishnan et al. 2024). India hosts 12.5% of the world's known earthworm species (Julka et al. 2009), with 71% of genera and 85% of species endemic (Julka & Paliwal 2005). *Glyphidrilus* (40 species-level taxa) is found in China, Cambodia, India, Indonesia, Laos, Myanmar, Sri Lanka, Singapore, and Thailand, but only one species, *G. stuhlmanni* Michaelsen, 1897, has been recorded from Africa (Chanabun et al. 2013). *Glyphidrilus* is mainly represented in the Gangetic plains and associated freshwater habitats. Classical works by Stephenson (1923) and Julka (1988) documented the presence of several species, including *G. gangeticus*, *G. tuberosus*, *G. fluviatilis*, *G. elegans*, *G. spelaeotes*, *G. papillatus*, and *G. annandalei*. These records highlight the genus as an important faunal component of Indian freshwater ecosystems. Recent surveys and taxonomic contributions (Narayanan et al. 2023) continue to confirm the occurrence of these species, while also emphasizing the need for detailed ecological and molecular studies to resolve species boundaries.

Despite these records, the earthworm fauna of West Bengal remains poorly explored for semi-aquatic *Glyphidrilus* species. Only *G. tuberosus* has been reported from the state (Ahmed et al. 2022), leaving a significant distributional gap for other species, including *G. gangeticus*, which is known from adjacent states (Uttar Pradesh and Bihar).

We hypothesize that *Glyphidrilus gangeticus* occurs in West Bengal due to the hydrological continuity of the Ganga River system, which may facilitate eastward dispersal along the Gangetic floodplains.

The present study was undertaken to: (1) survey selected riverbanks in West Bengal and Bihar for the presence of *Glyphidrilus* species; (2) confirm the identity of any newly collected material using morphological characters; (3) report the first record of *G. gangeticus* from West Bengal, if found; and (4) compile an improved identification key for all seven Indian *Glyphidrilus* species to aid future research.

Glyphidrilus species play important roles in sediment aeration and nutrient cycling and can serve as bioindicators of freshwater ecosystem health (Chanabun et al. 2013). Detailed ecological functions have been reviewed elsewhere and are not repeated here to avoid redundancy. Many regions of India remain unexplored for earthworms, and targeted surveys are needed to fill knowledge gaps. The present study addresses this need by providing a new state record and a practical identification tool.

MATERIALS AND METHODS

The study areas were the semiaquatic riverbanks of the lower Mahananda River in West Bengal and the Ganga River in Bihar (Figure 1).

The earthworms were collected in low-water conditions during the years 2021 and 2024 from the wet soil and mud by digging and sorting by hand from fallen tree trunks and leaf litter. The collected samples of earthworms were washed with water and preserved in 4% formalin overnight and then transferred to 70% alcohol for identification. Identification was done using a Leica EZ4HD stereomicroscope. The morphometric characters of the species were carefully recorded after preservation. Measurements were taken manually using a slide caliper, which allowed accurate determination of body length, width, and segmental details. This method ensured precision in documenting the diagnostic features essential for taxonomic study. The collected specimens were identified using Blakemore (2012), Gates (1972), Julka (1988), and Stephenson (1923). The specimens were deposited with the Zoological Survey of India, headquarters, Kolkata (ZSI), and additional specimens at the Gangetic Plains Regional Centre, Patna.

RESULTS

Genus *Glyphidrilus* Horst, 1889

Glyphidrilus Horst, 1889: 86. Type species: *Glyphidrilus weberi* Horst, 1889.
Bilimba Rosa, 1890: 386.
Annadrilus Horst, 1893: 44.
Glyphidrilus + Bilimba + Annadrilus - Beddard, 1895: 679, 686, 680.
Glyphidrilus Michaelsen, 1900: 459.
Glyphidrilus Michaelsen, 1909: 244.
Glyphidrilus Michaelsen, 1910: 99.
Glyphidrilus Michaelsen, 1918: 343.
Glyphidrilus Gates, 1972: 234.

Currently, 40 species of the *Glyphidrilus* genus have been reported from Asia (from the Indonesian islands

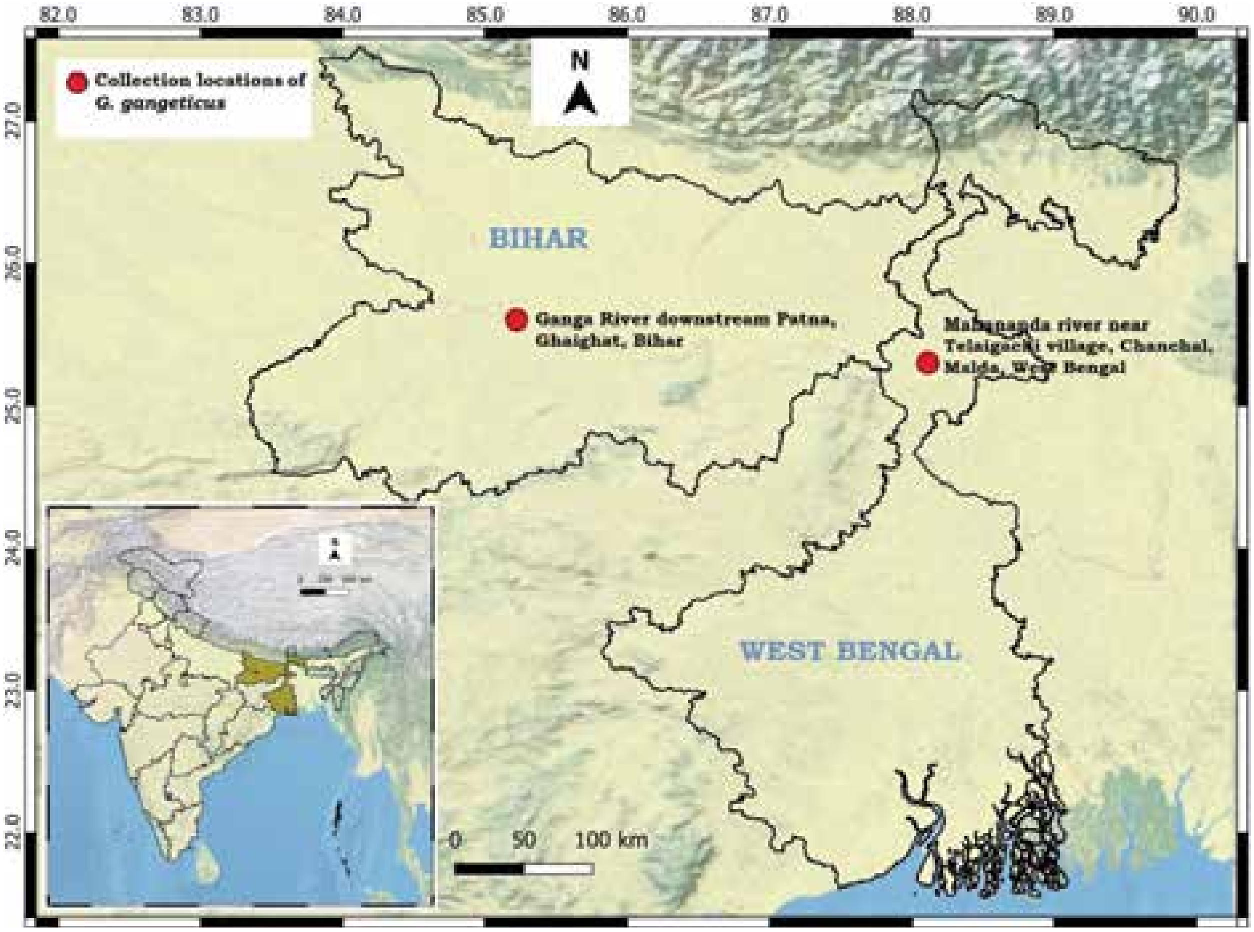

Figure 1. Study area of *Glyphidrilus gangeticus* Gates, 1958 in West Bengal and Bihar in India. (Map made by Q-GIS).

to the Malay Peninsula and Myanmar, extending to western India, to northern China and Africa (Gates 1951; Naidu 2005; Chanabun et al. 2013). Thus, a key for seven species of *Glyphidrilus* found in India is presented. These taxa are briefly characterized by their external features together with a short synonymy, based on the cited references.

1. ***Glyphidrilus gangeticus* Gates, 1958**

Glyphidrilus sp.? Michaelsen, 1909: 244.

Glyphidrilus papillatus Stephenson, 1920: 258–260.

Glyphidrilus papillatus (part) - Stephenson, 1923: 493.

Glyphidrilus sp. - Gates, 1947: 121.

Glyphidrilus papillatus Gates, 1948: 175–176.

Glyphidrilus papillatus Gates, 1951: 17.

Glyphidrilus gangeticus Gates, 1958: 58 Type missing (Reynolds & Wetzel, 2025).

Glyphidrilus gangeticus Narayanan et al., 2023: 114.

Type locality: Saharanpur, Uttar Pradesh State, India.

Material examined: (from Gates 1959; Stephenson 1920). India; West Bengal, Mahananda River near Telaigachi Village, Chanchal, Malda, 25.302° N, 88.111° E, 6 m; 26.xii.2021; M. Nurul Hasan leg.; 9 clitellate adults (0-0-9) ex. Reg. no. ZSI-An6247/1. Bihar State, Ganga River downstream Patna, Ghaighat, 25.606° N, 85.221° E, 64 m; 12.iv.2024, Gopal Sharma with Hasko Nesemann, 2 clitellate adults (0-0-2) ex. Reg. no. NDRC/IV/2024.

Brief description: Length 85–140 mm, diameter 3–5 mm. Number of segments 202–340. The prostomium is zygolobous. Clitellum, saddle, xiii, xvi, xvii–xxxiv. Wings xviii–xxiii. Spermathecal pores are not visible in 12/13–16/17 segments. One female pore on 14 near setal line B, about midway between 13/14 and the setal equator. Dorsal pores absent. The G. gangeticus morphological characters of the gizzard, heart, seminal vesicles (4 pairs), spermathecae (4 pairs), nephridia and dorsal blood vessels are provided in Image 1. Setae closely paired. Prostates absent. Typhlosole begins in xviii.

Distribution: India (Assam, Delhi, Uttarakhand, Uttar Pradesh, Bihar (Michaelsen 1909; Stephenson 1920;

Gates 1951; Naidu 2005; Chanabun et al. 2013), and West Bengal); Thailand (Nesemann et al. 2004, 2007).

2. ***Glyphidrilus tuberosus*** **Stephenson, 1916**

Glyphidrilus tuberosus, Stephenson, 1916: 349. Type: Zoological Survey of India, Calcutta, cat. no. 6517 (Reynolds & Wetzel 2025).

Glyphidrilus papillatus Gates, 1958: 59.

Glyphidrilus tuberosus Narayanan et al., 2023: 114.

Type locality. Kendrapara Canal near Cuttack, Odisha State, India.

Material examined: None.

Brief description: (from Gates 1958; Stephenson 1916). Length 60 mm, maximum diameter 3 mm. Number of segments 215–221. Size of the segments is smaller after the clitellar region. Colour is brown. Dorsal surface is concave in arrears of the clitellum xiv, xv, xvi–xxviii, xxix, xxx, ventral surface flat and concave occasionally. Wings ~~xx–~~xxiv. The section of the body looks four-sided. Prostomium pro- or zygolobous. Setae are widely paired. Gizzard in vii. No calciferous glands.

Distribution: India (Bihar, Jharkhand, Karnataka, Madhya Pradesh, Odisha, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh and West Bengal (Stephenson 1923, Julka & Senapati 1987 and Mandal & Kumar 2018)); Bangladesh (Das & Reynolds 2003).

3. ***Glyphidrilus annandalei*** **Michaelsen, 1910**

Glyphidrilus annandalei Michaelsen, 1910: 101. Type: Zoologisches Museum Universität Hamburg cat. no. 3600! (Reynolds & Wetzel, 2025)

Glyphidrilus annandalei Cognetti, 1900: 502.

Glyphidrilus achencoili (laps.) - Michaelsen, 1913: 92.

Glyphidrilus annandalei - Stephenson, 1916: 349.

Glyphidrilus annandalei- Michaelsen, 1918: 344.

Glyphidrilus annandalei - Stephenson, 1921: 767.

Glyphidrilus fluciatilis + G. elegans + G. rarus + G. saffronensis - Rao, 1922: 53, 66.

Glyphidrilus annandalei - Stephenson, 1922: 387.

Glyphidrilus annandalei - Narayanan et al., 2023: 112.

Type locality: Quilon (Kollam), Kerala State, India.

Material examined: None.

Brief description: (from Michaelsen, 1910; Stephenson, 1916, 1921). Length 90–265 mm, diameter 2.5–11 mm. Number of segments 125–322. Colour dark grey, without any pigmentation; a slight pink colour is found on the clitellum. Four-sided section found in its subsequent half of the body. The dorsal side broader than the ventral side.

Distribution: Endemic to India (Karnataka, Kerala (Rao 1922; Chanabun et al. 2013; Narayanan et al. 2023), Madhya Pradesh, Tamil Nadu, Uttarakhand, Uttar Pradesh (Stephenson 1923)).

4. ***Glyphidrilus elegans*** **Rao, 1922**

Glyphidrilus elegans Rao, 1922; 62. Type locality: Mysore, India. Type: British Museum (Natural History)

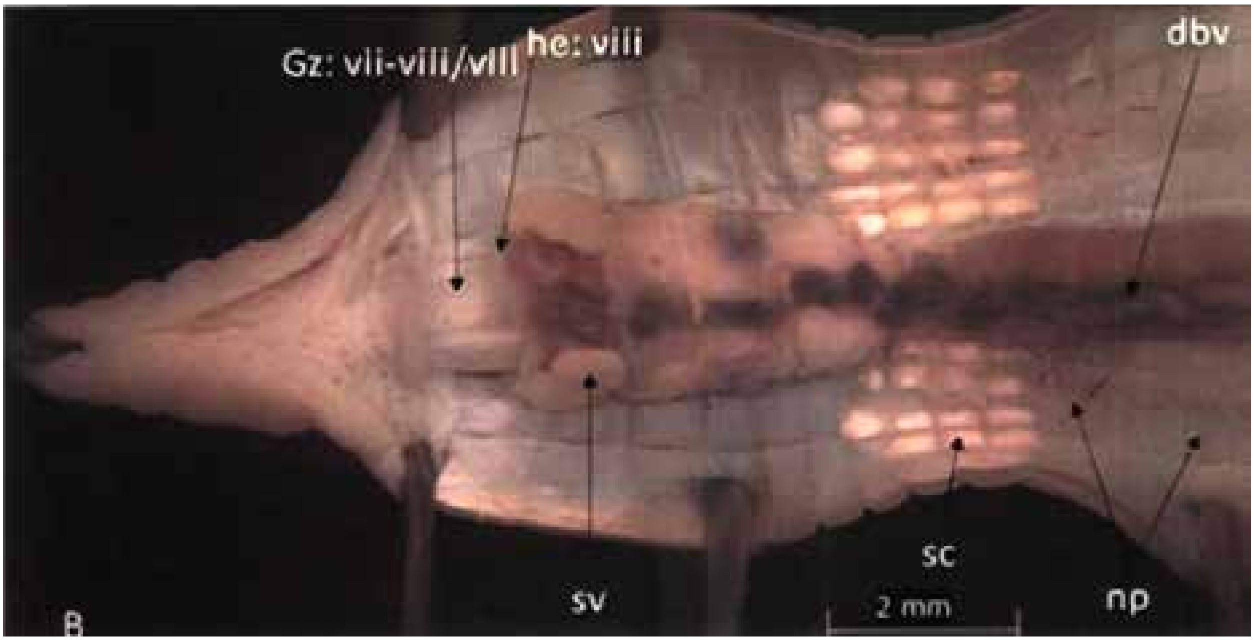

Image 1. *Glyphidrilus gangeticus* Gates, 1958: B-gz—Gizzard | he—Heart | sv—Seminal vesicle | sc—Spermathecae | np—Nephridia | dbv—Dorsal blood vessels.

1922:4:20:9! (Reynolds & Wetzel, 2025).

Glyphidrilus annandalei - Stephenson, 1923: 491.

Glyphidrilus annandalei Brinkhurst & Jamieson, 1971: 755.

Glyphidrilus elegans Chanabun et al., 2013: 27.

Glyphidrilus elegans - Narayanan et al., 2023: 113.

Type locality: Sandy islets in the Cauvery River in Dubari Forest at Fraserpett (=Kushalnagar), Karnataka State, India.

Material examined: None.

Brief description: (from Rao 1922; Stephenson 1923; Brinkhurst & Jamieson 1971). Length 139 mm. Body quadrangular in transverse section behind the clitellum, cylindrical in the anterior region. Total segments 248. Body tone light brown. Dorsal surface noticeably wider than the ventral surface at the posterior end. In the ventro-lateral region of the clitellum, setae are seen in 25–31.

Distribution: India (Karnataka, Tamil Nadu (Kathireswari et al. 2008), Rajasthan, Punjab, Haryana, and Gujarat (Dhiman & Battish 2006)); Bangladesh; Myanmar (Reynolds et al. 1995 as *G. e.* ssp. *paski* Stephenson, 1923); Thailand (Chanabun et al. 2013).

5. ***Glyphidrilus fluviatilis* Rao, 1922**

Glyphidrilus fluviatilis Rao, 1922: 53. Type: British Museum (Natural History) 1922:4:20:5! (Reynolds & Wetzel, 2025).

Glyphidrilus annandalei Stephenson, 1923: 481.

Glyphidrilus annandalei Brinkhurst & Jamieson, 1971: 755.

Glyphidrilus fluviatilis Chanabun et al., 2013: 27.

Glyphidrilus fluviatilis Narayanan et al., 2023: 113.

Type locality: Sandy banks of the Harangi River in Madapur, Telangana State, India.

Material examined: None.

Brief description: (from Rao 1922). Length 272 mm. Body quadrangular behind the clitellum, anterior half cylindrical. Number of segments 225.

Distribution: India (Karnataka); Thailand (Chanabun et al. 2013).

6. ***Glyphidrilus papillatus* (Rosa, 1890)**

Bilimba papillata Rosa, 1890: 386.

Bilimba papillatus - Beddard, 1895: 687.

Glyphidrilus papillatus Michaelsen, 1896: 196.

Glyphidrilus papillatus Michaelsen, 1900: 459.

Glyphidrilus papillatus Michaelsen, 1918: 344.

Glyphidrilus papillatus Stephenson, 1920: 58.

Type locality: Cobapo (Carin Mountains), Burma (Myanmar).

Material examined: None.

Brief description: (from Stephenson 1920). Body length 74–120 mm, maximum diameter 3–6 mm. Total number of segments 130–330. No pigmentation dorsally, colour greyish. Secondary annulation found after five segments of the anterior part. Posterior half flattened dorsally. Prostomium pro- or zygolobous. Dorsal pores absent. Clitellum, saddle xiii, xiv–xl. Wings begin in xvii–xix and end in xxiii–xxvii. Genital markings, unpaired and median in xi–xxi, paired and lateral to A in xii–xxx. Gizzard in viii. Intestinal origin in xv. Typhlosole, lamelliform beginning in xviii.

Distribution: India (Uttar Pradesh (Stephenson 1923)); Myanmar (Stephenson 1923).

7. ***Glyphidrilus spelaeotes* Stephenson, 1924**

Glyphidrilus spelaeotes Stephenson, 1924: 133. Type: Zoological Survey of India, Calcutta, cat. no. 1155–1156 (Reynolds & Wetzel, 2025).

Glyphidrilus papillatus (part.) Gates, 1958: 54.

Glyphidrilus papillatus Brinkhurst & Jamieson, 1971: 764.

Glyphidrilus spelaeotes Narayanan et al., 2023: 114.

Type locality: Siju Cave, Meghalaya State, India.

Material examined: None.

Brief description: (from Stephenson 1924; Brinkhurst & Jamieson 1971). Length 175 mm, diameter 2–3 mm, segment number 310. Pale or light brownish-grey colour, four-sided behind the wings. The wings are attached between the line of the dorsal and that of the ventral setal couples, and extend from xviii or xix to xxiv or xxv; they are bent downwards and inwards, and on segment xviii they are, if present, less prominent than in the rest of their extent.

Distribution: India: Assam, Meghalaya (Stephenson 1924).

DISCUSSION

Glyphidrilus are restricted to subtropical Africa and southern Asia (Magalhães et al. 2021). These semi-aquatic earthworms usually inhabit river banks, wetlands, and muddy substrates, where they play an important role in soil aeration and nutrient cycling. Their restricted distribution makes them ecologically significant indicators of freshwater-associated habitats. Many regions of India are still unexplored in terms of earthworm fauna. Extensive surveys have been conducted in some biodiversity-rich zones, but several river systems, wetlands, and floodplains remain poorly

Key to the Indian species of the genus *Glyphidrilus* Horst, 1889

1. Clitellum begins on segment 13 2
1′. Clitellum begins on segment 14 5

2. Clitellum on 13–34; wings on segments 17–25 .... *G. gangeticus*
2′. Wings begin on segment 25 3

3. Wings extend beyond segment 32; wings on segments 25–36; clitellum beginning 13–18, ending 35–41; spermathecal pores in 13/14–16/17 .... *G. annandalei*
3′. Wings end on or before segment 32 4

4. Wings on segments 25–31; clitellum on 13–35; spermathecal pores in 13/14–17/18 .... *G. elegans*
4′. Wings on segments 25–32; clitellum on 13–33 (occasionally extends to 36 or 38); spermathecal pores in intersegmental furrows 7/8 and 8/9 .... *G. fluviatilis*

5. Wings on segments 20–24 to 28; clitellum on 14–30; spermathecal pores in 14–15 .... *G. tuberosus*
5′. Wings begin before segment 20 6

6. Wings on segments 18–25; clitellum on 14–30; spermathecal pores in 13/14–15/16 .... *G. spelaeotes*
6′. Wings on segments 18–26; clitellum on 14–40; spermathecal pores in 14–17 .... *G. papillatus*

studied. This gap in knowledge highlights the possibility of discovering new records or even undescribed species, especially in areas with unique hydrological conditions. From West Bengal, only *Glyphidrilus tuberosus* was known (Ahmed et al. 2022). This species was previously reported from the Ganga-Brahmaputra Basin and is characterized by its distinct gizzard position and genital markings. *Glyphidrilus* gangeticus is the first record of this species from this state. Earlier, this species was reported from Uttar Pradesh and Bihar along the Ganga River system, and its occurrence in West Bengal extends the known distribution range eastward. The finding demonstrates the connectivity of aquatic habitats across the Ganga floodplains and lack of systematic studies. This list summarizes all known species from India with details of their diagnostic characters, type localities, and ecological preferences. *Glyphidrilus gangeticus* is the second species from this state. Thus, the state now contributes two members of this semi-aquatic genus, enriching the faunal diversity of the region. There are seven species of the genus *Glyphidrilus* known from India. These include *G. tuberosus*, *G. gangeticus*, and five others described from various river basins across Uttar Pradesh, Bihar, Assam, and Meghalaya. Their distributions are often linked to major river systems such as the Ganga, Brahmaputra, and Barak. This discovery is significant as it not only adds to the state checklist but also provides baseline information for future biodiversity assessments and conservation planning of semi-aquatic habitats. The study emphasizes the need for a taxonomy combining morphology with molecular data. The local faunistic studies largely contribute to our knowledge of poorly known semi-aquatic species. Such studies are crucial in recognizing habitat-specific taxa, detecting biogeographical patterns, and informing conservation priorities in freshwater ecosystems.

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ARTICLE

Succession of biofouling organisms on structural materials and their environmental drivers off the Kalpakkam coast, India

Bandita Badakumar [1], D. Inbakandan [2] & P. Sriyutha Murthy [3]

[1,2] National Facility Coastal and Marine Research, Centre for Ocean Research, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu 600119, India.
[1,3] Water & Steam Chemistry Division, Bhabha Atomic Research Centre, Kalpakkam, Tamil Nadu 603102, India.
[3] Homi Bhabha National Institute, Anushakti Nagar, Mumbai, Maharashtra 400094, India.
[1] bandita.badakumar@gmail.com, [2] inbakandan@gmail.com (corresponding author), [3] psmurthy@igcar.gov.in (corresponding author)

Abstract: The settlement and succession of marine fouling organisms were monitored on three structural materials—stainless steel (SS), titanium (Ti), and fibre-reinforced plastic (FRP)—over a 300-day static immersion in coastal waters of Kalpakkam along the eastern coast of India. Barnacles were found to be initial settlers, with 15 fouling species identified during the study period. The final climax community was dominated by green mussels, hydroids, and barnacles on all three substrates. Biofouling load was the highest on FRP (23.6 kg/m²), followed by SS (20.11 kg/m²) and Ti (16.19 kg/m²) after 300 days of exposure. Interestingly, green mussels colonized after 150 days of exposure signifying their preference for cues from the substratum. Correlation analysis revealed strong relationships between environmental parameters and fouling loads. Temperature and salinity were positively correlated (r = 0.874), while temperature and dissolved oxygen showed a negative correlation (r = -0.646). FRP surfaces supported the highest diversity and biomass accumulation compared to Ti and SS surfaces. Results of the study indicate material-specific differences in biofouling loads and findings have implication in the choice of material selection for cooling water system as well as for offshore aquaculture structures.

Keywords: Biofouling succession, coastal electric power station, coupons, cooling water systems, corrosion, environmental parameters, fouling area coverage, fibre reinforced plastic, macrofouling, microfouling, settlement, stainless steel, titanium.

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Author details: Bandita Badakumar: senior research fellow in Sathyabama Institute of Science and Technology, working for BRNS funded project titled "Development of antifouling technologies against green mussel fouling for process cooling water system of MAPS". Currently working in the field of marine ecology, biofoluing, ecotoxicology and biomarkers. D. Inbakandan: head and professor of National Facility for Coastal and Marine Research, Center for Ocean Research, at Sathyabama Institute of Science and Technology. Expert in marine biology, ecology, aquaculture and fisheries. P. Sriyutha Murthy: scientific officer and professor HBNI- BARC Facilities, Kalpakkam. Extensively worked in Biofouling control in Industrial cooling water system. Expert in biofouling, biofilms, antifouling technologies, and ecotoxicology.

Author contribution: BB—conceptualization, field work, sampling and formal analysis, data analysis, statistics, writing original manuscript. DI—funding, manuscript review. PSM—conceptualization, field work, manuscript review.

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INTRODUCTION

Marine biofouling is a ubiquitous and spontaneous process, beginning with the formation of a primary organic film, followed by microbial and algal adhesion, biofilm formation with extracellular polymeric substances (EPS) (More et al. 2014; Decho & Gutierrez 2017; Negm et al. 2019), and eventual settlement and succession of marine invertebrate larvae (Maki & Mitchell 2002; Wigglesworth-Cooksey & Cooksey 2005; Qian et al. 2007; Hadfield 2011). Succession in fouling communities is influenced by seasonality (Briand et al. 2017; Qian et al. 2022), temperature, salinity, and hydrodynamic conditions (Alotaibi & Bukhari 2021; Jamieson & Leterme 2021; Briand et al. 2022). Biofouling causes significant operational problems in industrial cooling water systems and hence control measures can be devised only after understanding the density, diversity, and seasonal settlement of fouling organisms at a given geographical location. Operational and economic losses due to biofouling are well documented in desalination plants (Azis et al. 2001; Henderson 2010; Alayande et al. 2022), power plant cooling water systems (Nair et al. 1999; Satpathy et al. 2010; Murthy et al. 2011; Rao et al. 2015), aquaculture installations (Durr & Watson 2010; Fitridge et al. 2012; Hopkins et al. 2021), offshore oil and gas platforms (Sanders et al. 2005; Yeo et al. 2009; Page et al. 2010), sensors and data buoys (Zhang et al. 2015; Venkatesan et al. 2017), and shipping (Schultz et al. 2011). Biofouling on ship hulls has been linked to the spread of invasive or non-indigenous species, causing ecological imbalance (Fernandes et al. 2016; Shevalkar et al. 2020; Yousef & Nasser 2023).

Titanium (Ti), stainless steel-304 (SS), and fibre-reinforced plastic (FRP) are widely used industrial materials, particularly in marine and coastal industries, due to their superior mechanical properties. Titanium is used as a heat transfer material, in heat exchangers at power plants in Kalpakkam, due to its excellent heat transfer and anticorrosion properties. However, it is prone to severe biofouling. SS-304 is used as a structural material in various pipelines and seawater pump casings along with FRP. Cost involved in maintaining the cooling system, heat exchangers, and structural materials is considerable (Todd et al. 2019; Wahl 2020) and therefore understanding the endemic species, their settlement, recruitment, and succession patterns on these structural materials is required to devise a suitable control strategy.

The southeastern coast of India supports a rich and diverse marine ecosystem (Satpathy et al 1996; Sahu et al. 2015; Ponnusamy et al. 2017). Several studies have characterized various aspects of this environment, including microbial diversity and the settlement and succession of biofouling organisms off the Kalpakkam coast (Nair et al. 1988; Rajagopal et al. 1997; Sahu et al. 2011, 2015). These investigations have consistently identified major macrofouling species such as barnacles, mussels, and ascidians in the region. While building upon these earlier findings, the present study provides an updated perspective by recording monthly biofouling load on different structural materials and documenting the seasonal succession of fouling communities. In contrast to earlier works, this study integrates environmental drivers (such as, temperature, salinity, dissolved oxygen, nutrients, and chlorophyll concentration) to examine their correlation with observed fouling trends. Notably, fluctuations in fouling community composition during the post-monsoon period appear to be influenced by changes in temperature and reduced nutrient availability (Venugopalan 1991; Venkatnarayanan 2018). This combined approach not only reaffirms previously observed patterns but also offers new insights into the environmental drivers that shape biofouling dynamics in this ecologically and industrially important coastal zone.

The present study evaluates biofouling accumulation and community succession on three structural materials (Ti, SS, and FRP) deployed in the coastal waters off Kalpakkam on the southeastern coast of India. The objective includes assessing the temporal variation in biofouling load and species composition over a one-year period; monitoring monthly settlement and succession patterns of fouling organisms; and correlating these patterns with variations in physicochemical parameters. The study further seeks to understand the timing and dynamics of organism settlement and its relationship with environmental conditions, providing insights into material-specific fouling behaviour in a tropical marine environment.

MATERIALS AND METHODS

Description of study area and coupon immersion

The study was carried out from January to December 2022 at the approach jetty area of MAPS an operating coastal power station, off Kalpakkam (12.335° N, 80.115° E) located on the eastern coast, of India (Image 1). Coupon mounted on holder with stainless steel screws were suspended at a distance of 350 m from the shore beyond the coastal surf zone at a depth of -1 m . Three different structural materials most commonly used in industry were used as coupons for the experiment such as stainless steel

Image 1. Map showing the coupon immersing site in the Madras Atomic Power Station (MAPS) (Source: Google Earth).

304 (SS-304), titanium (Ti), and fibre-reinforced plastic (FRP) with a size of 10 × 15 cm. Each coupon (in triplicate) was attached on a polypropylene frame and suspended at a depth of -1.0 m in coastal waters. The settlement pattern and succession of macrofouling organisms was monitored monthly on the coupons, for a period of 300 days. Every month the coupons were retrieved for checking the wet biomass and photographed (Canon, DS EOS RP) for the species composition. The percentage coverage of different organisms was estimated using Image J software (NIH, USA). The same set of coupons was monitored throughout the study period, with monthly retrieval for non-destructive assessment of biofouling (photography and wet weight estimation). Care was taken during handling and measurement to minimize disturbance, and the coupons were promptly re-immersed to allow continued development of the fouling community. Barnacles, polychaete tube worms, bivalves, and other organisms (such as crabs, snails) were counted individually and expressed as individuals/ cm^2. Coelenterate hydroids, ascidians, and encrusted bryozoans, being colonial organisms, were counted as area occupied per cm^2 on each of the coupons.

Measurement of environmental parameters

Physico-chemical parameters such as salinity, water temperature, pH, and dissolved oxygen (DO), were measured by using a multi-parameter water quality probe in seawater (HYDROLAB, DS5, USA). Chlorophyll a (Chl-a) concentration was determined by filtering 500 mL seawater through a Whatman GF/C glass fibre filter. The filter papers were then placed in 90% acetone (10 ml) and incubated at 4˚ºC in complete darkness for overnight to facilitate pigment extraction. The absorbance of the extracted solution was subsequently measured using a spectrophotometer to quantify the chlorophyll-a concentration. During the study period, sub-surface seawater samples were collected monthly from the coastal waters, transported to laboratory for the estimation of nutrient parameters viz: nitrite (NO_2), nitrate (NO_3), inorganic phosphate (PO_4), ammonia (NH_3), and silicate (Si) by following the standard method as described by Grasshoff et al. (1999). Total suspended solids (TSS) was estimated in water sample as per the gravimetric method (APHA 2005).

Statistical analysis

All samples were collected in triplicate and the measured values were expressed as mean with standard deviation. To evaluate the significant differences with physico-chemical parameters between different seasons were analyzed using one-way ANOVA using PAST- 4.03 software (UK) (Hammer et al. 2001). SPSS (version 10) software stats package was used for generating the minimum, maximum, mean and SD values with ANOVA *p*-values. Pearson correlation matrix was generated using PAST-4.03 software for *p*-values. Fouling load on the surface of coupons were quantified using ImageJ software (NIH, USA).

RESULTS AND DISCUSSION

Hydrobiology and species diversity

During the study, 15 species were identified across all three coupons, representing seven distinct phyla: Annelida (2 species), Arthropoda (3 species), Cnidaria (1 species), Ectoprocta (1 species), Mollusca (5 species), Echinodermata (1 species), and Urochordata (3 species) (Table 1) (Rajagopal et al. 1997; Venkatnarayanan 2018). Monthly observations revealed a notable dominance of hydroids, green mussels, and barnacles, reflecting their competitive advantage and prevalence within the fouling communities in this geographical location (Sahu et al. 2011; Venkataraman et al. 2012). Various epibiotic organisms such as crab, polychaete worms, amphipods and gastropods were also observed (Wickramasinghe et al. 2021). The species richness recorded on the panels (mean ± standard deviation) fluctuated based on the type of substrate and season.

Table 2 presents seasonal variations in physico-chemical and biological parameters, which were prominent throughout the study period, with fluctuations across different seasons observed at Kalpakkam on the southeastern coast of India. The categories are monsoon (MON: June–September), post-monsoon (POM: October–December), and pre-monsoon (PRM: January–May).. Seawater temperatures were lowest in the month of December (26.3 ^{o}C, POM) and January (26.5 ^{o}C, PRM), while the highest was observed in April and May (30.2—31.0 ^{o}C) in PRM season. A steady decline in water temperature occurred during the MON season (June to August), followed by a marginal rise during the POM phase (September–October), which then continued to increase during the subsequent pre-monsoon months. Earlier studies at the intake region of the power plant site reported fluctuation of temperature ranging from minimum 5.8 ^{o}C to maximum 8.0 ^{o}C (Sahu et al. 2012; Venkatnarayanan 2018). Previous studies on sea-surface temperature variability have well established the role of atmospheric temperature impacts on sea-surface temperature, which significantly influence the later leading to seasonal and regional variations (Deser et al. 2010). Temperature fluctuation can have cascading effects on chemical and biological process, affecting salinity, phytoplankton growth, and conductivity (Satheesh & Wesley 2009; Fernandez et al. 2022). Current findings align with the earlier observations regarding air temperature along the study area, which exhibited a bimodal pattern with peaks occurring in April–May and another during September–October.

The pH levels in Kalpakkam coastal waters ranged 8.07–8.26 across the three seasons, suggesting a generally well-buffered aquatic ecosystem, while salinity exhibited seasonal variation, reaching its lowest at 27.6 ppt in December and peaking to 35.4 ppt in June (summer). The lowest pH and salinity recorded in December (POM) are attributed to a large inflow of rainwater during the north-east monsoon (NEM) from both Sadras and Edayur estuarine systems (Venkatnarayanan 2018). The highest pH value (8.24) was recorded in July during the monsoon period. These fluctuations in pH and salinity may be linked to the north-east monsoon, with additional influences from freshwater influx from nearby estuarine systems and also due the influx of low-saline Palar riverine water (Varkey et al. 1996; Sahu et al. 2011). Dissolved oxygen (DO) was highest in post-monsoon (November, 6.91 mg/L) and lowest in the month of September (5.23 mg/L), reflecting seasonal changes. The peak DO levels were observed during month of November may be attributed to an increase in chlorophyll-*a* concentration, driven by the northeast monsoon and the influx of nutrient-rich estuarine waters (Satpathy 1996). Additionally, the reduction in salinity and enhanced oxygenation in large tidal action resulting from physical mixing processes could have further contributed to the elevated DO levels (Venkatnarayanan 2018).

Chlorophyll-*a* fluctuated between 6.3 mg L^{-1} (Oct) and 18.6 (Jun) mg L^{-1}, an indicator of phytoplankton growth, reflecting favourable conditions for algal growth due to nutrient availability (Rajagopal et al. 1991). Highest concentration was observed during pre-monsoon period and at the beginning of the monsoon period, which may be attributed to the relatively stable and optimal conditions of salinity, temperature, light, and nutrient levels prevailing during this period (Sahu et al. 2011). The low chlorophyll-a levels observed during the monsoon season may be attributed to reduced salinity, which is most likely unfavourable for marine phytoplankton growth, while the minimum concentration recorded in

Table 1. Composition of biofouling community on coupons.

Phylum	Class	Order	Family	Species
Annelida	Polychaeta	Canalipalpata	Serpulidae	*Hydroides elegans*
		Aciculata	Nereididae	*Pseudonereis* sp.
Arthropoda	Cirripedia	Thoracica	Balanidae	*Amphibalanus reticulatus* *Balanus amphitrite*
	Malacostaca	Amphipoda	Corophidae	*Corophium* sp.
Cnidaria	Hydrozoa	Thecata	Campanulariidae	*Obelia dichotoma*
Ectoprocta	Gymnolaemata	Cheilostomata	Bugulidae	*Bugula* sp.
Mollusca	Bivalvia	Mytilida	Mytilidae	*Perna viridis*
			Ostreidae	*Modiolus modiolus*
				Crassostrea madrasensis
	Gastropoda	Neogastropoda	Muricidae	*Thais* sp.
			Patellidae	*Patella* sp.
Echinodermata	Ophiurodea	Ophiurida	Ophiotrichidae	*Ophiothrix* sp.
Urochordata	Ascidiacea	Enterogona	Didemnidae	*Didemnum* sp.
		Aplousobranchia		*Lissoclinum* sp.
		Phlebobranchia	Perophoridae	*Ecteinascidia* sp.

October (6.23 mg L^{-1}) could be due to increased grazing pressure. Several studies conducted along the Kalpakkam coast have reported similar trends to those observed in the present study (Rajagopal et al. 1991; Satpathy 1996; Sahu et al. 2015; Achary et al. 2010; Venkatnarayanan 2018). Levels of total suspended solids (TSS) was found to be high during the month of November (88 mg L^{-1}), indicating a significant ($p < 0.001$) increase in sediment resuspension during post-monsoon period, while the lowest values were recorded in the month of August (29.3 mgL^{-1}). Nutrient concentrations, including nitrite, nitrate, ammonia, phosphate, and silicate, showed significant seasonal variation, with higher levels during the monsoon and post-monsoon periods, followed by a noticeable decline toward the end of the pre-monsoon season. The concentration for nitrate and nitrite was 5.18—9.45 µmol L^{-1} and 1.0—3.08 µmol L^{-1}, respectively. Levels of ammonia varied 1.0—3.7 µmol L^{-1}, maintaining a relatively consistent concentration across all seasons. Levels of inorganic phosphate ranged 1.68—5.7 µmol L^{-1} during all seasons. A significant ($p < 0.001$) rise in phosphate concentration was observed during MON and POM period, with a steady increase from August to December. However, the phosphate concentration spiked during the month of December (14.1 µmol L^{-1}), which could be due to the NEM rains which induced land runoff. This trend may be attributed to the phenomenon of 'coastal upwelling' which has been frequently reported in this region (Suryanarayan & Rao 1992). The silicate (Si) concentration was found relatively high in the POM with a value of 19.18 µmol L^{-1} compared to the other two seasons MON and PRM. The silicate level ranged 11.04—19.18 µmol L^{-1} throughout three seasons. This parameter also in turn coincides with the mixing of the backwater due to the NEM rains (Sahu et al. 2012).

ANOVA results indicate statistically significant seasonal variations ($p \leq 0.05$) in most parameters, including temperature, salinity, dissolved oxygen, chlorophyll-a, TSS, and nutrient concentrations, while silicate ($p = 0.742$) remained relatively stable. These findings highlight the influence of seasonal changes on water quality, with monsoon-driven fluctuations affecting salinity, nutrients, and biological activity. These findings underscore the dynamic influence of seasonal cycles on water quality, with monsoonal rainfall playing a crucial role in nutrient loading, salinity dilution, and biological productivity. The data suggest that freshwater inflows, evaporation, and biological interactions collectively shape the physicochemical characteristics of the aquatic system, highlighting the need for continuous monitoring to assess ecosystem health and potential anthropogenic impacts.

Biofouling loading on structural materials

The physical and chemical characteristics of structural materials play a crucial role in determining their susceptibility to biofouling. In the present study, distinct differences were observed in fouling intensity

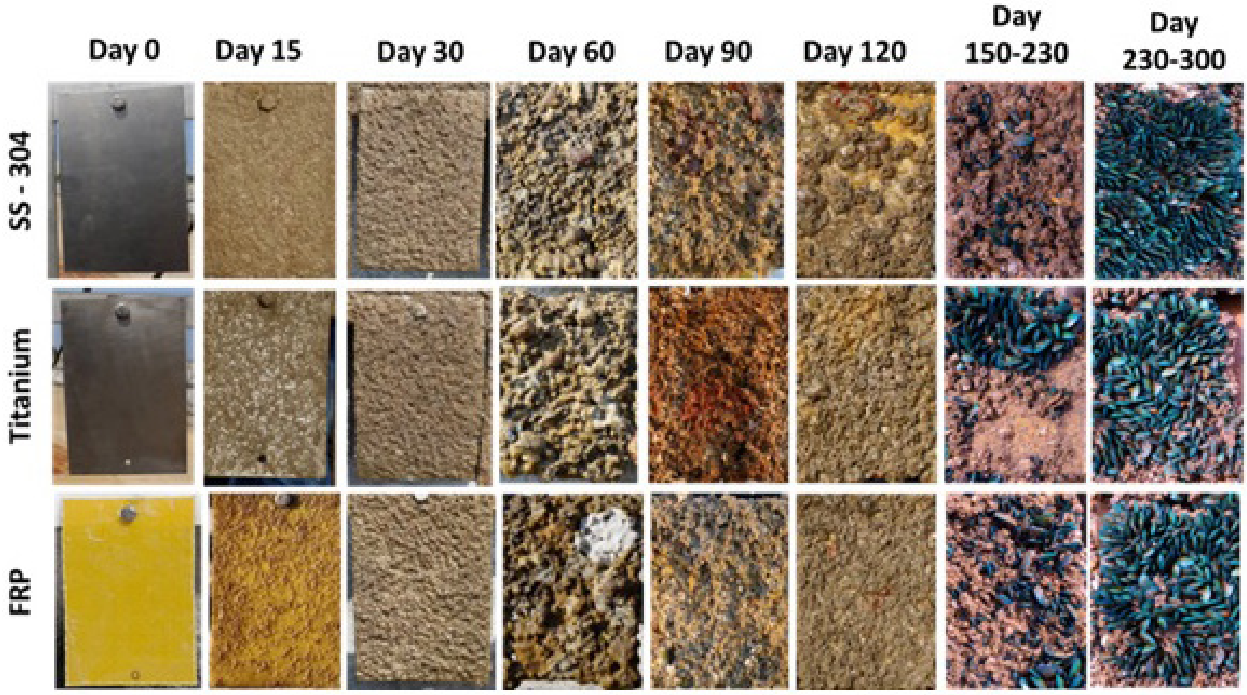

Image 2. Biofouling organisms observed on different structural materials (SS—stainless steel | Ti—titanium | FRP—fibre reinforced plastic) immersed in Kalpakkam coastal waters from Day 0 to 300.

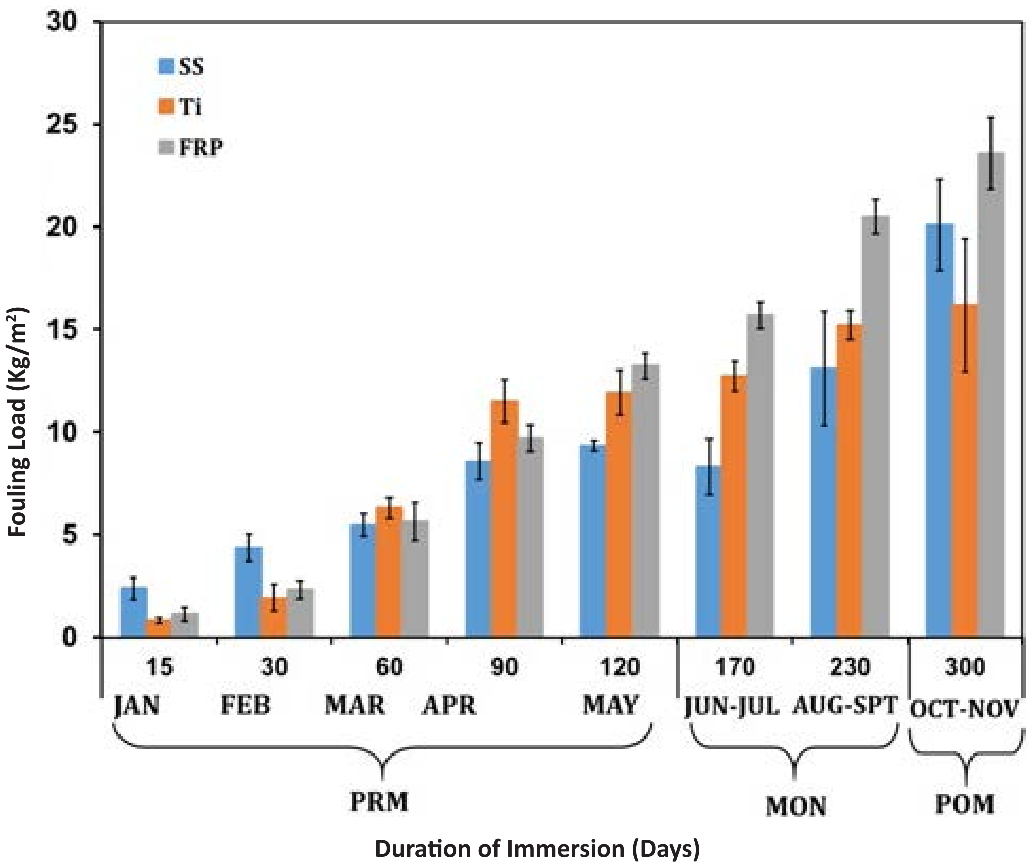

Figure 1. Temporal variation of biofouling loading observed on different structural material (SS—stainless steel | Ti—titanium | FRP—fibre reinforced plastic) with respect to seasonal variation (PRM—pre-monsoon | MON—monsoon | POM—post-monsoon) of fouling load.

among stainless steel (SS), titanium (Ti), and fibre-reinforced plastic (FRP), which can be attributed to their surface properties. Stainless steel possesses a relatively smooth surface with moderate surface energy, allowing initial microbial and larval attachment. However, the passive oxide layer formed on its surface provides a certain degree of corrosion resistance and reduces long-term colonization (Rajagopal et al. 1997; Dexter & Chandrasekaran 1998). Titanium, exhibits superior anticorrosive properties due to the formation of a stable and highly inert titanium oxide (TiO_2) film, which minimizes both corrosion and bio-adhesion (Kobayashi & Dauskardt 2001; Dobretsov 2010). Its low surface roughness and hydrophobic nature further contribute to its resistance to organism settlement (Zhao et al. 2014). Fibre-reinforced plastic on the other hand, has a comparatively rough and heterogeneous surface structure that provides micro-crevices for the attachment of fouling organisms (Patil et al. 2007; Ponnusamy et al. 2016). Its inert nature and surface irregularities create favourable conditions for larval settlement and growth of macrofouling communities. Consequently, FRP showed the highest fouling load in the present study, while titanium exhibited the least. These findings underscore that the surface texture, energy, and chemical composition of materials strongly influence initial colonization, community succession, and the overall biofouling load in marine environments (Callow & Callow 2011; Dobretsov et al. 2013).

Biofouling loading on different structural materials SS, Ti, and FRP, immersed over a period of 300 days in Kalpakkam coastal waters is given in Image 2. Larval settlement on all three substrates was found to occur within the first 24 hours of immersion. However, with time, shifts in community structure and species succession lead to dynamic changes in the fouling assemblage. A total of 15 organisms were identified on different substrates during the study period, with barnacles emerging as the initial settlers, rapidly colonizing the surfaces within the first 1–4 days of immersion. In addition to barnacles, other fouling species, including ascidians, bryozoans, oysters, and gastropods were also present. Various epizoic organisms such as crabs, copepods, brittle stars, and amphipods were also present. Barnacles and hydroids were found to attach between the 5th and 7th day of immersion whereas, settlement of oysters and polychaetes occurred later, establishing themselves between the 7th and 10th day of immersion. Even though green mussels spat settlement was detected as early as the 15th day of immersion, juvenile recruitment was observed only after 120–230 days of immersion. Rajagopal et al. (1997) similarly reported juvenile mussel settlement during May–June and October. In the present study, the juveniles that are settled after 120 days, eventually overgrew, covered the previously settled fouling organism on the coupons, a pattern previously reported along the same coast (Rajagopal et al. 1997; Sahu et al. 2011). Similar kind seasonal succession of green mussel pattern and fouling load were observed in the same coast (Rajagopal et al. 1997; Sahu et al. 2013; Venkatnarayanan 2018; Rao et al. 2021).

The settlement and recruitment of different biofouling organisms on different materials, season wise is given in Figure 1. Biofouling loading, increased with time on all three surfaces. However, there were significant differences in the intensity of colonization of different fouling species, between the three surfaces. Fibre-reinforced plastic (23.6 kg/m^2) surface exhibited the highest fouling accumulation, consistently compared to SS (20.11 kg/m^2) and Ti (16.19 kg/m^2) over the immersion period. Within the 120th day of immersion, fouling load on FRP surfaces reached (13 kg/m^2) which was significantly higher ($p < 0.05$). This increased to 15.67 kg/m^2 by the 170th day, with fouling accumulation accelerating even further, ultimately reaching 23.6 kg/m^2 by 300 days. The increased fouling on FRP suggests may be attributed to the surface texture and material properties which provide a more favourable substrate for marine organisms to attach and grow (Venkatnarayanan 2018).

Initial loading of stainless steel (9.2 kg/m^2), were much similar to that observed with FRP (9.72 kg/m^2) surfaces but diverged around 90–120 days. By 300 days, SS accumulated a fouling load of 20.11 kg/m^2 marginally lower compared to FRP (23.57 kg/m^2) but higher than Ti (16.19 kg/m^2), indicating, the surface was not immune to biofouling. Results suggests that SS surfaces in marine environment may still require protection by use of antifouling coatings for long-term applications. On the other hand, Ti surface was found to attract consistently low settlement and recruitment of fouling organism compared to both SS and FRP throughout the 300-day immersion period. This reduced settlement observed on titanium surfaces is likely due its smooth surface and formation of a passive oxide layer, which inhibit the attachment of marine organisms, making it the most suitable material for long-term marine applications.

Percentage of area coverage on different coupons

A comprehensive analysis of settlement and recruitment of biofouling organisms (Figure 2a,b,c) on SS, Ti, and FRP revealed that species settlement on SS

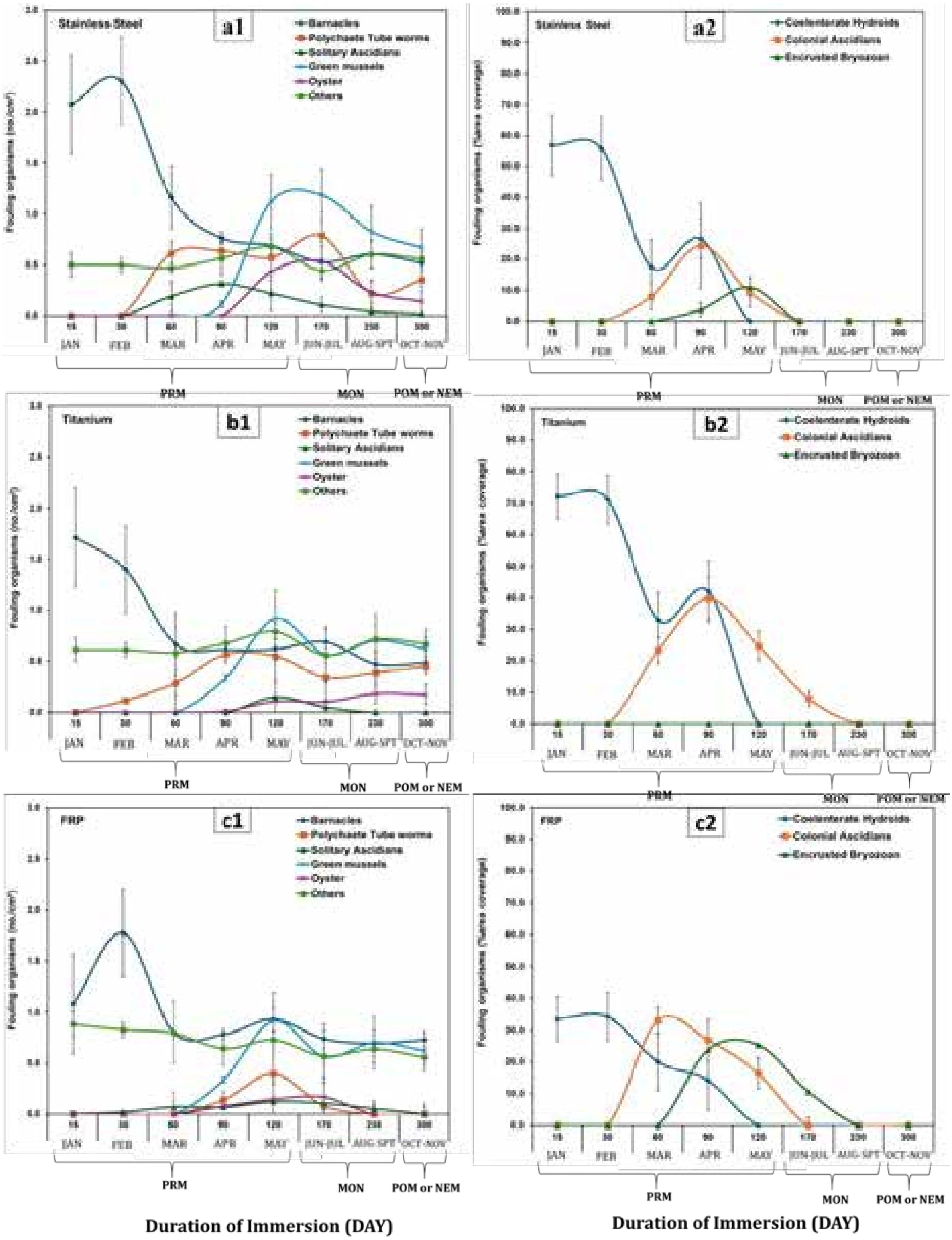

Figure 2. Biofouling load and percent area coverage observed on different coupons: a1 & a2—stainless steel | b1 & b2—titanium | c1 & c2—fibre reinforced polymer throughout the year in three seasons.

Table 2. Hydro-biological parameters observed in the coastal waters of Kalpakkam from January to December 2022, representing three distinct seasonal periods.

Season	Month		WT (˚C)	pH	Salinity (PPT)	DO (mg/L)	Chl-*a* (mg L^{-1})	TSS (mg L^{-1})	NO_3 (µmol L^{-1})	NO_2 (µmol L^{-1})	NH_3 (µmol L^{-1})	IP (µmol L^{-1})	Si (µmol L^{-1})
MON	August	**Minimum**	27.30	8.09	34.21	5.84	9.12	23.00	7.21	1.25	1.65	4.23	11.25
		Maximum	27.90	8.17	34.45	5.96	9.58	36.00	7.45	1.43	1.85	4.54	12.34
		Mean	27.60	8.13	34.30	5.89	9.35	29.33	7.33	1.35	1.75	4.37	11.86
		SD	0.30	0.04	0.13	0.06	0.23	6.51	0.12	0.09	0.10	0.16	0.55
	July	**Minimum**	26.20	8.22	34.58	5.67	7.39	26.00	6.34	1.04	3.45	3.42	15.45
		Maximum	27.30	8.26	34.96	5.89	7.89	34.00	6.95	1.14	3.99	3.67	15.87
		Mean	26.95	8.24	34.81	5.77	7.61	29.67	6.71	1.09	3.70	3.51	15.34
		SD	0.36	0.03	0.20	0.11	0.25	4.04	0.33	0.05	0.27	0.14	1.74
	June	**Minimum**	26.90	8.08	35.23	5.42	18.43	32.00	5.11	0.86	2.63	1.56	17.54
		Maximum	26.30	8.18	35.67	5.62	18.88	48.00	5.29	1.11	2.96	1.87	17.35
		Mean	26.50	8.13	35.45	5.53	18.61	40.67	5.19	1.01	2.82	1.69	17.59
		SD	0.40	0.05	0.22	0.10	0.24	8.08	0.09	0.13	0.17	0.16	3.46
	September	**Minimum**	27.90	8.12	33.43	5.23	9.89	47.00	7.69	1.45	2.54	4.56	12.35
		Maximum	28.50	8.15	34.69	5.46	10.12	65.00	7.88	1.68	2.87	4.87	12.96
		Mean	28.27	8.14	34.23	5.34	10.00	57.00	7.78	1.56	2.72	4.71	12.62
		SD	0.32	0.02	0.70	0.12	0.12	0.92	0.10	0.12	0.17	0.16	0.93
POM	December	**Minimum**	27.80	8.08	27.45	6.45	10.98	53.00	7.58	1.55	2.45	5.59	19.87
		Maximum	26.80	8.14	27.84	6.89	11.54	68.00	7.98	1.89	2.87	5.87	19.78
		Mean	26.30	8.11	27.66	6.70	11.25	59.00	7.73	1.70	2.62	5.70	19.18
		SD	0.50	0.02	0.20	0.22	0.28	0.94	0.22	0.17	0.22	0.15	0.48
	November	**Minimum**	27.20	8.18	28.35	6.54	8.56	79.00	9.32	3.45	0.87	5.24	13.56
		Maximum	27.70	8.23	28.79	7.23	8.87	98.00	9.67	3.75	1.12	5.49	13.45
		Mean	27.47	8.21	28.53	6.92	8.70	88.00	9.45	3.62	1.02	5.37	13.83
		SD	0.55	0.03	0.23	0.35	0.16	0.54	0.19	0.16	0.13	0.13	0.10
	October	**Minimum**	27.30	8.07	30.12	6.21	6.23	68.00	8.45	2.68	1.24	4.45	11.28
		Maximum	27.90	8.16	30.42	6.49	6.54	89.00	8.94	2.84	1.64	4.67	11.54
		Mean	27.63	8.11	30.26	6.36	6.37	76.33	8.68	2.77	1.41	4.56	11.05
		SD	0.31	0.05	0.15	0.14	0.16	0.15	0.25	0.08	0.21	0.11	0.65

Season	Month		WT (°C)	pH	Salinity (PPT)	DO (mg/L)	Chl-*a* (mg L^{-1})	TSS (mg L^{-1})	NO_3 (µmol L^{-1})	NO_2 (µmol L^{-1})	NH_3 (µmol L^{-1})	IP (µmol L^{-1})	Si (µmol L^{-1})
PRM	April	**Minimum**	30.90	8.13	34.54	5.46	15.22	70.00	5.32	0.95	3.11	2.21	15.21
		Maximum	29.50	8.21	34.98	5.89	15.68	78.00	5.63	1.12	3.57	2.37	15.24
		Mean	30.20	8.17	34.69	5.70	15.45	74.33	5.47	1.05	3.32	2.29	15.63
		SD	0.30	0.04	0.25	0.22	0.23	4.04	0.16	0.09	0.23	0.08	0.54
	February	**Minimum**	28.90	8.14	31.25	6.12	15.32	58.00	8.23	2.89	2.23	4.35	15.34
		Maximum	28.90	8.21	31.63	6.59	15.89	68.00	8.56	3.24	2.56	4.51	15.27
		Mean	28.37	8.18	31.38	6.31	15.62	63.00	8.41	3.08	2.43	4.44	15.99
		SD	0.50	0.04	0.22	0.25	0.29	0.60	0.17	0.18	0.17	0.08	0.11
	January	**Minimum**	26.70	8.13	29.23	6.09	8.23	49.00	7.98	2.12	1.45	3.12	14.63
		Maximum	26.80	8.15	29.40	6.42	8.96	59.00	8.16	2.29	1.86	3.25	14.23
		Mean	26.53	8.14	29.32	6.25	8.55	54.67	8.06	2.22	1.69	3.17	14.04
		SD	0.25	0.01	0.09	0.17	0.37	0.51	0.09	0.09	0.21	0.07	1.31
	March	**Minimum**	30.08	8.08	32.48	5.23	18.23	62.00	7.54	1.05	2.54	3.56	14.35
		Maximum	30.05	8.18	32.96	5.65	18.76	70.00	7.86	1.26	2.89	3.95	14.54
		Mean	30.08	8.13	32.71	5.48	18.48	65.33	7.69	1.15	2.77	3.76	14.41
		SD	0.36	0.05	0.24	0.22	0.27	0.42	0.16	0.11	0.20	0.20	0.10
	May	**Minimum**	32.30	8.09	34.57	5.67	17.23	74.00	6.35	1.03	3.18	2.54	14.27
		Maximum	31.80	8.18	34.72	5.84	17.52	81.00	6.59	1.20	3.46	2.78	15.62
		Mean	31.05	8.13	34.63	5.78	17.40	78.00	6.46	1.12	3.31	2.67	15.18
		SD	0.25	0.05	0.08	0.09	0.15	0.61	0.12	0.09	0.14	0.12	0.04
ANOVA (p values)			**0.001**	0.027	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	0.002	**0.001**	0.742

MON—monsoon | POM—post-monsoon | PRM—pre-monsoon | WT—water temperature | DO—dissolved oxygen | Chl-a—chlorophyll-a | TSS—total suspended solids | NO_3—nitrate | NO_2—nitrite | NH_3—ammonia | IP—inorganic phosphate | Si—silicate | SD—standard deviation. ANOVA values given in bold represents significant difference ($p < 0.001$).

surfaces showed notable changes over time. Barnacles exhibited an initial peak in settlement (2.31 individuals/cm^2) within the first 30 days on SS surfaces, but their numbers declined sharply subsequently, indicating early attachment followed by detachment, mortality, disturbance, overgrowth or competition with other fouling organisms. Settlement of polychaete tube worms, solitary ascidians, and green mussels gradually increased in density between 90 and 120 days. In terms of surface coverage, coelenterate hydroids dominated the initial phase (56.89%), covering nearly 80% of the surface from 0–60 days before declining. Following this, colonial ascidians peaked on the 90 day (24.44%), and declined after 120days (9.33%), replacing hydroids as the dominant organisms. Settlement of encrusting bryozoans was observed after 90 days (3.78%), and the recruits were observed on the coupons subsequently, but with a lower dominance compared to ascidians. Green mussels were observed to settle on the substrates from the 90^{th} day (0.11 individuals/cm^2) and peaked on the 120^{th} (1.12 individuals/cm^2) day. Settlement of green mussels was observed on empty barnacle shells and covered the entire coupon surface area on the outer layer, a trend which was observed in a previous study by Venkatnarayanan (2018). Species succession of foulants on SS surfaces was more prominent and dynamic compared to FRP surfaces.

Titanium surfaces exhibited a distinct biofouling pattern compared to (SS) and (FRP). On the SS surface, barnacles were the early settlers, within the first 30 days (1.40%). Subsequently, the surfaces were colonized by other fouling organisms such as polychaete worms, solitary ascidians, and green mussels showed a sporadic settlement with relatively lower fouling densities compared to SS and FRP. Results suggests that Ti resists dense fouling, likely due to its passive oxide layer, which makes it less appealing for biofouling attachment (Alshammari 2017). In terms of surface coverage, coelenterate hydroids, dominated during the initial 60 days (71.11%), and disappeared after 60 days.

Settlement of colonial ascidians also peaked around 90 (39.78%)–120 days (24.76%), similar to SS, but their presence was short-lived on Ti. Encrusting bryozoans were found in few numbers throughout the study period, further supporting the trend of lower fouling on Ti. Green mussels settled and dominated the fouling community after 120 days (0.92 individuals/cm^2) up to 300 days (0.72 individuals/cm^2). Similar to SS substrate, the presence of green mussels reduced the settlement of other organisms particularly barnacles, creating competitive pressure among species for space on the substrate. Overall, the relatively lower surface coverage on Ti indicates less biofouling accumulation compared to SS and FRP.

Fibre-reinforced plastic surfaces was found to accumulate higher biofouling compared to SS and Ti. Barnacle settlement peaked (1.77%), during the first 60 days of exposure. Additionally, green mussels and polychaete tube worms exhibit higher densities (0.92% and 0.40% respectively) on FRP, with continuous colonization observed after 120 days. Fibre-reinforced plastic supports a more diverse fouling community, likely due to its rougher surface texture and inert material composition, which provide more attachment points for organisms. In terms of surface coverage, coelenterate hydroids (20%), dominated along with barnacles during the early stages (first 60 days) but decline gradually, with the drop being less sharp than on SS and Ti. Colonial ascidians were found to appear later, peaking around 60 days (33.11%)–120 days (16.44%), and maintain a longer presence, suggesting that FRP provides a more stable environment for biofouling. Encrusting bryozoans were observed on the coupons and showed an increase in percentage coverage after 90 days (23.87%)–170 (10.67%) days, which was unique and not observed on SS and Ti surfaces. Green mussel density was notably high on this substrate, with spats beginning to attach from day 90 (0.34 individuals/cm^2) and steadily increasing, reaching a peak by 120 days (0.92 individuals/cm^2). In contrast, attachment on SS and Ti substrates was observed only after 120 days. Overall, the higher surface coverage on FRP suggests that it is the most prone to biofouling accumulation among the materials studied.

Hierarchical cluster analysis grouped the nine marine fouling species into four distinct clusters based on their standardized monthly abundance patterns shown in Figure 3. Although it does not display seasons explicitly, it reflects how closely species are aligned in terms of their temporal dynamics throughout the year. Species that are joined by short branches such as polychaete tube worms, oysters, and colonial ascidians exhibit similar seasonal trends, likely responding in comparable ways to environmental or ecological cues. In contrast, species like barnacles, solitary ascidians, and green mussels are separated by longer branch lengths, indicating distinctly different temporal behaviours. The stepwise clustering seen in the dendrogram highlights the presence of both tightly cohesive groups and more isolated taxa, providing insight into the degree of seasonal specialization or generalism.

Barnacles consistently appear as one of the most isolated species in the dendrograms, branching off at a large dissimilarity distance. This reflects their unique seasonal colonization pattern characterized by a distinct

Table 3. Pearson correlation between environmental parameters v/s biofouling load on each Substrate; Coloured grid - is the Pearson's value; (lowest value is mentioned in Green and the highest value is in Red, near to zero values are mentioned in tallow). Bold and black numbers with represent the p- value showing the significance at $p < 0.05$; normal numbers without bold do not have any significance. The stainless steel (SS), titanium (Ti), fibre-reinforced plastic (FRP) represents the fouling load during the three seasons.

	WT	pH	Salinity	DO	Chl-a	TSS	NO_2^-	NO_3^-	NH_4	IP	Si	SS	Ti	FRP
WT		0.101	**0.001**	0.023	0.146	0.286	**0.012**	**0.022**	0.075	**0.022**	0.993	0.678	0.363	0.776
pH	-0.496		**0.008**	0.001	0.184	0.142	0.209	**0.019**	0.164	0.079	0.293	**0.002**	0.159	0.048
Salinity	0.874	-0.723		0.001	0.145	0.077	**0.007**	**0.003**	0.013	**0.013**	0.840	0.156	0.900	0.565
DO	-0.646	0.863	-0.852		0.173	0.136	**0.026**	**0.001**	**0.020**	**0.018**	0.684	**0.034**	0.557	0.206
Chl-a	0.446	-0.411	0.447	-0.421		0.862	0.063	0.108	0.141	**0.049**	0.157	0.302	0.333	0.138
TSS	-0.336	0.450	-0.530	0.456	-0.056		0.079	**0.027**	0.068	0.295	0.512	0.234	0.751	0.621
NO_2^-	-0.696	0.391	-0.730	0.636	-0.551	0.527		**0.001**	**0.011**	**0.001**	0.119	0.415	0.871	0.590
NO_3^-	-0.650	0.661	-0.778	0.809	-0.488	0.634	0.839		**0.001**	**0.011**	0.322	0.215	0.983	0.505
NH_4	0.532	-0.429	0.691	-0.659	0.451	-0.543	-0.704	-0.843		0.051	0.095	0.307	0.881	0.514
IP	-0.649	0.526	-0.692	0.667	-0.578	0.330	0.844	0.700	-0.575		0.351	0.055	0.355	0.100
Si	0.003	0.331	-0.065	0.131	0.436	-0.210	-0.475	-0.313	0.504	-0.295		0.638	0.953	0.901
SS	-0.134	0.789	-0.436	0.613	-0.326	0.372	0.260	0.386	-0.322	0.566	0.152		**0.001**	**0.001**
Ti	0.289	0.433	0.041	0.189	-0.306	0.103	-0.052	0.007	-0.048	0.293	-0.019	0.845		**0.001**
FRP	0.092	0.580	-0.185	0.393	-0.455	0.159	0.173	0.214	-0.209	0.497	-0.040	0.918	0.961	

Note: Colour code presents the Pearson's values. WT—water temperature | DO—dissolved oxygen | Chl-a—chlorophyll-a | TSS—total suspended solids | NO_3—nitrate | NO_2—nitrite | NH_3—ammonia | IP—inorganic phosphate | Si—silicate

early-year peak (January–February) followed by a steep decline in their number through the rest of the year. Even though barnacles were year-round breeders at the tropical location, a peak in their settlement was observed in the months of January–February characterized by lower water temperatures. In all three dendrograms (Figure 3a,b,c), green mussels consistently appear as a distinct entity, clustering separately from other fouling species or joining groups only at high dissimilarity levels. This consistent isolation suggests that their seasonal abundance pattern is markedly different from the rest of the community. Unlike other taxa that exhibit synchronized settlement trends such as peaks during spring or declines in monsoon, green mussels show a unique temporal trajectory characterized by a decline in early spring followed by a steady increase through the summer and post-monsoon periods. This inverted pattern relative to species like solitary ascidians or barnacles likely reflects differences in ecological strategies, such as reproductive timing, settlement preferences, or environmental tolerance. As a result, their consistent unique status across all clustering analyses highlights their potential role as an indicator species for specific environmental conditions or seasonal shifts that are not captured by other taxa.

Solitary ascidians display a sharp spike in abundance during April and are otherwise low or negative throughout the year. Hydroids branch earlier in the clustering process and show a moderately distinct pattern, peaking early in the year (January–February) similar to barnacles and remaining low afterward. Polychaetes cluster more closely with species like oysters and ascidians, indicating moderately synchronized seasonal dynamics. Oysters follow a similar pattern to polychaete tube worms, showing moderate abundance through late spring and summer. Colonial ascidians exhibit mild abundance in PRM (March–May) and negligible presence afterward. Their limited seasonal window places them close to oysters and polychaetes in the dendrogram. Bryozoans show a brief spring peak (May), followed by low or absent values. They are structurally clustered with colonial ascidians, implying similar ecological timing.

The other species observed shows fluctuating presence without a sharp peak, resulting in a moderate position in the dendrogram. It clusters loosely with the mid-year species, reflecting variable and possibly opportunistic dynamics, possibly driven by less dominant or transient taxa. Based on the comparative analysis of the three dendrograms corresponding to SS, Ti, and FRP substrates, it is evident that FRP is the most favourable surface for the recruitment of green mussels. In the

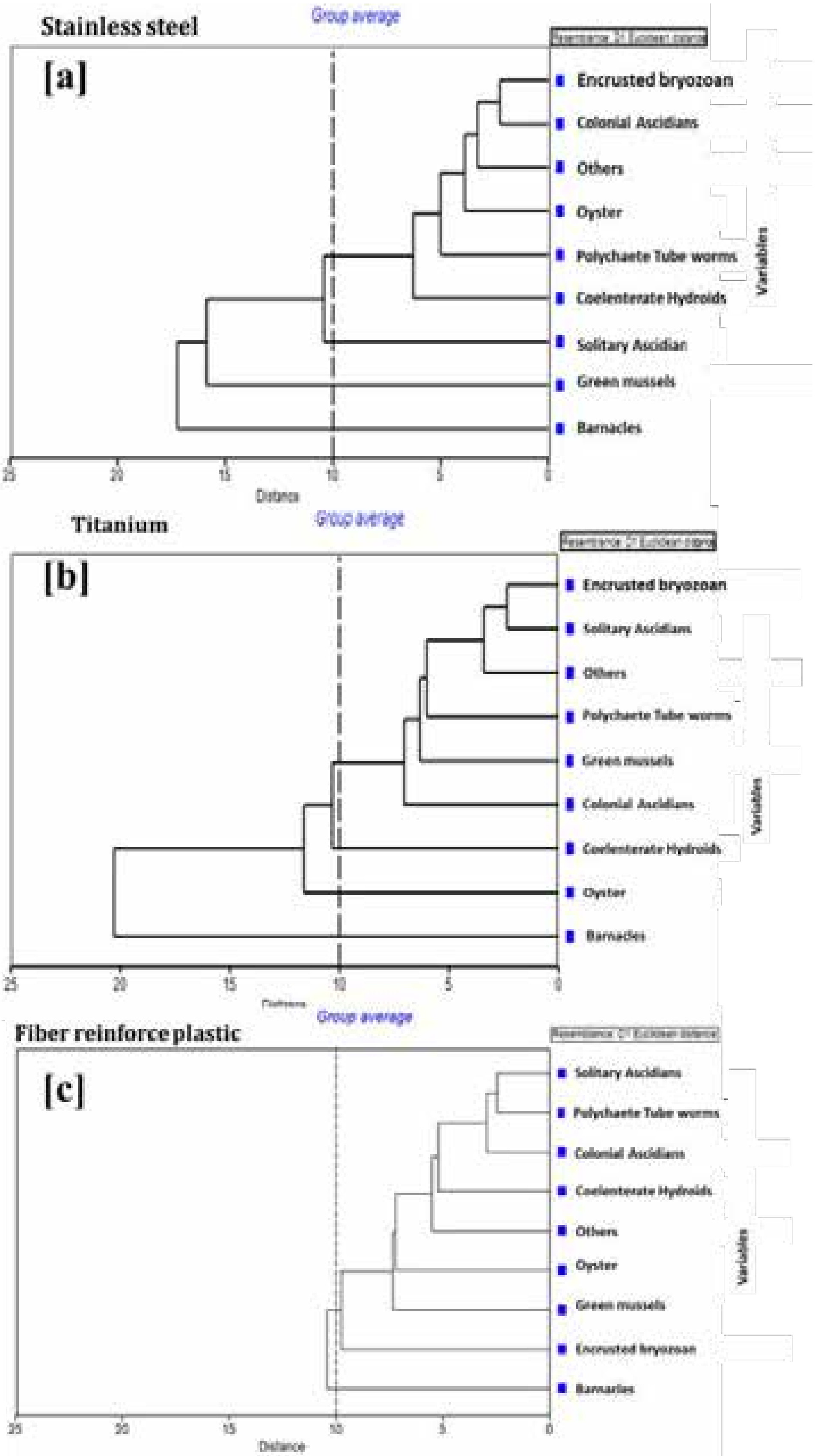

Figure 3. Bray-Curtis similarities of species diversity in different materials (a) stainless steel, (b) titanium, & (c) fibre reinforced plastic in a year (Jan–Dec 2022).

dendrogram for FRP, green mussels are less isolated and join clusters with other fouling species at a lower dissimilarity level. This suggests that their seasonal abundance pattern on FRP aligns more closely with the broader fouling community, indicating consistent and possibly robust recruitment.

In contrast, on SS, green mussels appear highly isolated in the dendrogram, branching off at a large dissimilarity distance. This implies that their occurrence on SS is ecologically distinct, likely reflecting limited settlement or poor substrate compatibility. Titanium shows an intermediate pattern, where green mussels still remain relatively isolated but to a lesser extent than on SS, suggesting moderate but less predictable recruitment. The overall trend points to FRP providing surface characteristics such as suitable roughness, favourable biofilm development, or lower material toxicity that better supports the settlement and establishment of green mussels compared to the other metallic substrates.

Relationship between environmental parameters and fouling load in different coupons

Environmental parameters and correlations

Correlation matrix provides insight into the relationships between different water quality parameters and biofouling loading on coupons. Water temperature (WT) is strongly correlated with salinity (0.874, $p < 0.001$), Table 3. This could be due to the evaporation of water, which concentrates salts in the remaining water body. Conversely, dissolved oxygen (DO) and temperature exhibit a strong negative correlation (-0.646, $p = 0.023$), suggesting that higher temperatures reduce the solubility of oxygen in water. This is a well-documented phenomenon, as warmer water holds less oxygen, potentially leading to hypoxic conditions in aquatic ecosystems. Additionally, salinity and DO also show a significant negative correlation (-0.852, $p < 0.001$), indicating that areas with higher salinity tend to have lower oxygen levels, possibly due to reduced mixing or increased biological oxygen demand. pH was positively correlated with DO (0.863, $p < 0.001$). This could be due to increased photosynthetic activity in the water, which both raises pH (due to CO_2 uptake) and increases oxygen levels. On the other hand, pH and salinity have a negative correlation (-0.723, $p = 0.008$), suggesting that higher salinity waters tend to be more acidic. This could be due to the influence of dissolved salts and carbonate chemistry in marine or estuarine environments.

Among the inorganic nutrients a strong correlation between nitrite and nitrate (0.839, $p < 0.001$) was observed. Similarly, ammonium (NH_4) and nitrate have a strong inverse correlation (-0.843, $p < 0.001$), meaning that when ammonium concentrations are high, nitrate levels tend to be lower. This could indicate active nitrification, where ammonium is converted to nitrate through microbial processes. The overall pattern in these relationships points to active nitrogen cycling, likely influenced by biological activity and environmental conditions such as oxygen availability. Stainless steel is often used in marine environments due to its corrosion resistance, but does not inherently possess anti-fouling properties. Earlier studies with SS in seawater environments revealed that interaction of metals under neutral pH conditions results in an increase in electrostatic interactions, which can affect microbial adhesion, while alkaline conditions potentially accelerate surface oxidation (Ferris et al. 1989; Sedriks 1996).

Alternatively, it might indicate that SS structures are more commonly used in environments where pH is naturally higher. A decrease in pH reduces electrostatic interactions, thereby diminishing the free energy available for metallic ion adsorption (James & Healy 1972). Stainless steel corrosion is known to be affected by oxygen levels, as oxidation processes (such as the formation of chromium oxide protective layers) require oxygen (Kritzer 2004). Higher DO levels might enhance corrosion under certain conditions, especially in the presence of chlorides (Kritzer et al. 2000). Stainless steel can be prone to biofouling, but factors like surface roughness, passive oxide layer formation, and environmental conditions play a role.

Material-specific fouling and corrosion

Titanium is known for its excellent corrosion resistance in seawater due to its strong passive oxide layer (TiO_2), which reduces microbial attachment (Órdenes-Aenishanslins et al. 2014). Additionally, the photocatalytic properties of TiO_2 have been utilized for disinfection purpose, demonstrating antimicrobial activity under certain conditions (Simonin et al. 2016). Titanium is generally corrosion-resistant, but its interactions with dissolved organic matter, suspended solids, could initiate primary biofilm formation aiding settlement and colonization of higher organisms.

FRP surfaces are generally more prone to biofouling than metals due to their rough texture and ability to trap microorganisms. Several researchers have examined the adhesion of marine bacteria on various surfaces and concluded that bacterial attachment is lower on low-energy (hydrophilic) surfaces compare to high-energy surfaces, which promotes stronger adhesion (Dexter et al. 1975; Hamza et al. 1977). Muthukumar et al. (2011) reported that glass fibre reinforced polymer and carbon fibre reinforced showed maximum fouling (barnacle) attachment on hard surfaces (Muthukumar et al. 2011) than on flexible surfaces (Silicon rubber). FRP is the most prone to biofouling among the three due to its rough surface and micro plastic shedding, which can support microbial colonization.

Green mussel settlement patterns

Green mussel settlement was observed after 150 days and continues by covering the coupons completely. The attachment was seen during June–December with peak in August–September. In our study the first peak was lesser spat settlement. Green mussels dominating the whole surface area and not letting any other organisms to grow during this time. In previous report, it was observed that green mussel settlement during April–November with peaks in May–June, which showed some similarities to our current study carried out at the study area (Rajagopal et al. 1997; Sahu et al. 2011). It is also reported that the peak during March–November and with second peak August–September by (Paul 1942) Madras harbour. This peak settlement coincided with relative high temperature during the period (Selvaraj 1984). Myint & Tyler (1982) reported that spawning occurs according to the availability of food resources and high salinity. This indicates that more larval abundance and settlement pattern of green mussels influenced by the availability food, high temperature and salinity (Pieters et al. 1980; Newell et al. 1982).

Implication of materials selection

The present study highlights the significant differences in biofouling accumulation on SS, Ti, and FRP over time. Titanium is the most resistant material, while FRP shows the highest susceptibility to fouling, making it less favourable for long-term marine applications. Seasonal variations in fouling loads have also been reported in studies conducted at other locations (Swami & Chhapgar 2002; Swami & Udhayakumar 2010; Sahu et al. 2015). Understanding these material-specific trends is crucial for selecting appropriate materials for offshore structures, cooling water systems, and other marine applications where biofouling can impact performance and maintenance costs. When considering the other side of the story, it is important to recognize that the same materials that may be prone to biofouling can also serve as valuable substrates for recruiting desired marine organisms for aquaculture purposes. Among the three substrates used for recruitment studies, Ti remained to be highly resistant to fouling. However, stainless steel, with its moderate resistance to fouling, may offer a balanced substrate for attracting certain species, particularly those that thrive in semi-clean environments. Its ability to support a variety of organisms, from barnacles to algae, can be advantageous for applications like marine habitats or artificial reefs where biodiversity is desired.

CONCLUSION

In conclusion, the comparative analysis of the materials reveals distinct differences in their susceptibility to biofouling as well as species succession patterns. Among the three surfaces, evaluated titanium showed the least biofouling with a low density of fouling organisms and minimal surface coverage, highlighting its resistance to biofouling. Stainless steel surfaces on the other hand, experienced moderate fouling, with barnacles settling early but eventually their numbers decreased as settlement of other organisms occurred, leading to a more balanced fouling community over time. In contrast, FRP was found to be a most suitable substrate for settlement and recruitment of many biofouling organisms and was found to support a higher density of organisms due to its inert nature and rough surface. Ideally barnacles were the initial settlers on all three surfaces during the first 30 days of exposure followed by coelenterate hydroids which dominated the surfaces after 30 days of immersion. Colonial and mat forming ascidians, solitary bryozoans settled and colonized from the 60th day. Green mussels formed the mature fouling community with on all three surfaces with settlement observed from 120 day. Results of the study provide the biofouling potential of these three surfaces and FRP surfaces was found to sustain a more diverse fouling community.

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ARTICLE

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Addition of five lesser known angiosperm species from Mizoram, India

R. Lalthantluanga [1], Dorothy Lalbiakhluni [2], Vanlalawmpuia Sailo [3], Rose Laldinaii Darnei [4], R. Lalhruaitluangi [5], Sanatombi Devi Yumkham [6] & Sandhyarani Devi Khomdram [7]

[1,2,3,4,5,7] Department of Botany, Mizoram University, Aizawl, Mizoram 796004, India.
[6] Department of Life Sciences (Botany), Manipur University, Canchipur, Manipur 795003, India.
[1] lalthantluangarenthlei06@gmail.com, [2] dorothylalbiakhluni@gmail.com, [3] vanlalawmpuiasailo@gmail.com,
[4] rosedarnei7@gmail.com, [5] nonoiralte02@gmail.com, [6] rifle_yumkham@rediffmail.com (corresponding author),
[7] sandhyakhomdram@gmail.com (corresponding author)

Abstract: Five angiosperm species, *Cajanus elongatus* (Benth.) Maesen (Fabaceae), *Crotalaria meghalayensis* Danda & A.K.Pandey (Fabaceae), *Mycetia malayana* (G.Don) Craib (Rubiaceae), *Microchirita karaketii* D.J.Middleton & Triboun (Gesneriaceae), and *Peliosanthes griffithii* Baker (Asparagaceae) are reported as new distribution records for Mizoram, India. Species identification was confirmed through detailed morphological examination, supported by relevant literature and herbarium studies. Comprehensive taxonomic descriptions, distribution data, and photographic documentation are provided.

Keywords: *Cajanus elongatus*, *Crotalaria meghalayensis*, Indo-Burma hotspot, *Microchirita karaketii*, *Mycetia malayana*, northeastern India, *Peliosanthes griffithii*.

Mizo: Angiosperm (Pangpar nei chi) hrang hrang panga -*Cajanus elongatus* (Benth.) Maesen (Fabaceae), *Crotalaria meghalayensis* Danda & A.K.Pandey (Fabaceae), *Mycetia malayana* (G.Don) Craib(Rubiaceae), *Microchirita karaketii* D.J. Middleton & Triboun (Gesneriaceae), leh *Peliosanthes griffithii* Baker (Asparagaceae) te chu Mizoram, India-ah a vawikhat nan hmuh thar an ni. Hei hi uluk taka an pianhmang (morphology) zirchianna te, lehkhabu hrang hrang (literature) leh thlai ro vawnna hmun (herbarium) te nen a khaikhin anih hnuah nemngheh a ni. He zirchianna ah hian thlai tin te nihphung (taxonomic descriptions), an awmna hmun (distribution), leh an thlalak te tarlan tel a ni.

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Author details: R. Lalthantluanga is a Ph.D. scholar in the Department of Botany at Mizoram University, Aizawl, Mizoram. His research focuses on the taxonomic diversity of the family Araceae. Dorothy Lalbiakhluni is a master's student (IV Semester) in the Department of Botany at Mizoram University, Aizawl, Mizoram. She is currently working on the subfamily Faboideae for her M.Sc. dissertation. Vanlalawmpuia Sailo is a research scholar at Mizoram University, Aizawl, Mizoram specializing in the taxonomic diversity of the family Begoniaceae. Rose Laldinaii Darnei is a research scholar in the Department of Botany at Mizoram University, Aizawl, Mizoram where her work centers on the diversity and taxonomy of orchids. R. Lalhruaitluangi is a master's student (IV Semester) in the Department of Botany at Mizoram University, Aizawl, Mizoram currently focusing her M.Sc. dissertation on the family Rubiaceae. Dr. Sanatombi Devi Yumkham serves as guest faculty in the Department of Life Sciences (Botany) at Manipur University, Imphal. Her research interests encompass plant systematics, palynology, ethnobotany, plant anatomy, and cryptogamic studies (pteridophytes, bryophytes). Dr. Sandhyarani Devi Khomdram is an associate professor in the Department of Botany at Mizoram University, Aizawl, Mizoram. Her primary fields of expertise include plant systematics, ethnobotany documentation and conservation of endemic, Rare, Endangered, and Threatened (RET) plant taxa in the Indo-Burma biodiversity hotspot.

Author contribution: RL—field surveys, conceptualization, investigation, and initial manuscript drafting; DL, VS, RLD and RLI—field surveys, investigation, methodology and proofreading; SDY and SDK—conceptualization, supervision, photographic preparation, writing, editing and finalization of the manuscript. All authors read and approved the final manuscript.

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INTRODUCTION

Mizoram, situated within the Indo-Burma biodiversity hotspot, is a region of exceptional ecological significance that urgently requires comprehensive taxonomic investigation (Mittermeier et al. 2004; Rai & Lalramnghinglova 2010; Khomdram et al. 2026). The state, located in northeastern India, spans an area of about 21,087 km² and shares international boundaries with Myanmar to the east and south, and Bangladesh to the west. Despite its diverse physiography and climatic conditions supporting major vegetation types such as tropical wet evergreen, montane subtropical, temperate, bamboo forests, Quercus forests, and jhumland, floristic documentation remains far from complete (Singh et al. 2002). The ecological heterogeneity of the state fosters high endemism and floristic richness, making it a critical repository of plant genetic resources. Botanical investigations in Mizoram have lagged behind those in other parts of the Himalaya and northeastern India, leaving significant gaps in floristic knowledge. In recent years, the discovery of several new species has markedly enriched global plant diversity and the known flora of Mizoram, emphasizing the exceptional and ongoing potential for botanical exploration in the region.

The last few decades have witnessed multiple additions to the documented plants' distribution of Mizoram (Panday et al. 2014, 2016, 2020; Rathi et al. 2016; Sarkar et al. 2022; Tlanhlui et al. 2023; Lalnunfeli et al. 2024). Although Singh (1997) established a baseline of 2,141 angiosperm species in Mizoram (1,627 dicots and approximately 500 monocots), the discovery of more than 11 species new to science in intensive surveys since 2021 demonstrates the continued significance of the region as an expanding frontier for botanical discovery (Krishna et al. 2021; Prasanna & Gowda 2021; Lalhlupuii et al. 2023, 2025; Sengupta & Dash 2024, 2026; Lalfakawma et al. 2024; Sâwmliana et al. 2024; Tlanhlui et al. 2025; Lalnunfeli et al. 2026; Sailo et al. 2026).

During floristic surveys of 2024 to 2025 across diverse habitats in Mizoram, five angiosperm species—*Cajanus elongatus* (Fabaceae), *Crotalaria meghalayensis* (Fabaceae), *Microchirita karaketii* (Gesneriaceae), *Mycetia malayana* (Rubiaceae), and *Peliosanthes griffithii* (Asparagaceae)—were recorded for the first time from the state. These findings represent significant additions to the floristic inventory of the state, situated within the Indo-Burma biodiversity hotspot, and highlight the importance of continued botanical exploration.

MATERIALS AND METHODS

Extensive floristic explorations were carried out in various habitats across Aizawl and Mamit districts of Mizoram during 2025. Herbarium voucher specimens were deposited in the Herbarium of the Department of Botany, Mizoram University (MZUH). Species identification relied on available floras and relevant literature (Singh et al. 2002; Chen & Taylor 2011; Danda et al. 2016; Leeratwong et al. 2018; Tanaka 2018; Kumar et al. 2022; Rhuthuparna & Gowda 2024; Bora et al. 2025), and all accepted names were cross verified through Plants of the World Online (POWO 2025) and the World Flora Online (WFO 2025). The documented species are arranged alphabetically and include detailed descriptions covering type, taxonomy, phenology, habitat, ecology, distribution, and examined specimens. Morphological features were analyzed using photographs and microphotographs captured with a Sony DSC-W610 digital camera and a BT-E Benchtop Biological Digital Microscope.

RESULTS

Taxonomic treatment

***Cajanus elongatus* (Benth.)** (Image 1)

Maesen Agric. Univ. Wageningen Pap. 85(4): 115 (1986)

Type: Nepal, 1821, Wallich 5543 (holotype K-W [K001121245!]; isotypes BM [BM000574466!], CAL n.v., E [E00301629!], G [G00364706!, G00364708!], K [K000900563!, K000900564!], K-W [K000900562!], L [L0018799!], LE [LE00014567!, LE00014568!]).

Synonyms: *Atylosia elongata* Benth. in F.A.W.Miquel, Pl. Jungh.: 243 (1852), *Cantharospermum elongatum* (Benth.) Raizada in H.Mooney, Suppl. Bot. Bihar & Orissa: 53 (1950).

Climbing or crawling vine with a twining stem. Stem round, densely covered with yellow-brown fine hairs. Leaves trifoliate, terminal leaflet circular-rhomboid or obovate-rhomboid, base slightly cordate, 2.2–4.6 × 2–3.5 cm, lateral leaflets obliquely ovate, rounded cuneate base, 2.0–3.6 × 1.1–2.7 cm, apex acute, margin entire, hairy with more hairs along margin and midrib, secondary veins 3–4 pairs. Petioles 1.0–7.0 × 0.5–1.0 cm, covered with long brownish hairs, petiolules 0.1–0.2 cm, pulvinate. Stipules caducous, 2.5–3 × 0.5–2 cm, hairy, ovate triangular. Inflorescence axillary raceme, 3–8.4 cm long, lax, 2–4 flowers per inflorescence, peduncle 3.0–5.0 cm, flowers one pair at each node, pedicel 0.4–1.0

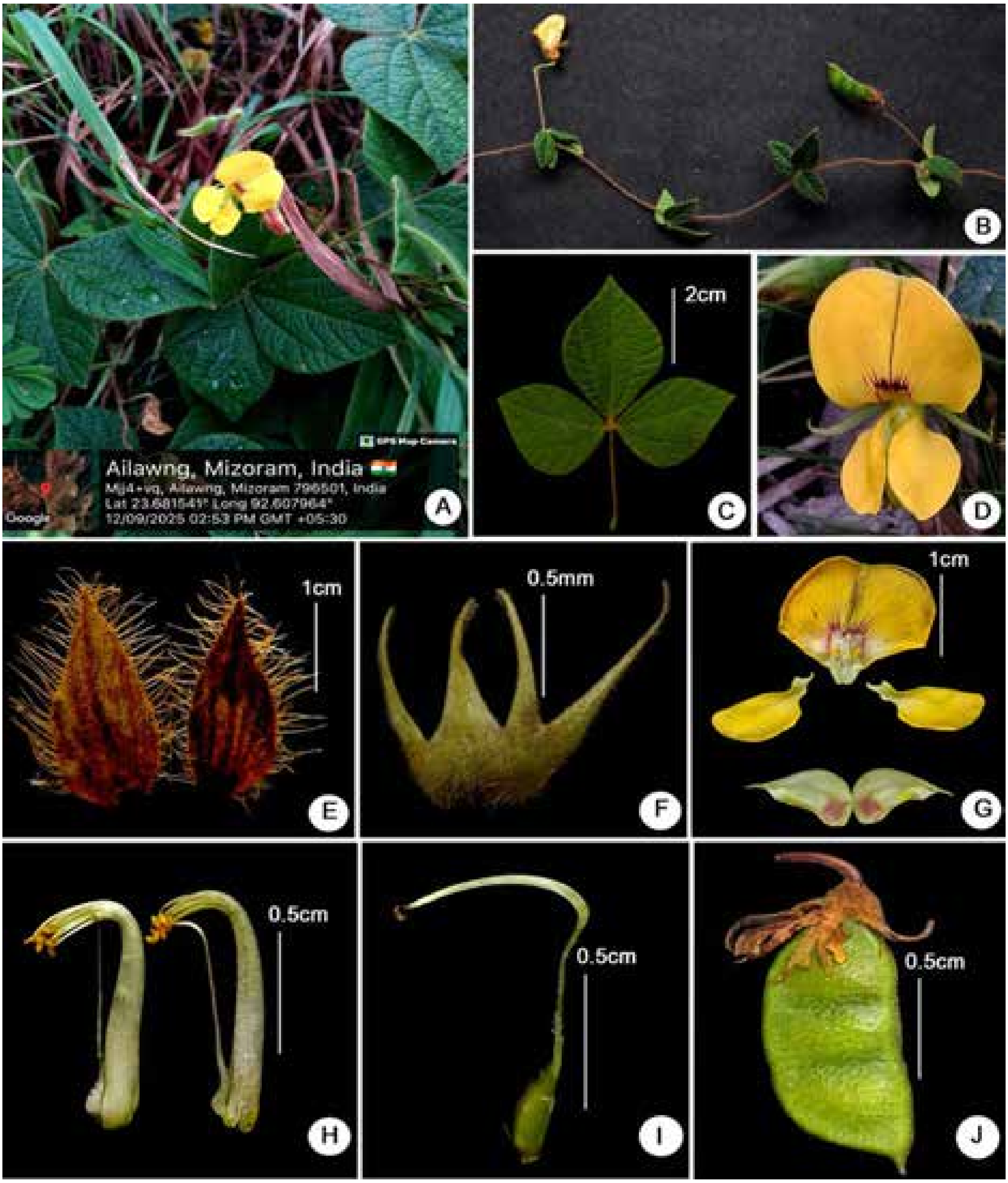

Image 1. *Cajanus elongatus* (Benth.) Maesen: A—Habitat | B—Habit | C—Palmately 3-foliolate leaves | D—Flower | E—Stipules | F—Calyx | G—Dissected petals | H—Androecium | I—Gynoecium | J—Pod. © Dorothy Lalbiakhluni.

cm. Calyx 5-lobed, hairy, upper lobes 0.5–0.7 cm, lower lobes 1.0–1.2 cm, upper two lobes fused for up to half of their length, sepal cup 0.3–0.4 cm. Corolla yellow, glabrous. Standard petal striated with crimson-red veins, obovate, 1.3–1.5 × 1.1–1.6 cm, apex emarginate, base bi-auriculate, claw 1–2 mm; wing petals irregularly oblong, 1.0–1.4 × 0.5–0.7 cm, auriculate, limb incurved, claw 2–3 mm long; keel petals boat shaped, 8–12 × 5–8 mm, obtuse apex, limbs incurved. Stamen diadelphous, staminal tube 0.8–1.3 cm, free part of filament 3.5–

4.5 mm anthers dorsifixed, all fertile, ovate-oblong to elliptic. Gynoecium 1–1.7 cm long, ovary 2–5 × 1–1.5 mm, densely hairy, style 1–1.2 cm, glabrous, bent at the upper part like a falcate. Pods hairy, 3–4 seeded, 2.4–3.5 × 0.7–1.0 cm, stalk 6–9 mm.

Phenology: August to November.

Habitat and ecology: Found on dry, open subtropical montane grasslands. Thrives in wet tropical biome.

Distribution: India (Assam, Meghalaya, Mizoram, Odisha), Myanmar, Nepal, Thailand, Vietnam.

Species examined: India, Mizoram, Mamit District, Reiek Village, 23.681° N, 92.607° E, 1,465 m elevation, 03.ix.2025, Dorothy Lalbiakhluni, 201101 (MZUH001312) (Image 6).

Conservation status: A recent extinction-risk analysis concludes that Cajanus elongatus does not currently meet the criteria for a threatened species (Bachman 2024). Nevertheless, its highly fragmented distribution across dry, open hillsides and grasslands points to underlying potential vulnerabilities, emphasizing the necessity for targeted field surveys to precisely evaluate its national conservation status.

Crotalaria meghalayensis Danda & A.K.Pandey (Image 2)

Syst. Bot. 41: 309 (2016).

Type: India, Meghalaya: Jaintia hills, Jarain, 25.491° N, 92.061° E, 17.x.2014, S. Danda & A.K.Pandey 1318 (holotype: DUH!; isotypes: DUH!, BSD!).

Herb up to 67 cm tall; stems slender, green, pubescent. Root a well-developed taproot; lateral roots are nodulated. Leaves simple, narrowly lanceolate, 6.5–9.5 × 1.6–1.8 cm; apex acute; base cuneate–attenuate; margin entire; adaxial surface sparsely hairy along midrib; abaxial surface densely pubescent with simple uniseriate multicellular hairs; venation pinnate with prominent midrib and 6–9 secondary veins; petiole 2–2.5 × 1.2–1.5 mm; stipules absent. Inflorescence axillary or terminal raceme, terminal raceme to 6 cm, 7–12 flowered; pedicel 4–6 mm, pubescent. Bracts oblong–lanceolate, 3.5–5 × 0.5–0.8 mm, base truncate, apex acute–acuminate, pubescent. Calyx bilabiate, externally densely hairy, internally glabrous, imbricate, 4-veined; upper lip bilobed, lobes ovate–obovate, apex abruptly acute, mucronulate, 1.6–2.5 × 0.8–1.2 cm; lower lip trilobed, lobes narrowly lanceolate, apex acute, 1.7–2.5 × 0.3–0.8 cm. Standard petal broadly obovate–orbicular, 1.15–1.5 × 1–1.4 cm, apex rounded, central dark blue patch; claw 2–3 mm, woolly at margins. Wings narrowly obovate, 1.2–1.3 × 0.5–0.6 cm, apex obtuse–rounded. Keel sub-angled, 1.2–1.4 × 0.4–0.5 cm, apex rostrate with twisted beak; surface paleaceous-tomentose, white-silky. Androecium monoadelphous, 10-merous, 5–8 mm; 5 stamens fertile with dorsifixed ovoid–sagittate anthers, 5 sterile with basifixed elongate anthers. Ovary sessile, 3.5–6 × 1–2.5 mm; style 1.2–1.3 cm, geniculate; placentation marginal. Pods cylindric, elliptic to oblong.

Phenology: August to November.

Habitat and ecology: The species inhabits open subtropical montane grasslands on well-drained slopes at 1,400–1,800 m elevation, growing among tall grasses and sparse shrubs in sunny, exposed hill environments.

Distribution: India (Meghalaya, Mizoram).

Species examined: India, Mizoram, Mamit District, Reiek Village, 23.683° N, 92.608° E, 1,465 m elevation, 03.ix.2025, Dorothy Lalbiakhluni, 201100 (MZUH001313) (Image 7).

Conservation status: The present record from Mizoram represents a significant range extension, underscoring the need for further surveys to assess population status.

Microchirita karaketii D.J.Middleton & Triboun (Image 3)

Thai Forest Bull., Bot. 41: 17 (2013)

Type: Thailand, Chiang Dao, Chiang Mai, Middleton, Karaket & Triboun 4526 (holotype at BKF; isotypes at E, P, QBG).

Lithophytic herbs, caulescent, up to 25 cm tall, with fibrous roots. Stem erect to sub-erect, green to maroon tinge below, 1–24 × 0.15–0.5 cm, glabrous or sparsely clothed with eglandular hairs. Leaves 1–5, opposite towards apex, lowermost solitary; petiole 2–6 × 2–4 mm, green, sparsely pubescent, lamina ovate, 5–16.3 × 4–11.2 cm, base cordate, margins entire, ciliate, apex acuminate, sparse uniseriate hairs on both surfaces, secondary veins 6–16 pairs, adaxially dark green, abaxially pale green. Inflorescence cristate, few to many flowered, peduncles 10 mm; bracts absent. Pedicels 3–14.5 mm, pale green, sparsely pubescent. Calyx green, bilabiate, lower lip three lobed, lobes free to the base; upper lip two unequal lobed, irregularly fused; lobes narrowly lanceolate, 1–5 × 0.7–1.2 mm, margins entire, apex acuminate, sparsely hairy. Corolla white, throat with a central yellow stripe, a lavender patch on either side of the stripe; lobes white; tube slender, curved downwards, upper 11.5–15 mm long, lower 12–16 mm, outer with uniseriate hairs, glabrous within; lobes orbicular to elliptic; upper lobes spreading, 3.2–4.4 × 3.3–5.2 mm; lateral lobes 3.7–4.4 × 4.2–5.2 mm; lower lobes 3.5–4.4 × 3.8–4.7 mm, apices rounded to

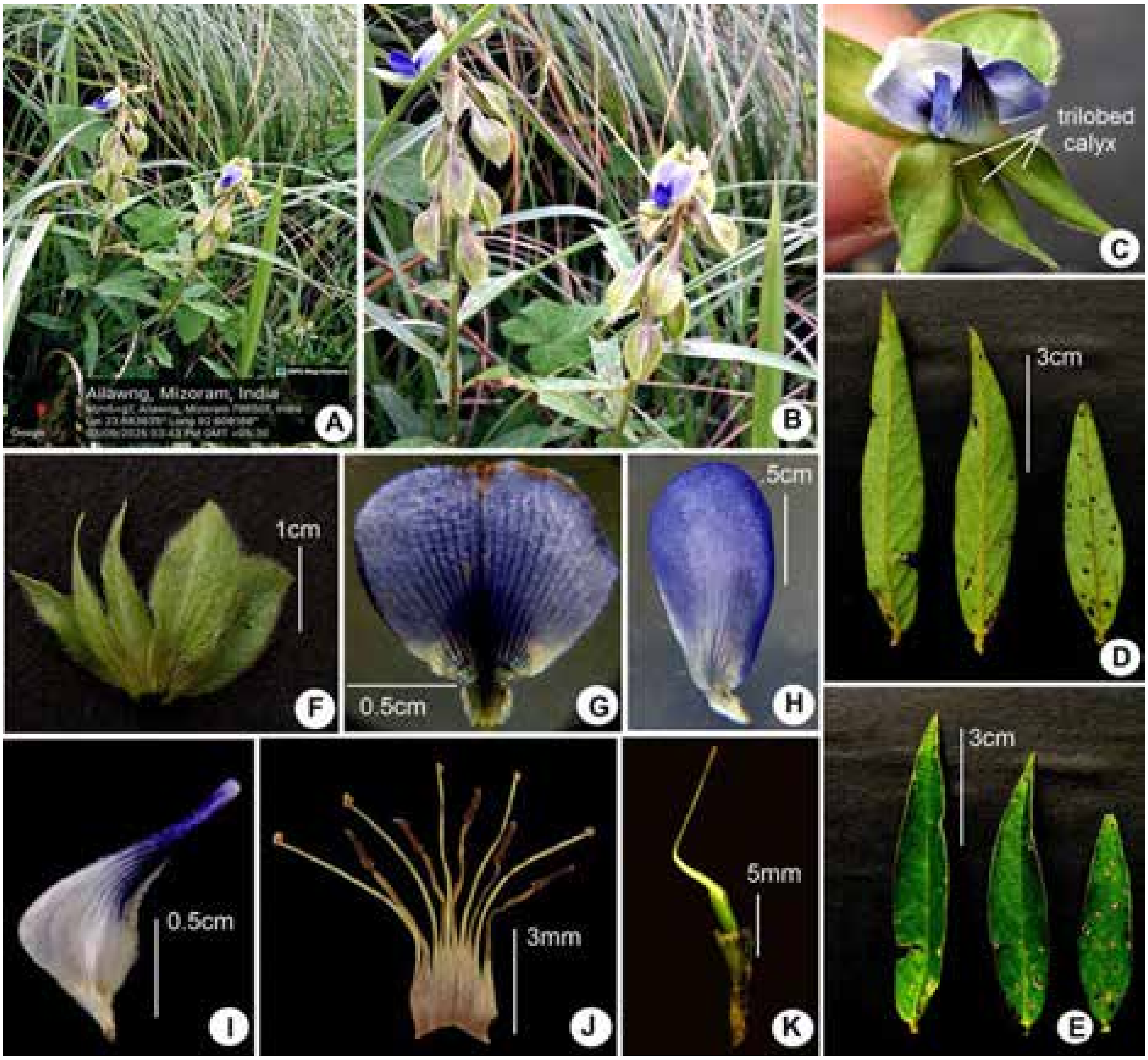

Image 2. *Crotalaria meghalayensis* Danda & A.K.Pandey: A & B—Habitat | C—Flower | D— Leaves, abaxial view | E—Leaves, adaxial view | F—Calyx | G—Standard petal | H—Wing petals with cavae | I—Keel petals with twisted beak | J—Androecium | K—Gynoecium with geniculate style. © Dorothy Lalbiakhluni.

occasionally obtuse. Stamens two, arising 4.4–6.5 mm above the corolla base, straight, 2.2–3.6 mm × 0.4 mm, glabrous, creamy white. Anthers 1.4–2 × 0.9–1.3 mm, pale yellow, sparse long hairs at the point of attachment, thecae coherent face to face. Disk absent or represented by a ventral half-ring. Pistil 9.5–15 mm long; ovary 3.6–5 mm long, 1 mm in diameter, pale green and papillose; style 5–7 mm long, pubescent, creamy white; stigma chiritoid, 1 mm long, creamy white. Fruit (immature, indehiscent) 4–5 cm long, 2 mm in diameter, glabrous at the base, pubescence at the upper half, green. Seeds narrowly elliptic, 0.4 × 0.2 mm, brown.

Phenology: September to December.

Habitat and ecology: Lithophytic, typically occurring near streams and other persistently damp locations. They often anchor themselves in small crevices or thin soil layers on moist rock faces, thriving in humid, shaded microhabitats.

Distribution: India (Meghalaya, Mizoram), Myanmar, Thailand.

Species examined: India, Mizoram, Aizawl District, Tanhril, 23.746° N, 92.643° E, 732 m elevation, 30.ix.2025, Vanlalawmpuia Sailo, 202000 (MZUH001314) (Image 8).

Conservation status: In India, it is restricted to a single known population in Meghalaya and Rhuthuparna & Gowda (2024) consider it as Critically Endangered. The

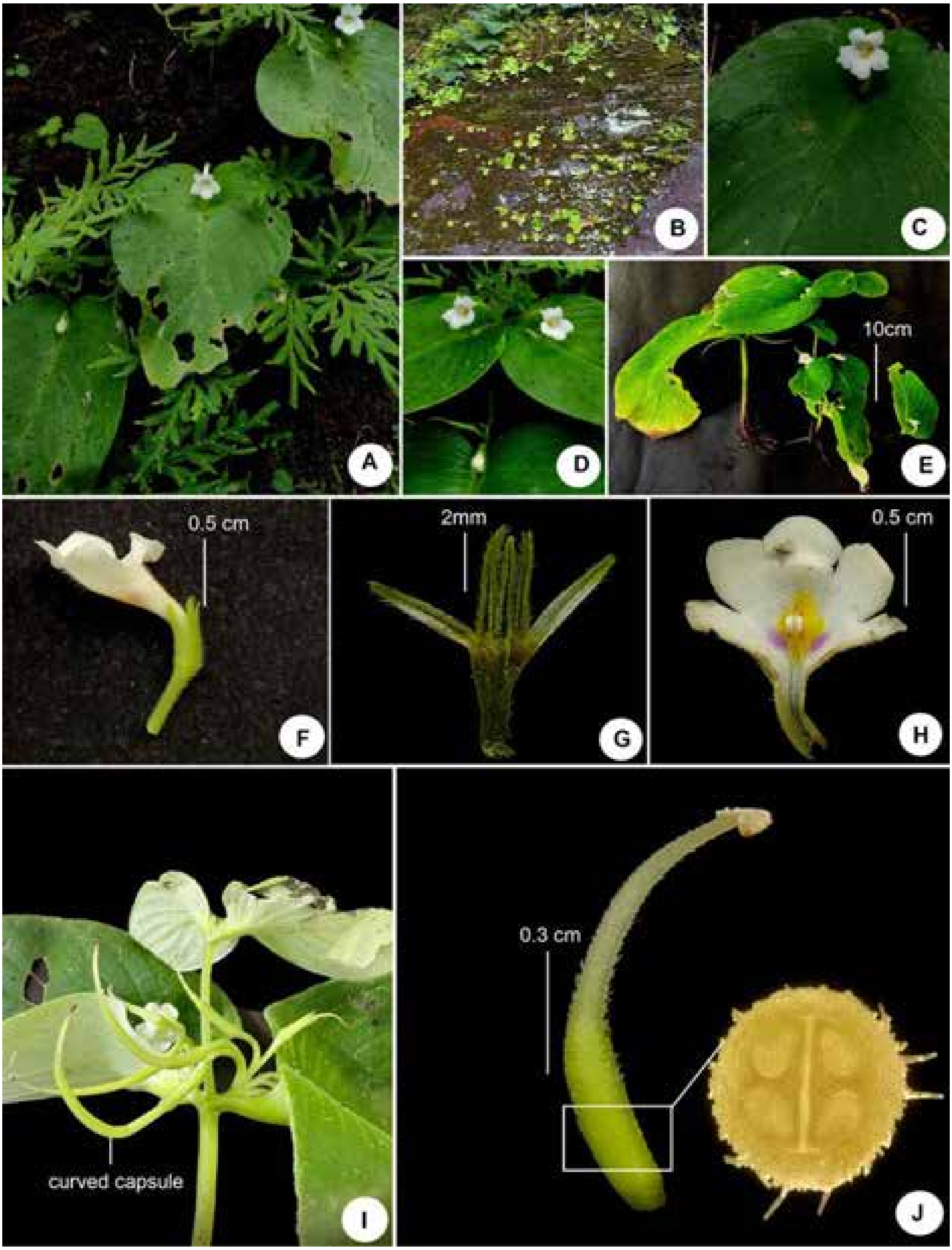

Image 3. *Microchirita karaketii* D.J.Middleton & Triboun: A & B—Habitat | C–E—Habit | F—Flower | G—Opened calyx | H—L.S. flower | I—Young curved fruits | J—Gynoecium with cross section of ovary showing hairs. © Vanlalawmpuia Sailo.

present record from Mizoram represents a significant range extension, emphasizing the urgent need for detailed population studies, habitat assessment, and conservation planning to ensure its long-term survival.

Mycetia malayana (G.Don) Craib. (Image 4)

Bull. Misc. Inform. Kew 1914: 29 (1914)

Type: Malaysia, Penang, Wallich s.n. [EIC 6282], lecto K [K000760581] (Designated by Wong et al. 2019).

Synonyms: *Adenosacme malayana* (G.Don) Wall. ex Ridl. in Fl. Malay Penins. 2: 63 (1923), *Wendlandia malayana* G.Don in Gen. Hist. 3: 519 (1834).

Shrub or small tree, single-stemmed, often unbranched, up to 1 m tall; young shoots hairy, matured glabrous; bark smooth, shining white. Stipules lanceolate, 4–6 mm. Leaves crowded toward upper stem, slightly anisophyllous; petioles 1–1.5 cm, sometimes weakly winged at base; lamina membranous, oblanceolate to elliptic-lanceolate, 8–23.6 × 2.5–6.8 cm, base gradually tapering, apex acuminate, surfaces pale green; secondary veins 10–20 pairs; hairs present along nerves beneath. Inflorescences terminal, many-branched cymes, numerous-flowered, 7–8 cm long; branchlets slender; bracts minute, 3–4 mm; peduncle 2.5–3.5 mm. Flowers 5–6 merous; pedicels slender, 4–8 mm; calyx lobes triangular, c. 2 mm, margins with stalked colleters; corolla 4–5 mm, tube urceolate, green, 2–3 mm, glabrous externally and internally except hairy throat; lobes triangular, 1.0–1.2 mm, short-pilose on both surfaces. Stamens subsessile; filaments 0.2–0.5 mm; anthers 0.8–1.0 mm, inserted just below corolla throat. Style 0.3–0.4 mm; stigma bifid, 0.7–0.8 mm, included, ovary 2-locular, ovules numerous, glabrous. Berry small, smooth, fleshy, glabrous, globose to subglobose, 7 × 5 mm, creamy white.

Phenology: April to November.

Habitat and ecology: Occurring along roadsides, often mixed with other weedy vegetation, typically grows in moist, shaded habitats where soil remains damp, thriving in partially disturbed areas such as forest margins, drainage edges, and shaded embankments.

Distribution: India (Mizoram, Tripura), Bangladesh, Borneo, Malaya, Thailand.

Species examined: India, Mizoram, Mamit District, Ailawng Village, 23.712° N, 92.660° E, 1,139 m elevation, 23.v.2025, R. Lalhruaitluangi, 201150 (MZUH001315) (Image 9).

Conservation status: *Mycetia malayana* is a 'Least Concern' species on the IUCN Red List of Threatened Species (Oldfield 2021). It was regarded as nationally extinct in Singapore (Wong et al. 2019). Within India, previously documented only from a single population in Tripura (Bora et al. 2025). The present record from Mizoram indicates a broader distribution than previously recognized. The new record shows wider distribution, but insufficient data necessitate urgent surveys and monitoring for conservation planning.

Peliosanthes griffithii Baker (Image 5)

J. Linn. Soc., Bot. 17: 506 (1879).

Type: India, Darjiling, W. Griffith 5840 (holotype at K herbarium, specimen number K-000099365)

Perennial, rhizomatous herbs, up to 26 cm tall. Rhizomes short and slightly creeping, bearing numerous wiry roots up to 33 cm long and ca. 2.5 mm in diameter, densely clothed with root hairs. Stem short, stout, and erect, 0.4–4 × 0.4–0.8 cm, purplish to creamy white. Cataphylls up to 8.1 cm long and 1.5 cm wide, chartaceous, triangular-ovate to lanceolate. Leaves 7–14, arising in clusters from the stem apex. Petiole rigid, adaxially flattened, erect or curved, 0.8–2.3 x 0.13–0.2 cm. Lamina narrowly elliptic-lanceolate to lanceolate, 8.3–15 × 2.2–4.3 cm; apex acute to acuminate, base attenuate to cuneate, margin entire, surface glabrous. Venation parallel with 7–11 distinct veins visible adaxially and slightly raised abaxially, texture sub-coriaceous, glossy green above, paler beneath. Inflorescence solitary, arising from the leaf base, racemose, slender, 15–31 cm long, purplish to dark violet. Peduncle erect, 5–10 cm long, glabrous, dark violet. Sterile bracts 1.3–1.5 × 0.15–0.3 cm, triangular. Rachis densely flowered, bearing up to 91 flowers arranged spirally. Fertile bracts two at the base of each pedicel, small, ovate-triangular to linear-lanceolate, 0.8–1 × 0.1–0.2 cm, inner bracts usually twice smaller. Pedicels green to violet, 3–4.2 × 0.5 mm. Flowers bisexual, actinomorphic, greenish purple to dark violet, 5–6 mm in diameter. Perianth six, free, linear-lanceolate, 2–3 × 0.7–1.3 mm, concave, homochlamydeous, with valvate aestivation; segments revolute, greenish purple to violet. Stamens 6; filaments united, forming a fleshy corona-like structure, corona stellate to triangular-ovate, 0.7–1 x 2 mm in diameter, margin serrate to sinuate. Anthers six, sessile, inserted on the inner surface of the corona lobes just below the orifice; introrse, dorsifixed, minute (less than 0.5 mm long), oblong to ovate, bilobed. Gynoecium c. 2.5 mm high; ovary perigynous, trilocular, globose to ovoid, with three longitudinal parietal folds meeting at the center, exhibiting axile placentation; style 0.6–0.9 mm long; stigma distinctly 3-carinal. Seeds 12, ovoid to narrowly ovoid.

Phenology: October to December.

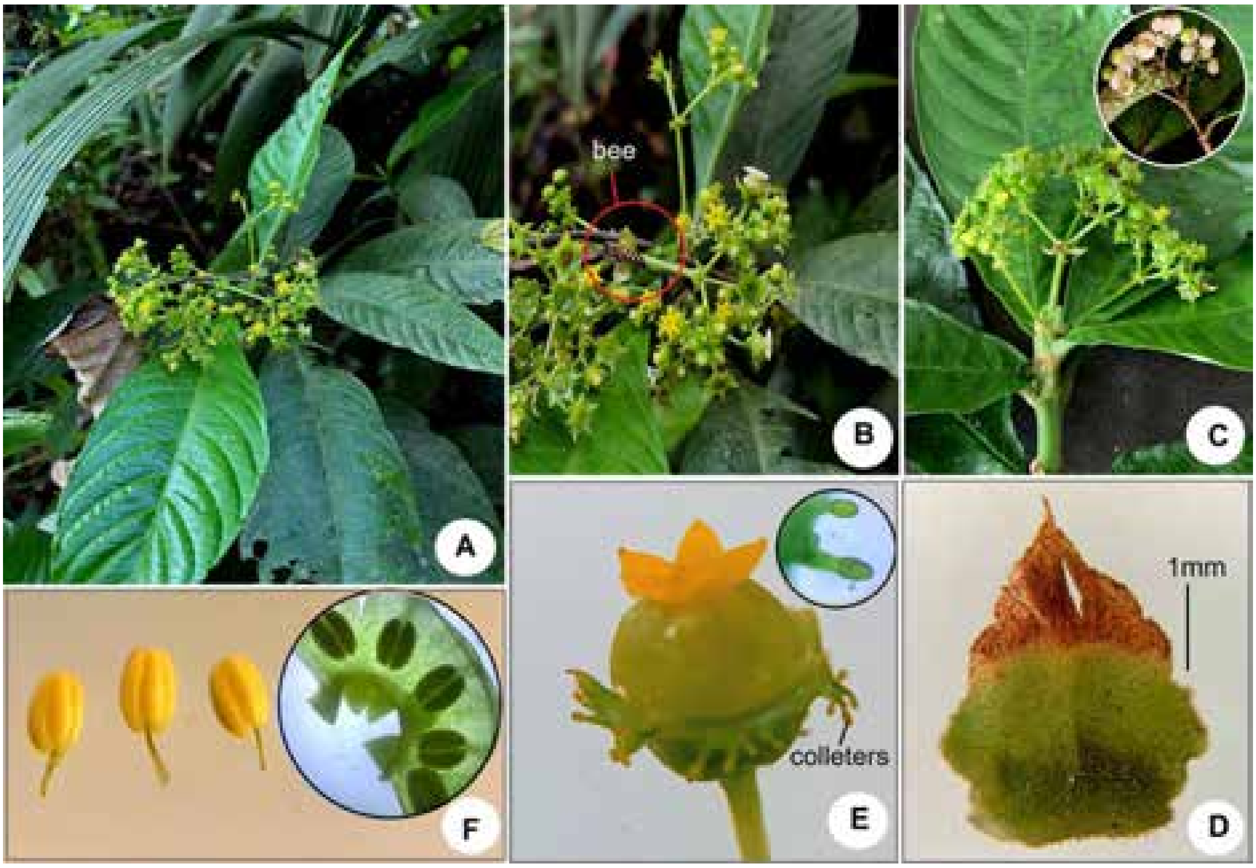

Image 4. ***Mycetia malayana*** **(G.Don) Craib: A—Habit | B—Flowering twig with pollinator | C—Inflorescence (inset: matured infructescence) | D—Stipule | E—A single flower (inset: stalked colleters on calyx lobe margins) | F—Stamens (inset: subsessile stamens below corolla throat). © R. Lalhruaitluangi.**

Habitat and ecology: Rhizomatous forest herb grows in the shady, moist understorey of evergreen and semi-evergreen forests. It prefers humus-rich, well-drained soil and occurs at mid to high elevations (up to 1,600 m).

Distribution: India (Assam, Mizoram), eastern Himalaya, Nepal, Vietnam.

Species examined: India, Mizoram, Aizawl District, Hmuifang Village, 23.455° N, 92.754° E, 1,619 m elevation, 16.x.2025, R. Lalthantluanga, 201010 (MZUH001316) (Image 10).

Conservation status: Within India, its distribution appears highly fragmented and restricted to scattered populations in forest understorey habitats, suggesting potential vulnerability to habitat disturbance and warranting further field assessments to determine its national conservation status.

DISCUSSION

The present record of *Cajanus elongatus*, an uncommon and sparsely distributed species, extends its known range and underscores the need for targeted field surveys and conservation attention in view of its fragmented populations. Similarly, *Crotalaria meghalayensis*, originally described from Meghalaya and long known only from its type locality, exhibits a highly restricted distribution with its occurrence in Mizoram; therefore, it represents a significant range extension for this regionally rare species (Danda et al. 2016). *Mycetia malayana*, previously reported from peninsular Malaysia, Thailand, and Borneo, was only recently recorded in India from Tripura, highlighting its extreme rarity within the country and representation by a single confirmed locality (Bora et al. 2025). *Microchirita karaketii*, first documented from northern Thailand and Myanmar, shows a highly restricted and localized presence in northeastern India with very few collections reported, supporting its rarity within the Indian flora

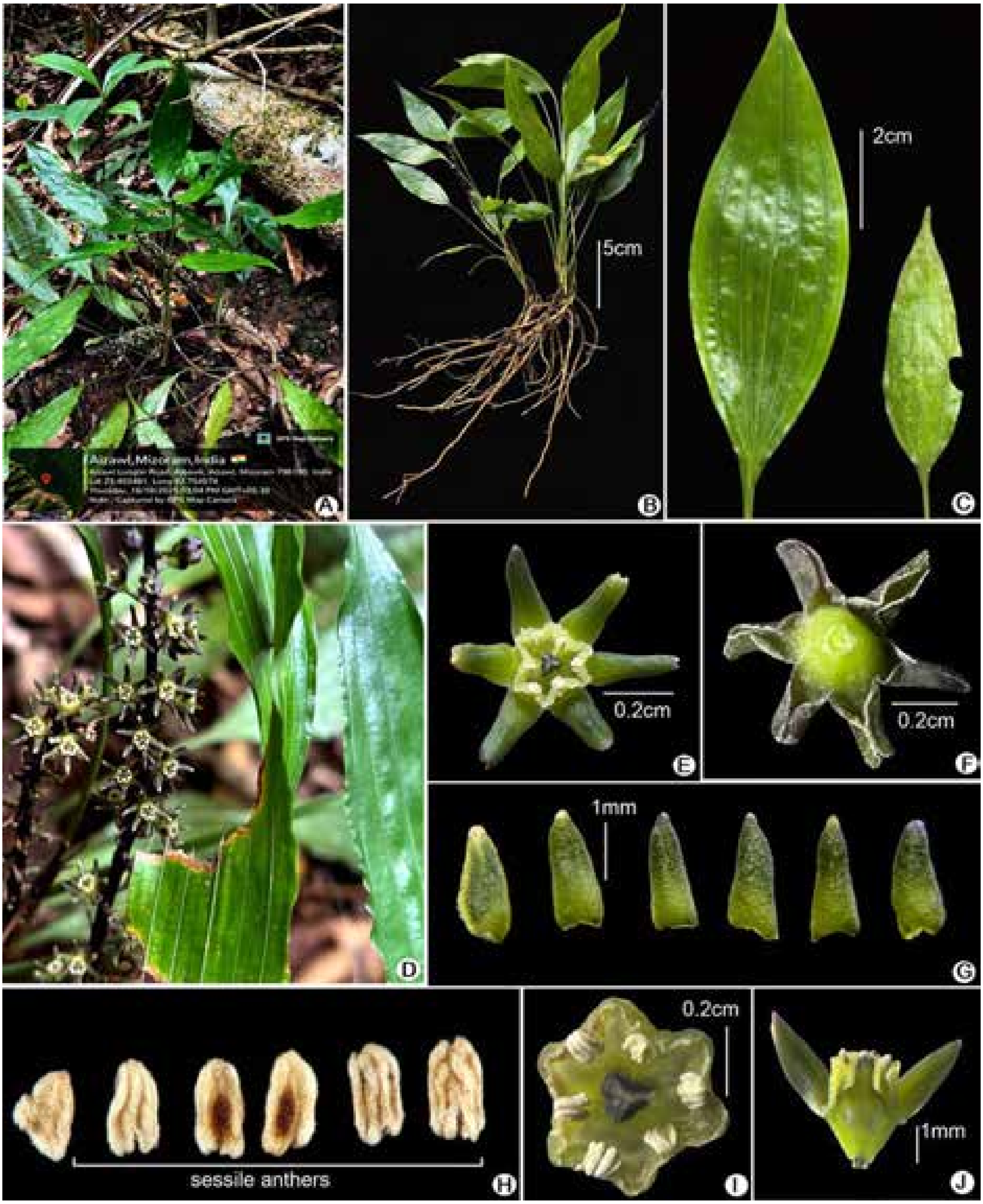

Image 5. *Peliosanthes griffithii* Baker: A—Habitat | B—Habit | C—Leaves | D—Inflorescence | E—Flower, front view | F—Flower, dorsal view | G—Tepals | H—Sessile anthers | I—Corona, front view | J—Flower, sagittal section. © R. Lalthantluanga.

(Rhuthuparna & Gowda 2024). *Peliosanthes griffithii* occurs in Nepal, northeastern India, and adjacent regions of southeastern Asia, but within India, it is found as scattered populations with limited occurrences in forest understorey habitats, indicating a rare status depending on locality (Baker 1879; Tanaka 2018). Overall, the five

Image 6. Herbarium sheet of *Cajanus elongatus* [# MZUH001312].

Image 7. Herbarium sheet of *Crotalaria meghalayensis* [# MZUH001313].

angiosperm species reported in the present study may be considered rare, based on their restricted distributions, limited collections, and localized occurrences.

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Image 6. Herbarium sheet of *Microchirita karaketii* [# MZUH001314].

Image 8. Herbarium sheet of *Mycetia malayana* [# MZUH001315].

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Image 10. Herbarium sheet of *Peliosanthes griffithii* [# MZUH001316].

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ARTICLE

Legislative and evidentiary challenges faced by the Indian law enforcement agencies in social media-enabled wildlife offences

Pradipty Bhardwaj [1], **Jayadevan S. Nair** [2] & **H.V. Girisha** [3]

[1,2] School of Law, CHRIST (Deemed to be University), Bengaluru, Karnataka 560029, India.
[3] Forest Department, Jhansi, Uttar Pradesh 284001, India.
[1] pradipty.bhardwaj@res.christuniversity.in (corresponding author), [2] jayadevan.nair@christuniversity.in, [3] girishhvifs2004@gmail.com

Abstract: Social media has become a popular platform for enabling wildlife offences in India. Protected species or their body parts are openly traded, displayed, and promoted on such platforms in violation of the law. When enforcement agencies detect such illegal activities on a larger scale, they aim to disrupt and prosecute the offenders. During this process, they face challenges while invoking the law, and issues concerning prosecution. This study aims to explore such challenges through the lens of enforcement agencies. While there is significant literature on wildlife offences taking place on social media, the challenge that unfolds after detection of such activity online from the law and prosecution perspective remains understudied. Hence, identifying and understanding them is necessary to implement and to effectively enforce the laws on the ground. This study primarily utilises a qualitative socio-legal framework by carrying out inductive thematic analysis on interview data collected from 25 experts using Atlas.ti software. The enforcement perspectives or themes were used as foundational empirical evidence for the doctrinal analysis. The key finding on the legislation side reveal that the Wild Life (Protection) Act, 1972, does not explicitly address electronic or social media-facilitated offences, and no express provision regulates the indirect and unintentional promotion of such content. In relation to digital evidence, there are gaps in maintaining the chain of custody and complying with authentication and admissibility criteria. These findings, combined with others, offer insights into both objective and subjective hurdles incurred while proceeding in such cases. They signal the need for long-pending legislative reforms, skill development training on digital evidence handling, and awareness for effective on-ground enforcement to cope up with the contemporary challenges.

Keywords: Conservation, digital evidence, endangered species, illegal wildlife trade, wildlife prosecution, wildlife trafficking, wildlife law.

Abbreviations: AI—Artificial Intelligence | BNS—The Bharatiya Nyaya Sanhita, 2023 | BSA—The Bharatiya Sakshya Adhiniyam, 2023 | CITES—Convention on International Trade in Endangered Species of Wild Fauna and Flora | GI-TOC—Global Initiative Against Transnational Organized Crime | ICCWC—International Consortium on Combating Wildlife Crime | IFAW—International Fund for Animal Welfare | IT Act—Information Technology Act, 2000 | IT Rules—The Information Technology (Intermediary Guidelines and Digital Media Ethics Code), 2021 | LEA—Law Enforcement Agency | MoEFCC—Ministry of Environment, Forest and Climate Change | SOP—Standard Operating Procedure | TRAFFIC—Trade Records Analysis of Flora and Fauna in Commerce | UNODC—United Nations Office on Drugs and Crime | UT—Union Territory | WCCB—Wildlife Crime Control Bureau | WLPA—Wild Life (Protection) Act, 1972 | WWF—World Wide Fund for Nature.

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CHRIST (DEEMED TO BE UNIVERSITY) BANGALORE · INDIA

Author details: Pradipty Bhardwaj is currently pursuing a Ph.D. at the School of Law, Christ University. She is known for leading wildlife law training sessions for the forest departments across India. Her work also focuses on analyzing international conservation laws and conducting OSINT analysis on illegal wildlife trafficking networks globally. Dr. Jayadevan S. Nair is a professor and former Dean at the School of Law, Christ University, Bengaluru. He teaches Constitutional Law, Intellectual Property Rights, and laws relating to the environment and the entertainment sector. H.V. Girisha, an IFS officer belonging to the 2004 batch (UP Cadre), currently serves as CCF (Bundelkhand), Jhansi. He holds extensive expertise in forest and wildlife conservation, enforcement, and administration. He has also served in WCCB, MoEFCC, GoI, New Delhi. He is presently pursuing a Ph.D. from Amity University, Noida.

Author contribution: PB designed the study, interviewed the participants, analysed the data, and wrote the manuscript. JSN contributed with the legal insights, doctrinal methodology, and supported the writing of the manuscript. HVG helped with interview questions, empirical data collection design, and reviewed the manuscript.

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INTRODUCTION

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) defines 'wildlife crime linked to the Internet' as a crime facilitated or enabled by information and communication technology platforms, networks, or applications. It includes social networking and instant chat platforms within its ambit. The global trend report indicates that social media is a major player in online trade (Eco-solve 2024), and as of January 2025, there are 491 million active social media user identities in India (DataReportal 2025). To combat wildlife crimes, non-governmental organisations like the World Wildlife Fund (WWF), Trade Record Analysis of Flora and Fauna in Commerce (TRAFFIC), and the International Fund for Animal Welfare (IFAW) came together and launched the Coalition to End Wildlife Trafficking Online. According to its 2025 Progress Update, a total of 63.3 million illegal posts and listings on wildlife were blocked or removed from more than 50 online platforms between March 2018 and December 2025 (IFAW, TRAFFIC & WWF 2025). Operation Wildnet, an initiative by India's nodal agency, the Wildlife Crime Control Bureau (WCCB) under the Ministry of Environment, Forest and Climate Change (MoEFCC), also indicates that the internet has become an enabler of wildlife crime. Around eighty cases were booked between 2017 and 2021 based on intelligence developed through e-commerce websites, social media platforms, and other online portals (WCCB 2017, 2019, 2020 & 2021).

The advertisement of wildlife items online or on social media poses a threat to protected species (Roy & Kumar 2022). The global reach of such online posts is significant, considering active engagement and views (Gondhali et al. 2024). Hence, it is essential to understand and track the intensity and quantify the scale of such activity (Stringham et al. 2021) for proper enforcement action. To address this issue, a dedicated framework for online open-source monitoring of illegal wildlife activities is needed (Pragatheesh et al. 2022). However, the use of spurious names or terminology to advertise a wildlife item pose a challenge for enforcement agencies (Sharma et al. 2018). Additionally, difficulty in identifying species or distinguishing real from fake increases the complexity of detection (TRAFFIC 2020). It has also been observed that less attention is given to smaller and non-charismatic (Fukushima et al. 2021) or lesser-known species, like the pygmy hog and sea cucumbers. Another concern is that enforcement officials are not prepared to determine and ascertain the locations of illegal virtual activities operating across multiple jurisdictions (Wingard & Pascual 2018). They also perceive that they have a smaller workforce, resource constraints, and insufficient funding to do their jobs efficiently (Ariffin 2015).

When it comes to the governing legislation, limited observations are made in the existing literature. It has been noted that the Indian Wild Life (Protection) Act, 1972 (WLPA) and the Information Technology Act, 2000 (IT Act) do not specifically cover cyber wildlife crime (TRAFFIC 2020). There is a need for stringent provisions to address the sophisticated challenge of wildlife crime taking place online (Rana & Kumar 2023). According to the best practices on legislative reforms, nations' domestic law should also keep up with the latest trends in cybercrime (Yang 2019). Even the CITES has encouraged its parties to review their national legislation concerning wildlife crime linked to the internet (CITES Notification to Parties 2020).

Digital evidence is a fundamental aspect in prosecuting social media-linked offences. Hence, it is essential to monitor social media for evidence on wildlife offences, as it provides valuable information (Haq et al. 2023). Social media posts on misconduct or anti-wildlife conservation activity can be used as evidence in the form of images, screenshots, and geo-tagged locations (Bergman et al. 2022). Such images of species or their body parts need to be verified through morphological examination, which is sometimes challenging even for the experts (Trail 2021). It is also hard for law enforcement agencies to obtain all the digital evidence by themselves (TRAFFIC 2019). Technological sophistication in cyberspace makes it difficult to attribute digital evidence to a user or an individual (Prasad et al. 2025). Additionally, improper investigation and the failure to gather reliable digital evidence in online wildlife offences result in the accused person's acquittal (Chaurasia 2023a).

There is considerable literature covering the themes of reporting, identification, detection, monitoring, and digital evidence. However, the topic remains underexplored from the viewpoint of the implementation or enforcement side of the legal framework in relation to wildlife offences on social media from an Indian lens. Therefore, this study employs a qualitative socio-legal framework (Pound 1910) to explore the law and prosecution challenges faced by the enforcement agencies from the perspective of the subject experts. This framework provides a conceptual basis for the study by exploring the gap between 'law in books' and 'law in action' while addressing a social media-enabled wildlife offence. Hence, this present study was taken up based on the following objectives:

(1) To explore the concerns while invoking the legal provisions in wildlife offences on social media.

(2) To explore the prosecution challenges faced by

enforcement agencies while addressing social media-enabled wildlife cases.

The present study provides an understanding of the enforcement challenges in combating social media-enabled wildlife offences in India from the perspective of legislative frameworks, which will also serve as the baseline for future research.

METHODOLOGY

This study employed a semi-structured interview method to gather data on law and prosecution-linked challenges faced by Indian law enforcement agencies, based on their experiences and perspectives. While the result has been quantified to highlight the number of participants corresponding to each of the themes or challenges, a qualitative approach through a thematic analysis was adopted to gain a better understanding.

Participants were identified and selected through a purposive sampling technique, aiming at those directly or indirectly involved in combating social media-enabled wildlife offence cases or assisting enforcement agencies. A total of around 15 hours were spent collecting media reports and open-source information through keywords like 'cyber,' 'wildlife,' 'crime,' 'offence' and 'social media' for each of the Indian states and union territories using Google's Advanced Search feature. As a result, a total of 257 unique online open-source media links were gathered in a span of one month in December 2023**.** Experts quoted in these media reports, or those who authored literature, were identified and considered for the interview. Identified experts working in a similar landscape or organisation were excluded to ensure diversification of information and perspectives. More participants were recruited based on the suggestions or referrals given by the identified experts. Thereby, a total of 25 participants were finalised to ensure a broad representation of the expert group. These participants were from the central law enforcement agencies (LEAs) (20%), state or union territory (UT) LEAs (36%), non-governmental organizations (NGO) (12%), law professionals (8%), academia (12%), and forensic experts (12%), as indicated in Figure 1.

Participants from the central and state LEAs, forest and police departments, state tiger strike forces, and the WCCB were included to ensure sample heterogeneity. On achieving thematic saturation (Guest et al. 2006), no further participants were interviewed, as the focus was on rich and in-depth information rather than statistical representation.

It is pertinent to mention that this article is a specialised component of a larger research work on law enforcement challenges. Hence, the participants were interviewed using semi-structured questions that were explicitly developed for the larger research. The representative sample of open-ended questions specific to this part of the research, in relation to the law and prosecution challenges are listed below to provide insights into the framework for inquiry:

(1) In your view, are there any emerging issues while applying the existing legal framework to social media-enabled wildlife offences?

(2) Could you describe any specific concerns that are encountered in relation to digital evidence in relation to social media wildlife cases?

(3) From your perspective, what are the common frictions that emerge in the court of law in such cases?

The open-ended questions gave flexibility to the participants to share their experiences by elaborating on their responses. The online interview session was conducted for approximately one hour, which was recorded and transcribed using Google's features with the consent of the participants to ensure the accuracy of the data captured in English. Before the interview, the information sheet was shared with all the participants, outlining the objectives and other information about the study. Their consent was formally obtained, and they were also informed about the confidentiality measures, anonymity, and the right to withdraw at any stage without any consequences.

Transcripts of interviews were anonymised and imported into the qualitative analysis software tool Atlas. ti Web (version: v8.4.0-2024-08-06). The confidential and case-sensitive information that came up during the discussion was masked and excluded. An inductive thematic approach (Braun & Clarke 2006) was primarily used during the coding process. An initial round of familiarisation was carried out to identify recurring themes and patterns. With constant iteration, organisation, and comparison, refined themes were coded, developed, and structured to examine and interpret data. These themes served as foundational empirical evidence and were synthesised through a doctrinal analysis using the relevant legislative frameworks. The in-depth insights into the challenges highlighted by the subject domain experts were prioritised so that the data presented serves as an analytical and indicative function rather than a statistical generalisation. Additionally, there is also a likelihood of potential sampling bias due to the recruitment of publicly prominent and established experts with exposure to enforcement operations.

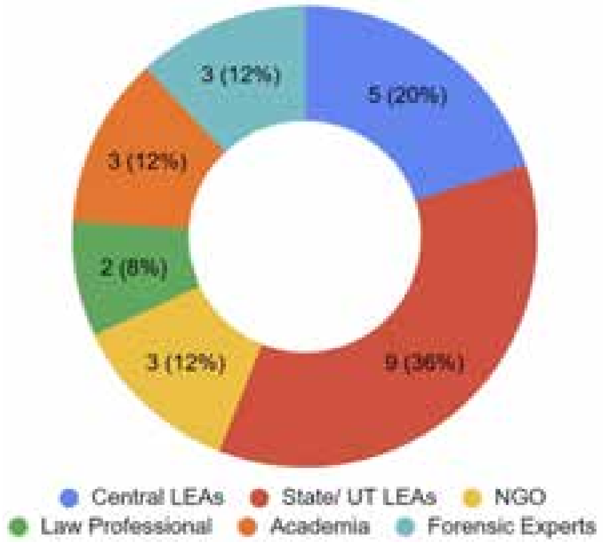

Figure 1. Number and percentage of the total participants (N = 25) under the expert groups.

FINDINGS

The findings reveal diverse challenges from the perspective of the domain experts. The themes under the legislative framework were primarily associated with potential gaps in the legal provisions on tackling wildlife offences on social media. In relation to digital evidence, the emerging themes were primarily linked to knowledge, awareness, concerns and handling protocols. Regarding the broader aspect of prosecution, the data did not reveal any major challenges, as most participants believed that social-media cases have not yet proceeded to the trial phase. However, those participants who had the exposure beyond the pre-trial phase shared their insights on hurdles to the admissibility of digital evidence. Therefore, the identified themes on challenges were categorised under 'legislative' and 'evidentiary' challenges and are stated hereinafter.

Legislative Challenges

Out of the total 25 participants, only 16 highlighted the legislative challenges faced by the enforcement agencies while implementing the law. Among the 16 participants, some shared more than one challenge based on their area of expertise and knowledge. Figure 2 indicates the list of legislative challenges coded in alphabetical order from 'A' to 'I', which were highlighted by the participants.

Nine participants (total N = 25) revealed that the WLPA is unclear or does not have explicit provisions regarding wildlife offences taking place on social media (indicated as 'A'). This was identified as the most prominent challenge, as it was brought forth by the maximum number of participants. The second major challenge was that the state forest departments are not authorised under the IT Act ('B'), which was brought to the attention by five participants. Regarding this, one of the participants observed that the forest department does not have the power to directly access details of the suspect's social media handles from the platform service providers and has to go through the police.

Other challenges underlined by participants include the absence of an express provision banning promotional content on social media ('C'), dependency on the interpretation of indirect provisions of the WLPA ('D'), and, to invoke the offence of 'abetment' under WLPA, an offence has to occur ('E'). Each of these three challenges was expressed by three participants. Regarding promotional content, one of the participants expressed frustration, stating, *"defense advocates ask us to show the provision where it is written that you should not advertise wildlife or its products".* On the offence of 'abetment' under Section 52 of the WLPA, a participant believed that the offence must take place, and it has to be proved that the offender got motivated from a particular social media video. Another participant who has tried invoking abetment in at least three of the cases shared the experience that abetment cannot be merely instigation, but an actual act of abetment is required for the court to accept.

According to the two participants, there is no harmonization of the WLPA and the IT Act ('F') in the context of wildlife offences on social media. The participants specified that the WLPA is a special law and it must be read in conjunction with the IT Act.

It is noteworthy to mention that the other three challenges were highlighted by a minor set of experts (1 participant) out of the total (N = 25). Regarding the absence of substantive provisions under the IT Act ('G'), the participant, based on their extensive study, asserts, *"There is no such provision under the IT Act that can be fully invoked if a cyber-enabled wildlife offence is happening".* With respect to another challenge, the academician stressed the need for harmonization of the WLPA and social media policies ('H'). Concerning the last challenge, the WLPA does not specifically govern the spreading of wildlife-related fake or misinformation unless linked to offences('I'). The participant called it an emerging trend and shared an example of a video of lions entering a particular jurisdiction that went viral in the region, where it was never reported historically, and hence created panic in the public.

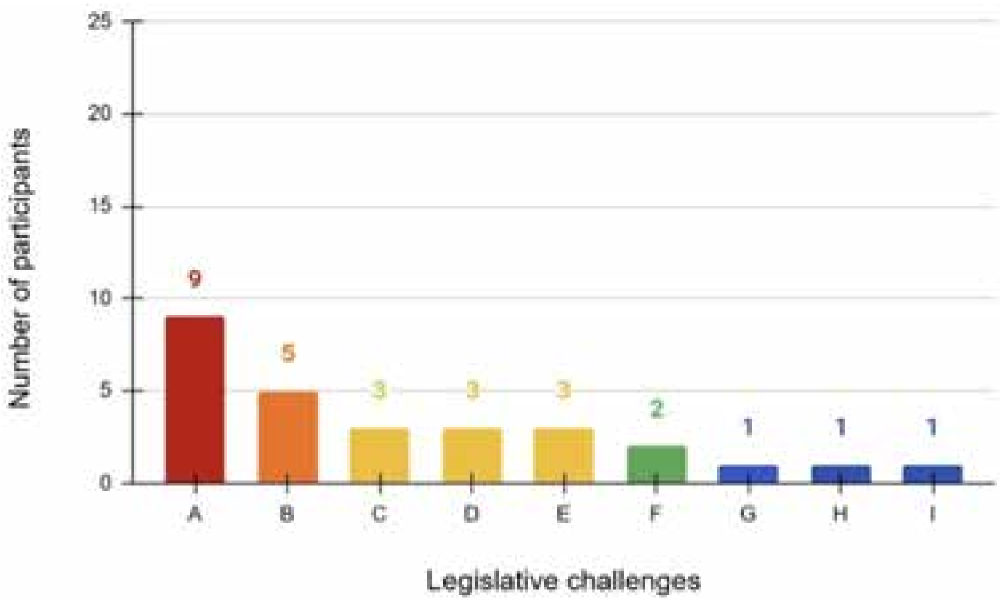

Figure 2. Number of participants who highlighted each of the 'A' to 'I' legislative challenges.
A—WLPA is unclear on social media offences | B—Forest department is not authorised under the IT Act | C—Absence of express provision banning promotional content | D—Dependency on the interpretation of indirect provisions of WLPA | E—To invoke abetment, an offence has to occur | F—No harmonization of WLPA and IT Act | G—Absence of substantive provisions under the IT Act | H—Gaps in harmonization between WLPA and social media policies | I—Spreading fake information is not an offence.

Evidentiary Challenges

Among the total 25 participants, 24 highlighted the evidence-related challenges faced by the enforcement agencies. Out of these 24 participants, all of them shared at least more than one challenge based on their exposure and experience. Figure 3 provides the list of evidentiary challenges coded in alphabetical order from 'J' to 'R', as was highlighted by the participants.

When it comes to evidentiary challenges, 17 participants out of the total (N = 25) upfront felt that the forest and wildlife officials lack expertise in identification, collection, and handling of digital evidence (indicated as 'J'), hence, need capacity-building training. Although it does not come under the literal meaning of a challenge, it became indispensable to include this response, considering that it was bluntly highlighted by the maximum number of participants.

Concerning specific evidentiary challenges, the absence or gap in the chain of custody ('K') was brought into focus by 10 participants as a major concern. 'Chain of custody' is a legal term that implies sequential and complete documentation of the custody of the evidence that was seized in a case (Badiye et al. 2023).

The subsequent three categories of challenges were interlinked and were brought forth by six participants. Under these categories, there were overlapping sets of participants, and they shared similar experiences and observations. Based on their hands-on exposure, they stated that the focus of the enforcement agency is on the investigation or seizure of wildlife items or related biological evidence ('M'). Just having social media posts in the form of digital evidence is not sufficient for proving a case ('L'). Because such digital evidence is often produced or treated as corroborative evidence in a court of law ('O').

There is also another category of challenge, where six participants (N = 25) have either indicated the absence or need for a standard operating procedure (SOP) and knowledge to deal with digital evidence ('N'), apart from its related legal course of action during prosecution of a case.

Five participants mentioned that there is a lack of knowledge and awareness on the Section 65B Certificate ('P') under the Indian Evidence Act, 1872 (hereinafter referred to as the Section 63(4) Certificate as per the new Bharatiya Sakshya Adhiniyam, 2023 (BSA)). Section 63(4) Certificate is a 'Certificate of Authentication' (Sonone et al. 2024) that is required to be produced before the court to ensure the admissibility of digital evidence. On this, one of the participants observed, *"magistrates have refused to even consider the digital evidence in court, saying that unless you bring in 65B, we are not going to consider this".*

Another challenge, that the enforcement agency does not proactively send digital evidence for digital forensics unless its authenticity is contested by the defence or

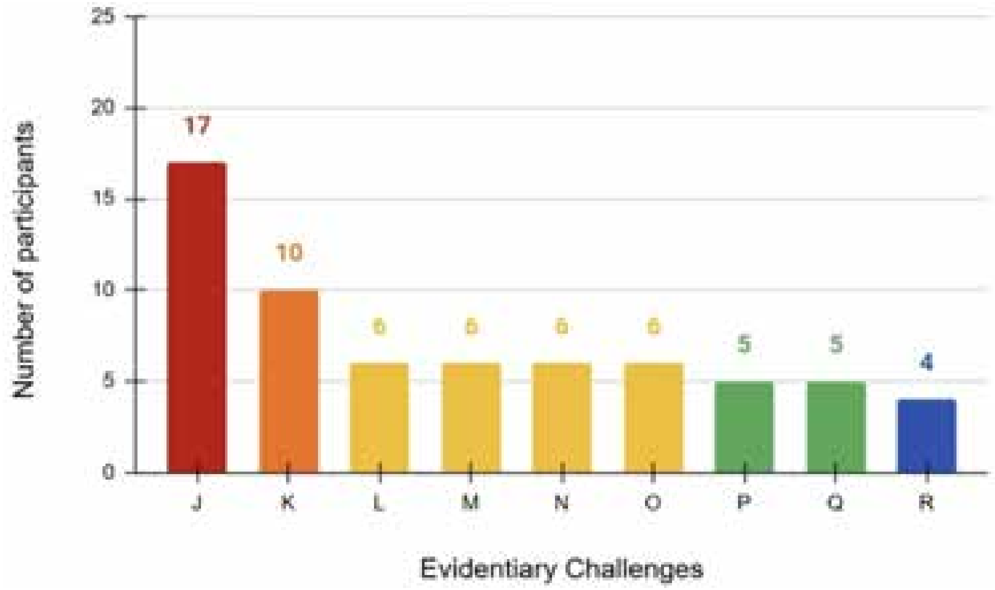

Figure 3. Number of participants who highlighted each of the 'J' to 'R' evidentiary challenges.
J—Forest Department needs training on digital evidence | K—Absence or gaps in the chain of custody | L—Just a social media post as evidence is not sufficient | M—Focus is on the investigation or physical seizure | N—Absence or need for a standard operating procedure | O—Often treated as corroborative evidence | P—Lack of knowledge on the Section 63(4) Certificate | Q—Not sent for forensics, unless contested | R—Unaware of the need and generation of the hash value.

directed by the court ('Q'), was stated by five participants. Lastly, four participants who had more profound technical knowledge revealed that the enforcement agency is unaware of the need and lacks knowledge to generate the hash values ('R'). The 'hash value' is a string of numeric values that identifies data. It is an electronic fingerprint of digital data that helps to ensure that the integrity and authenticity of the digital evidence have not been compromised (Chaurasia 2023b; Supreme Today AI nd).

DISCUSSION

The themes show a list of diverse and interlinked legislative and evidentiary challenges that are experienced by the enforcement agencies while implementing the law in social media-enabled wildlife offences. These findings are discussed below in relation to the relevant provisions of the law under various heads.

Online Offences

The wildlife offence taking place by 'online' means includes social media within its ambit. The key finding that the WLPA has no specific provisions relating to social media offence is also consistent with the legal lacuna that Dr. Karnika Seth highlighted (TRAFFIC 2020). She stressed the need to bring in amendments due to the absence of online or cybercrime provisions for wildlife offences. However, despite the latest parliamentary debates (Lok Sabha Debates 2022) on the WLPA amendment in 2022 relating to cyber-enabled offences, nothing in line with the same was included in the final version of the Act. According to the Wildlife Legislative Guide by the United Nations Office on Drugs and Crime (UNODC), a national law should keep up with the dynamic nature of wildlife crime online (UNODC 2018). It may be done by either automatically including electronic or distance selling within the meaning of trade or by introducing specific provisions on trade by electronic means, like the Chinese Wildlife Law (Wang & Chen 2019). Under the WLPA, the term 'trade' is not defined in terms of native species (listed under the Schedule I, II, and III). The nearest definition that exists is of a 'dealer' as the one who carries out the business of buying and selling; however, it does not elaborate on the 'means' of carrying out deals. Even though it can be interpreted to infer that it includes even by means of online or social media platforms, at present, in its current form, it is not explicit, unless a precedent is set by the court through a landmark judgment. Hence, it can be said that the law is unclear or not explicit on this aspect. Precisely, it falls short of the current realities, as the framers of the WLPA legislation in 1972 did not foresee and expect the world of the Internet revolution and the unfolding of contemporary cyber-enabled wildlife offences.

Promotion or Advertising

The insights shared by the participants that the WLPA does not expressly regulate or restrict the act of promotion or advertisement of wild animals on social media align with our assessment. Even though the enforcement can invoke the offence of attempting to sell under Section 52 read with 44 and 49B of the WLPA for advertisement or promotional content, the advertiser has room to defend that they were just sharing information about the species and do not even possess or own them. Such instances make the investigation and establishment of the legal basis more difficult in the courts (Wingard & Pascual 2018). Hence, it's important to prove that the particular act of promotion was reasonably 'proximate' and the user had 'clear intention' to commit such an illegal act. These requirements for proving the offence of 'attempt' were held in the case of State of Maharashtra vs Mohd. Yakub & Ors. (1980 AIR 1111). According to the analytical toolkit published by the International Consortium on Combating Wildlife Crime (ICCWC), ideally, the existing laws of the countries should prohibit promotional wildlife advertisements by electronic means (ICCWC 2022). Indian laws do not expressly prohibit advertising of wildlife (Bhardwaj et al. 2024), and hence, it does not extend to such acts by electronic means. To put this into perspective, it is noteworthy to mention that Article 32 of the Chinese Wildlife Law 2022 prohibits the publication of advertisements in relation to the purchase, sale, and use of wildlife as an offence.

Offence of Abetment

When it comes to the promotional content on social media, assessing the offence of 'abetment' is also relevant. Samir Sinha, in his Handbook on Wildlife Law Enforcement in India, gave an indication towards using the offence of 'abetment' under Section 52 of the WLPA to address the challenge of illegal advertising of wildlife crime in India (Sinha 2010). The meaning of 'abetment' as prescribed under Section 45 of the BNS includes, by means of (a) 'instigation', (b) 'engagement', and (c) 'aiding'.

Mens rea: 'Instigation' must be 'wilful' or 'voluntary' as per Explanation 1 of Section 45 of the BNS. The act of 'engagement' is associated with conspiracy and hence implies agreeable terms or shared intention. Finally, in terms of 'aiding', it must be 'intentional.' Hence, mens rea (guilt state of mind) is an essential element for the offence of abetment. It is pertinent to note that the act of promotion may also be unintentional in nature. Especially, the instances where people are unaware of the legal protection given to lesser-known species like stag beetles and share such information, which has the potential to stimulate their indirect and unintentional demand in the market. In such a case, establishing or proving guilt intent may become challenging in the court of law while invoking Section 52 of the WLPA for abetment.

Commission of an abetted act: The participants believed that, to invoke the abetment clause against any person, an offence has to occur. However, this finding reveals a partial misconception, as Explanation 2 of Section 46 of the BNS clearly states that, in order to constitute abetment, it is not a necessary prerequisite for the offence to occur. Even the Supreme Court in the case of CBI vs. VC Shukla and others (1998) 3 SCC has held that abetment by means of 'instigation' and 'engagement' does not necessitate that the offence should have been committed. However, abetment through 'intentional aiding' requires the actual commission of the aided act or offence as per the Explanation 2 of Section 45 of the BNS. Therefore, in the social media-enabled wildlife offences, when there is no proof of the actual offence taking place on the ground, abetment either through 'instigation' or 'engagement' can be invoked and has to be backed by guilty intention.

Active instigation and proximity: In social media-enabled wildlife offences, the prosecution needs to prove that there is a direct link between the act committed and the act abetted. Abetment through 'instigation' is not merely tempting to do a forbidden thing, but also 'actively stimulating' a person to do it (Ratanlal & Dhirajlal 2010). The court in the case of Abhinav Mohan Delkar vs. State of Maharashtra & Ors. (2025 INSC 990) mentioned about the 'proximate-trigger' doctrine according to which there must be a 'live link' and 'proximity' to a temporal and causal connection between the offender and the act of abetment.

Hence, to sum it up, while abetment may be applied in the instances of illegal wildlife posts on social media, in certain instances, it may pose a challenge in proving before the court of law. Therefore, based on the facts of the case, it is important to assess the means of abetment as an act of instigation, engagement, or aiding through social media to strengthen the prosecution's arguments.

Fake or Misinformation

Although the emerging trend of sharing fake or misinformation on wildlife prima facie may appear harmless, it impacts the attitude and mindset of the people who consume such content on social media (Tandon 2020). The bare reading of the WLPA shows that it does not cover anything related to fake or misinformation unless it is linked to other offences. In relation to the Bharatiya Nyaya Sanhita (BNS), 2023, Section 353(1)(b) prohibits the circulation and publication of false information by electronic means, but its scope is limited to the extent when it is used to create fear or alarm among the public and hence, may be applied to a certain extent in cases relating to wildlife, too. Recently, in February 2026, the IT Rules 2021 were amended to include 'synthetically generated information' to regulate deepfakes or artificial intelligence (AI) content in India. The main aim is to move beyond the 'safe harbour' and have proactive compliance requirements in place to hold social media accountable and responsible. It deals with 'made using AI' kind of disclosure on the part of users, prominent labelling on the part of social media, and the removal of such content within three hours of being notified, except for the routine, good faith, or educational content. Since the amendment is fairly new, its implementation and effectiveness are yet to be seen.

Information Technology Law

Wildlife offences on social media are cyber-enabled in nature as they are facilitated by means of online platforms. The IT Act predominantly lays down provisions for cyber-linked offences such as phishing, hacking, and identity theft in India. In relation to cyber-enabled or online content-based offences, it provides for a definite list, such as the prohibition of offensive messages, obscene material, and sexually explicit material under its Chapter XI. As this list does not include violations under other laws, it fails to prohibit violations under the WLPA as a predicate offence unless there is a violation of other offences under the IT Act. From a global perspective, a similar pattern has also been identified (Wingard & Pascual 2018). It is pertinent to mention the provisions of Section 46 of Kenya's 'Computer Misuse and Cybercrimes Act 2018' and Section 6 of the Philippines' Cybercrime Prevention Act of 2012 prescribes for additional or aggravated penalties if illegal acts are facilitated by means of the Internet or digital platforms.

On the procedural aspect, the observation made by participants that the forest department personnel are not authorised under the IT Act, was accurate. The forest department believes that they need power to investigate offences when it is related to social media or internet platforms. While they are authorised to investigate and compel the discovery of documents and objects under Section 50(8) of the WLPA, their power might appear limited on the ground. This may be arising from Section 78 of the IT Act, as it authorises only police not below the rank of inspector to investigate the offences under the Act. If any other officer apart from a police officer arrest under the IT Act, they are supposed to hand over the offender to the officer-in-charge of the nearest police station or to the magistrate having the jurisdiction as per Section 80(2) of the IT Act. Therefore, owing to these legal mandates and also access to operational infrastructure such as cyber cells in police stations, even in social media-enabled wildlife offences, the forest department is expected or bound to work with the police.

Harmonisation of Laws and Policies

The need for harmonisation was cited in the context that the laws should complement each other, and the social media platform policies should also align with such laws. When it comes to the WLPA and the IT Act, the general review of both laws suggests that there is no direct convergence between the two. Under Section 56 of the WLPA, the operation of other laws is not barred, which means the IT Act can be invoked in wildlife cases. Section 81 of the IT Act is also enabling because it provides for an overriding effect over other laws. However, the setback is that the IT Act does not extend to cover the violation of any other laws for the time being in force, even though it is cyber-enabled, as noted in the earlier paragraph. As a result, the harmonisation of the two laws becomes fundamentally at odds. The only way the IT Act links to social media-enabled wildlife offences is by mandating due diligence compliance requirements on intermediaries through its 2021 Rules on digital media ethics code. Regarding the policies of the social media companies, it is important to note that they have a global presence, and most of the significant ones are headquartered in the United States. These platforms mainly prioritise legal compliance in their home countries. As a result, it may or may not match the expectations of the rules and regulations of the countries where it's being used by the people (Gillespie 2018). Therefore, it is obvious that a potential gap exists between the social media policies framed by foreign-owned companies and the domestic legislation of India.

Interpretation of the Laws

The findings pointed out that there is a dependency on interpreting indirect legislative language as a challenge. This may be stemming from a lack of training, expertise, and technical legal support. According to the report, only 40% of rangers surveyed from Asia's Tiger landscapes received law and regulation training in the past twelve months (WWF 2022). Another study that was carried out in the Mudumalai Tiger Reserve revealed that 48% of forest officers are unaware that the institutional training has content on handling wildlife crime investigation, and 33% have never received such training (Prakash 2022). An author who carried out a study on Indian legal texts found that the average length of a legal sentence is 70 words, with a maximum of 404 (Verma 2016). Her findings indicate that, along with the legal concepts, sentence structure also increases the complexity of understanding or interpreting legal texts. Therefore, it is a valid concern that interpreting technical legal provisions is a perplexing task without receiving proper skill sets through consistent training sessions and exposure to enforcement activities.

Nature of Digital Evidence

Corroborative and Direct Evidence: The findings revealed that the focus of the enforcement officials' is on 'physical seizure' of wildlife items and investigation of the offence. The social media posts are mostly treated as corroborative evidence in the court of law. This practice may be emerging from the language of Section 50(1)(c) under the WLPA. As it mandates the seizure of *"any captive animal, wild animal, animal article, meat, trophy or uncured trophy, or any specified plant or part or derivative thereof, in respect of which an offence against this Act appears to have been committed, in the possession of any person together with any trap, tool, vehicle, vessel or weapon used for committing any such offence"*. The literal scope of this provision is limited and does not extend beyond other types of evidence, which would have the potential to encapsulate even electronic or digital records. The wildlife crime investigation handbook also states that the digital evidence is strong, 'circumstantial' or 'supporting' evidence for proving the guilt of the suspect (WCCB 2013). It has been observed that the focus of the wildlife protection laws is often on real-world offences rather than on online activities. As it is very easy for online offenders to isolate themselves from liability, thus, the enforcement agency faces difficulty in establishing a legal basis in the court of law (Wingard & Pascual 2018). Whereas, the general practice in criminal law cases does not bar enforcement from filing a case based on social media posts as direct evidence due to their evidentiary value (Sowndharyaa 2024), and also because they are facts all by themselves. This was also seen in the successful conviction case of S.Ve. Shekher vs. State (2025 SCC OnLine Mad 6) regarding the derogatory comments made on social media against women journalists.

Primary and Secondary Evidence: In social media-enabled wildlife offences, digital evidence can be of a primary or secondary nature. They can either be in the form of devices that were used for posting content online or copies of broadcasted posts. Earlier, most of the digital records were considered secondary evidence. However, the new legislation, BSA, has expanded the scope of primary evidence under Section 57 and clarified the ambit of secondary evidence under Section 58. Primary digital or electronic evidence now includes those obtained from: multiple files (Explanation 4), proper custody (Explanation 5), video recording and broadcasts (Explanation 6), and storage locations (Explanation 7), in addition to the original devices. On the other hand, secondary electronic or digital evidence includes certified copies, produced from mechanical machines, compared copies, oral or written accounts or descriptions, counterparts, and expert testimony.

Admissibility of Digital Records

63(4) Certificate: Previously, there was a lack of clarity in the interpretation of the older 65B Certificate due to jurisprudential ambiguity (Sonone et al. 2024). However, the Supreme Court in the landmark case of Arjun Panditrao Khotkar vs. Kailash Kushanrao Gorantyal (AIR 2020 SC 4908) settled the stance that the Certificate is mandatory for the admissibility of secondary electronic records. This judicial clarification has now transitioned to a codified, stringent mandate under Section 63(4) of the new BSA. This new version has also introduced a mandatory hash value requirement and signature of both the person-in-charge and an expert in the standardised certificate format. The provision also mandates submission of the Certificate at the time of admission, as compared to the earlier flexible provision that allowed for the submission of the same even during the trial phase. Even in the latest case of ABS Tour & Travels vs. SNV Aviation Pvt Ltd (CS (COMM) 322/2024), the relevance of new 63(4) was reiterated. As the court noted that the Akasa airline lapsed in filing the mandatory 63(4) Certificate for the electronic PNR data, an adverse inference was drawn against them. It is important to understand here that even though the PNR data stored in a server was primary evidence, the entire airline server cannot be brought to the courtroom. Hence, to ensure its admissibility while producing its copy, Certificate 63(4) is mandatory as it serves more like a fitness test or integrity report, even for producing primary evidence.

Hash Value: The findings on the unawareness of the need for hash values and the lack of knowledge to generate them for the digital records are a valid concern, as it plays a significant role in ensuring the integrity of such evidence. In the case of Ram Kishan Fauji vs. State of Haryana and Ors. (CWP No.4554 of 2014), the court has emphasized the importance of hash value details to confirm that the digital evidence submitted is an accurate and true representation of the original. It is of such great significance that even minor alterations in electronic data can bring a change in the hash value (Kumar et al. 2012). If a wildlife law enforcement officer is accused by the defence lawyer of planting incriminating evidence against the suspect, then the hash value can be recalculated and compared with the original one, and if both match, it would indicate that no tampering has been done by the enforcement officer (Chaurasia 2023b). With the latest developments, even the 63(4)(c) Certificate template under BSA has a mandatory section on attaching a hash report with the values and the algorithm (SHA1, SHA256, or MD5) through which it was obtained.

Chain of Custody: The gaps in the chain of custody, as noted by the participants in terms of digital evidence, are a genuine concern and pose a significant challenge in admissibility. It is important to establish and maintain a chain of custody as it assures the court that the evidence is authentic, credible, untampered, and has been accessed only by authorised personnel (Badiye et al. 2023). Electronic or digital data is more vulnerable and prone to tampering at all stages of handling, considering the pace of technological advancement (Kumar 2023). Hence, in a criminal case, the defense would always tend to challenge or point out a broken chain of custody to create doubts in the mind of the judge relating to the integrity of evidence. In the case of Mahesh Kariman Tirki and Others Vs. State of Maharashtra, With G.N. Saibaba Vs. State of Maharashtra (2024 SCC OnLine Bom 3353: (2024) 2 AIR Bom R (Cri) 389), which solely rested upon the electronic evidence, the defence argued that there were gaps in establishing the chain of custody of the seized items. According to them, the confiscated items that were kept in the malkhana were taken out from time to time and handled by multiple hands without any documented record of endorsement and re-sealing in the registry, signalling tampering. Hence, due to the lack of credibility of the digital evidence, it eventually led to an acquittal of the suspect. Although this case relates to tangible digital evidence like laptops and mobile phones, it highlights the significance and role of the chain of custody in the admissibility of evidence. Similarly, intangible digital evidence like photos or social media posts requires a separate logging protocol for documenting capture, preservation, transfer, and production, along with a hash value report and 63(4) Certificate, which was observed to be generally lacking.

Opinion of Experts: As was seen previously, under the BSA, submission of the 63(4) Certificate is mandatory for the admissibility of digital records. If this Certificate is presented with the expert signature, the court shall presume under Section 79 that the evidence record was duly taken by the authorised officer. Opinion of the examiner of electronic evidence as experts under Section 39 can be sought if, during the proceedings, the court has to form an opinion on the information that was transmitted or stored. Therefore, the approach of the participants not to send digital records for forensic examination unless contested or directed by the judge in the court is legally sustainable when such evidences are corroborative. In the instances wherein these digital records are the sole ground for investigations, there will be a higher burden to obtain opinions of experts beforehand.

Standard Operating Procedures and Trainings

The participants were of the view that there is no SOP for handling digital evidence for wildlife law enforcement agencies and that there is a need for one. A study also observed that there are no uniform procedures followed across India (Gupta & Das 2023). The Supreme Court in the case of Arjun Panditrao Khotkar vs. Kailash Kushanrao Gorantyal (AIR 2020 SC 4908) stressed that there is a need to frame rules, guidelines, and directions regarding data retention, segregation, chain of custody, preservation, stamping, and record maintenance relating to digital evidence. At a state level, some enforcement agencies like the police (Kerala Police 2021) and the Orissa Forest Department (Maharana 2024) have certain manuals or guidelines in place. However, not all the states and departments likely have access to such handbooks. In December 2023, the Supreme Court, in the petition Foundation for Media Professionals vs. Union of India (W.P. (Crl.) No. 395/2022), on model guidelines for the search and seizure of digital devices, passed an interim order directing the enforcement agencies to follow CBI's 2020 Manual. In light of this petition and the new BSA frameworks, new model guidelines or SOP at the central and state levels are mandatory and likely underway.

RECOMMENDATIONS

The study shows that the barriers in combating social media-enabled wildlife crime go beyond the detection and investigation of such cases. Most of them cannot proceed to the trial phase. Even if they proceed, there is no successful conviction because of the weak prosecution. This shows that even if there is a law that prohibits wildlife offences in India, its enforcement or implementation in relation to social media-enabled cases remains ineffective due to various legislative and evidentiary challenges.

At the legislation level, there is a struggle to identify, interpret, and apply the accurate legal provisions on such social media-linked wildlife offences. Absence of express prohibition on social media or online wildlife offences, coupled with higher reliance on the interpretation of the technical legal provisions are valid impediment. Even if the provisions are rightly invoked, the battle lies in successfully proving it before the court of law, which requires a specialised skill set.

Most of the evidentiary challenges primarily signalled knowledge gaps, unawareness and expertise requirements. The admissibility of the social media-related digital evidence was assessed to be a major catalyst for ensuring the success of such cases. However, there are insufficient procedural guidance protocols and trainings are also sidelined and remain under-prioritized. Therefore, in line with these, the following are some of the recommendations that may help address the challenges identified in this study.

For the lawmakers, it is recommended that under the WLPA, wildlife offences which take place by 'any means', whether 'direct' or indirect, should also be expressly prohibited to counter social media or online facilitated activities. Even the act of 'advertising', 'display', 'usage', 'utility', and sharing of 'unscientific or misinformation' that stimulates the demand for protected species should also be regulated, with an exception to educational content disseminated from authorised sources. The scope of Section 50(1)(c) WLPA may also be broadened to facilitate the seizure of all kinds of evidence, including digital, to effectively authorise the power to enforcement agencies.

At the policy level, there needs to be a dedicated enforcement division across all the states within the forest and wildlife department, whose capacity could be strategically developed in relation to the legal and technological skill sets. Such a division can collaborate and liaise with cyber cells of the state police department and local prosecutors in social media wildlife cases. A uniform SOP either directed by the centre or at a state level will act as a guiding manual for the enforcement agencies as well as for the court considering the new amendments.

The training component on the law should include modules on the WLPA, IT Act, IT Rules 2021, and the BSA. These should not be limited only to the extent of 'what the law is' but should also be supplemented by the practical realities of 'how to prove' with insights on the court procedure. Training may be backed by the subject matter experts and NGOs. It would be best to have a focused and interagency approach to the training with the involvement of the identified officers from the forest and police departments.

As the digital landscape evolves, complex challenges will continue to emerge. Social media-enabled wildlife offences are no longer 'small scale' given their unprecedented reach. Considering its magnified gravity and cross-border impact, an interdisciplinary approach from the perspective of law, enforcement, and prosecution is a necessity to protect the endangered species.

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COMMUNICATION

Occurrence and prevalence of gastrointestinal parasites in herbivores in Dampa Tiger Reserve, Mizoram, India

G.S. Solanki [1], Lalrinkimi [2] & Phoebe Lalremruati [3]

[1–3] Department of Zoology, Mizoram University, Aizawl, Mizoram 796009, India.
[1] drghanshyam.solanki@gmail.com (corresponding author), [2] kimipangamte@gmail.com, [3] phoebemamteii@gmail.com

Abstract: Gastrointestinal parasite (GI) infection causes serious illnesses, reproductive impairment, and fitness problems in animals. Animals in the wilderness are not given prophylactic measures against parasites. A study was undertaken to recognize the prevalence of gastrointestinal parasites in herbivores at Dampa Tiger Reserve. Different species of herbivores belonging to the families Cercopithecidae, Sciuridae, Elephantidae, Cervidae, and Bovidae were considered for this study. Fresh faecal samples were collected from individuals in the field during January–March 2019, processed to isolate various stages of GI parasites, and examined for the presence of parasite categories and stages. A total of 70 samples were collected and analyzed, 59 samples found positive for gastrointestinal parasite ova. The overall prevalence level was 84.29% of the positive samples. Thirteen parasite species were found, which belong to four groups of parasites, namely, Nematodes, Trematodes, Protozoa, and Cestodes. *Ascaris* sp. had the highest prevalence, followed by Strongyle and *Dicrocelium* sp. exhibited the lowest prevalence. The prevalence of *Ascaris* sp. and Strongyle were 47.68% and 30.23%, respectively. The overall prevalence level was highest in family Cervidae (54.65%), followed by Cercopithecidae (43.02%), and Sciuridae (31.39%). The family Cervidae showed a high prevalence of *Ascaris* sp., whereas the family Cercopithecidae exhibited a high prevalence of Strongyle compared with other families.

Keywords: Cestodes, faecal pellet, footprint, herbivores, nematodes, parasites, protozoa, terei forest range, trematodes, zoonotic.

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Author details: G.S. Solanki, professor of Zoology, and dean, School of Life Sciences, Mizoram University, Aizawl. Thrust area for research was Biodiversity & Conservation Biology, Wildlife Ecology and Resource Management. After a long experience, he has been superannuated from active service of Mizoram University. Lalrinkimi was a PG student in the Department of Zoology and completed her M.Sc. degree. She did her dissertation under the supervision of Prof. Solanki. Phoebe Lalremruati was a research scholar in the Department of Zoology and completed her PhD degree under the supervision of Prof. Solanki on captive primates.

Author contribution: GSS-conceptualization of the study, arrangement of funds, finalizing the data analysis, writing and reviewing the final draft, and correspondence with the journal. Kimi collected the data and faecal samples from the field and performed preliminary screening of the samples. PL-helped in the final sample preparation of parasites and assisted in the identification of species. She also initiated the first draft of the manuscript.

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INTRODUCTION

Parasites are integral components of ecosystems, influencing host population dynamics, regulation, and community biodiversity (Hochachka & Dhondt 2000; Hudson et al. 2002). The intensity of parasitic infection can affect host fitness by reducing survival and reproductive success (Behnke 1990; Despommier et al. 1995; van Vuren 1996; Hilser et al. 2014). Intrinsic host features, together with environmental factors and parasite transmission mechanisms, shape overall vulnerability (Gibb et al. 2020). Primates, like other species, inhabit diverse environments and are exposed to variations in temperature and rainfall (Nunn & Altizer 2006; Solanki & Parida 2022). Many parasites are sensitive to these climatic factors; for instance, the eggs and larvae of several nematodes require adequate humidity to complete their development (Anderson 2000).

Wild animals are subjected to human exploitation or interventions, such as hunting and the wildlife trade, often experience heightened stress (Clark et al. 2008; Dickens et al. 2010) and are used in therapeutic activities and sociocultural & religious purposes (Solanki & Chutia 2009; Solanki et al. 2016). The growth of human populations, particularly in herbivore habitats, has further increased the risk of zoonotic transmission (Devaux et al. 2019). Chronic stress can suppress immune function, making animals more vulnerable to parasitic infections, leading to declining health and ultimately, death (Glaser & Kiecolt-Glaser 2005; Clark et al. 2008; Coe 2011). Habitat fragmentation and the resulting inbreeding have also been linked to higher parasite prevalence (Schad et al. 2005), although fragmentation may in some cases reduce parasite diversity (Anderson & May 1982). Human encroachment in natural habitats facilitates contact between people and wild herbivores, thereby increasing the chances of disease spillover and is viewed as a potential zoonotic agent for human wellbeing (de Thoisy 2001; Graczyk et al. 2001; Johnson et al. 2015; McLennan et al. 2018; Keatts et al. 2021).

Increasing anthropogenic activities are heightening contact between humans, domestic animals, and wildlife. These increases have been linked to changing human ecology, a growing human population, and its demand for bushmeat, wild animals as pets, agricultural land, natural resources, and the shrinking of wildlife habitats (Jones et al. 2008; Herrera & Nunn 2019; Gibb et al. 2020a; Plowright et al. 2021). However, the impact of human-herbivore interactions, both legal and illegal, on zoonotic pathogens remains insufficiently explored in the Dampa Tiger Reserve (DTR). Along the periphery of DTR, twelve villages practice shifting cultivation, which often attracts herbivores and other mammals into farmland areas (Gouda et al. 2020). Nath et al. (2021) provided a concept of "one health moment" and recognised wildlife as a major source of zoonotic infections, highlighting the need for further research in wildlife pathogen detection. In light of these implications, an attempt was made to study the occurrence and prevalence of parasites among wild herbivores in the Dampa Tiger Reserve, Mizoram, India.

MATERIALS AND METHODS

Dampa Tiger Reserve is located between 92.220–92.4566^0 E and 23.545–23.693^0 N, encompassing 500 km² of core area and 488 km² of buffer zone at elevations ranging 200–1,200 m. Situated within the Indo-Myanmar biodiversity hotspot, the reserve supports rich floral and faunal diversity, including numerous herbivore species. The climate is moderately seasonal, with winter temperatures ranging from 11–21 ^{0}C and summer temperatures from 19–37 ^{0}C. Twelve villages lie within the buffer zone, where shifting cultivation is the primary livelihood practice. The study site map is presented in Figure 1.

Dampa Tiger Reserve (DTR) supports 23 herbivore species (Table 1) representing the families Cercopithecidae, Sciuridae, Elephantidae, Cervidae, and Bovidae. Owing to this diversity, faecal samples were collected from multiple individuals within each family rather than from all species. The sampling area was the Terei range of DTR. As only one Asian Elephant was recorded, repeated samples were collected from the same individual at different time intervals. Faecal samples were identified in the field based on pellet morphology (shape, size, colour, and consistency) following Gopal (1993), with species confirmation through footprints and associated field signs (Apeldoorn et al. 1993). Fresh samples were collected between January and March 2019 from active sites within the known distribution of individuals, with assistance from the local forester. This study is a part of the fulfilment of the Master's degree program; therefore, the study was conducted for a limited period. Approximately, 10 g of each sample was preserved in 10% formalin and transported to the laboratory (Gillespie 2006). In total, 70 samples were obtained from 21 individuals (Table 2).

Samples were processed to detect enteric parasitic eggs and oocysts using direct smear, sedimentation,

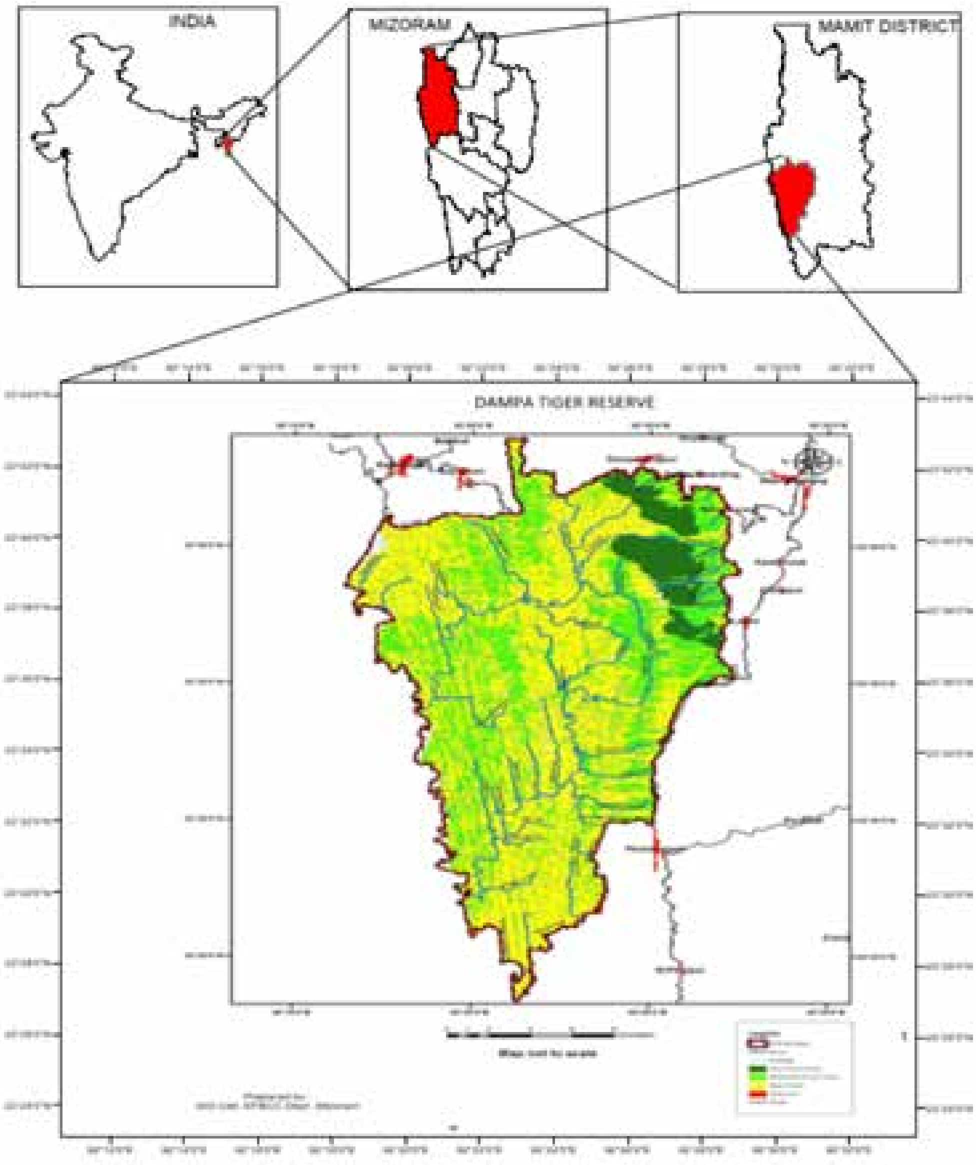

Figure 1. Map of Dampa Tiger Reserve.

and flotation techniques (Gillespie 2006). Prepared slides were systematically examined under a compound light microscope at varying magnifications. Parasite identification and confirmation were conducted at the College of Animal Husbandry and Veterinary Sciences. The data were compiled and organized for further analysis and graphical representation. Differences in gastrointestinal (GI) parasite prevalence among host families were assessed using the Kruskal-Wallis test. Pairwise comparisons between families were performed using the Mann-Whitney U test and the Wilcoxon rank sum test to evaluate variations in GI parasite prevalence.

RESULTS

Of 70 samples, 59 samples were found to be positive with ova or other stages of gastrointestinal parasites (GI). These parasite species include *Spirometra* sp., *Balantidium coli, Capillaria* sp., *Eimeria* sp., *Paragonimus* sp., *Giardia* sp*., Opisthorchis* sp., *Toxocara* sp*., Dicrocelium* sp., *Trichuris* sp*., Isospora* sp., Strongyle and *Ascaris* sp. In total, 84.29% of samples were found to be positive for the prevalence of GI parasites, and 15.71 % of the samples were found to be negative (Table 2).

Thirteen species of gastrointestinal parasites (GI) were recorded from herbivores of five different families (Table 3, Images 1 & 2). The highest level of

Table 1. List of herbivorous species present in Dampa Tiger Reserve.

Family	Common name	Scientific name
Cercopithecidae	i) Stump-tailed Macaque ii) Assamese Macaque iii) Northern Pig–tailed Macaque iv) Rhesus Macaque v) Phayre's Leaf Monkey vi) Capped Langur	i) *Macaca arctoides* ii) *Macaca assamensis* iiii) *Macaca leonina* iv) *Macaca mulatta* v) *Trachypithecus phayrei* vi) *Trachypithecus pileatus*
Sciuridae	i) Hairy-footed Flying Squirrel ii) Parti-coloured Flying Squirrel iii) Red-bellied Squirrel iv) Red Giant Flying Squirrel v) Orange-bellied Himalayan Squirrel vi) Black Giant Squirrel vii) Hoary-bellied Squirrel viii) Himalayan Striped Squirrel	i) *Belomys pearsonii* ii) *Hylopetes alboniger* iii) *Callosciurus erythraeus* iv) *Petaurista petaurista* v) *Dremomys lokriah* vi) *Ratufa bicolor* vii) *Callosciurus pygerythrus* viii) *Tamiops macclellandi*
Elephantidae	i) Asian Elephant	i) *Elephas maximus*
Cervidae	i) Hog Deer ii) Northern Red Muntjac iii) Brow-antlered Deer iv) Sambar	i) *Axis porcinus* ii) *Muntiacus muntjak* iii) *Rucervus eldii* iv) *Cervus unicolor*
Bovidae	i) Gaur ii) Red Serrow iii) Himalayan Serrow iv) Chinese Goral	i) *Bos gaurus* ii) *Capricornis rubidus* iii) *Capricornis thar* iv) *Naemorhedus griseus*

prevalence of *Ascaris* sp. was reported, followed by Strongyle whereas the prevalence of *Dicrocelium sp*. was the least. The prevalence of *Ascaris* sp. and Strongyle was 47.68% and 30.23%, respectively (Figure 2). Among the four categories of gastrointestinal parasites, nematodes and protozoans were predominant with 38.5% and 30.8% prevalence of GI parasites, followed by trematodes with 23.1%. These two categories of parasites, nematodes, and protozoans, together showed a prevalence of 69.3%, with heavy infection in herbivores in DTR. Occurrence of the cestode (*Spirometra* sp.) was also recorded. Five species of nematodes found in herbivores were: *Ascaris* sp., Strongyle, *Capillaria* sp., *Trichuris* sp., and *Toxocara* sp. Of these species, *Ascaris* sp. and Strongyle were the most common parasites found in almost all samples. The level of prevalence of gastrointestinal parasites in herbivores in the DTR, in general, is given in Figure 2.

Parasites from different families

Ascaris sp. and Strongyle are family specific; *Ascaris* prevailed more in members of the Cervidae family, and the Strongyle exhibited high prevalence in members of the Cercopithecidae family. Gastrointestinal parasites were highest in Cervidae (54.65%) followed by Cercopithecidae (43.02%) and Sciuridae (31.39%). The overall level of GI parasites in different herbivore families is given in Figure 3. The variations in prevalence in different families of herbivores were tested using the Kruskal-Wallis test and revealed that variations in the number of parasites in different families were significant ($\chi^2 = 36.822$, df = 5, $P < 0.01$). The Mann-Whitney test was then performed for pairwise variation on the infection with different families. The pairwise analysis of the different families of the herbivore is given in Table 4 The pair-wise variation in GI prevalence level showed a significance at $P < 0.001$ between Ceropithecidae vs. Elephantidae, Cercopithecidae vs. Bovidae, Sciuridae vs. Elephantidae, Bovidae vs. Cervidae, and Sciuridae vs. Bovidae (Table 4. This indicates that the level of infection

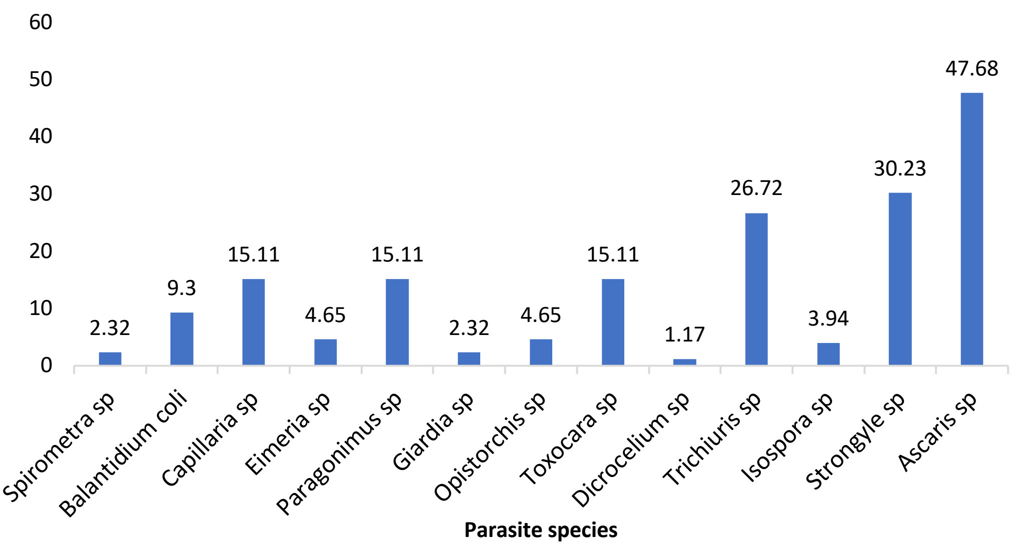

Figure 2. Prevalence (%) of gastrointestinal parasites in herbivores.

Table 2. Number of samples showed the prevalence of parasites in different families.

	Name of the family	No. of samples collected	No. of positive samples	No. of negative samples
1	Cercopithecidae	25	23	2
2	Sciuridae	12	12	0
3	Elephantidae	01	01	0
4	Cervidae	31	23	8
5	Bovidae	01	0	1
	Total	**70**	**59**	**11**
	Percentage		**84.29**	**15.71**

Image 1. Ova of gastrointestinal parasites: A—*Ascaris* sp. | B—Strongyle | C—*Trichuris* sp. | D—*Capillaria* sp. | E—*Toxocara* sp. | F—*Opisthorchis* sp.

Table 3. Class of gastrointestinal parasites.

Nematodes	Trematodes	Protozoan	Cestode
Ascaris sp. Strongyle *Capillaria* sp. *Trichuris* sp. *Toxocara* sp.	*Opisthorchis* sp. *Paragonimus* sp. *Dicrocelium* sp.	*Isospora* sp. *Balantidium coli* *Giardia* sp. *Eimeria* sp.	*Spirometra* sp.

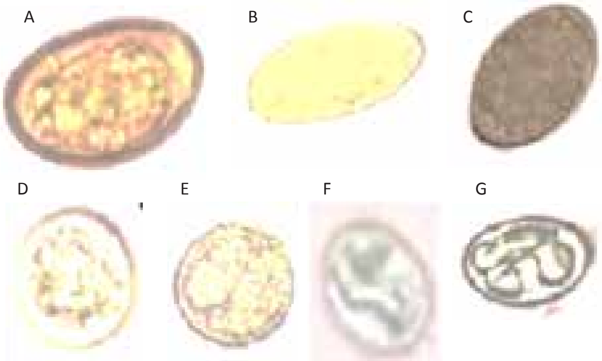

Image 2. Ova of gastrointestinal parasites: A—*Dicrocelium* sp. | B—Paragonimus sp. | C—*Spirometra* sp. | D—*Isospora* sp. | E—*Balantidum coli* | F—*Giardia* sp. | G—*Eimeria* sp.

Table 4. Comparison of different families using the Mann-Whitney 'U' test.

	Different families	Mann-Whitney U	Wilcoxon W	P
1	Cercopithecidae vs. Sciuridae	136.5	227.5	0.818
2	Cercopithecidae vs. Elephantidae	23	114	0.001
3	Cercopithecidae vs. Bovidae	23	114	0.001
4	Cercopithecidae vs. Cervidae	78	169.5	0.753
5	Sciuridae vs. Elephantidae	30.5	121.5	0.001
6	Sciuridae vs. Bovidae	30.5	121.5	0.001
7	Sciuridae vs. Cervidae	69	160	0.411
8	Elephantidae vs. Bovidae	84.5	175.5	1
9	Bovidae vs. Cervidae	23	114	0.001

by GI parasites was high in family Cercopithecidae (92% [23/25 samples]), Sciuridae (100% [12/12 samples]), and Cervidae (74% [23/31 samples]) (Table 2).

DISCUSSIONS

This study provides the first systematic assessment of gastrointestinal (GI) parasite occurrence and prevalence in herbivores of Dampa Tiger Reserve. *Ascaris* sp. had the highest prevalence (47.68%), followed by Strongyle (30.23%), and *Trichuris* sp. (26.72%). *Capillaria* sp., *Paragonimus* sp., and *Toxocara* sp. had a prevalence level of 15.11% each. Similar patterns have been reported in herbivores across different habitat conditions by Cisek et al. (2004), Santin et al. (2004), Pilarczyk et al. (2005), and Lim et al. (2008). Although prevalence rates varied among the studies reported, the ranges were 40%–18%, 52%–27.5%, 67%–35%, and 34.5%- 21.8% for helminths and protozoans, respectively. The prevalence of the cestode parasite (*Spirometra* sp.) was found in the present study (Table 3).

Nematodes are primarily transmitted through faecally contaminated soil, water, and forage, particularly in agricultural landscapes (Bethony et al. 2006). Grazing herbivores inadvertently ingest infective eggs or larvae while feeding, making them highly susceptible to infection. In DTR, primates of the family Cercopithecidae frequently forage in adjacent jhum (shifting cultivation) fields, increasing contact at the wildlife-agriculture

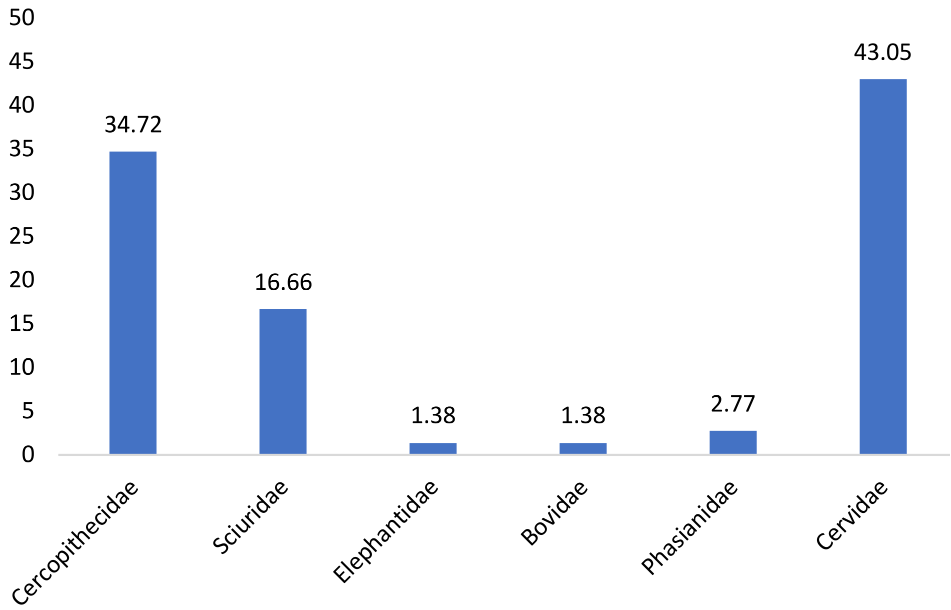

Figure 3. Overall prevalence level (%) of parasites in different families of herbivores.

interface and thereby elevating the risk of nematode and protozoan transmission (Dazak et al. 2000). Many nematodes and protozoans have direct life cycles that do not require intermediate hosts; transmission occurs via the faecal-oral route through contaminated feed, water, or soil (Thawait et al. 2014). Local communities draw untreated water directly from streams flowing through the reserve, thereby facilitating zoonotic transmission. Additionally, the reliance of approximately 21% of the local population on wild animals for bushmeat and ethnomedicinal purposes (Sloanki & Chutia 2009; Solanki et al. 2016) increases the likelihood of cross-species parasite exchange between wildlife and humans (Johnson et al. 2015).

Comparable trends for prevalence of helminths and protozoans have been observed in wild captive animals, including elephants, with prevalence rates of 58% & 6% (Varadharajan & Kandasamy 2000), and 50% & 18.8% (Parasani et al. 2001), respectively. The overall prevalence of gastrointestinal parasites in this study (84.29%) (Table 2) was higher than that reported by Corden et al. (2008) at 72.5% and Dahal et al. (2023) at 47.57%. Lower prevalence rates have also been documented as 42.4% (Reddy et al. 1992), 40.4% (Chakraborty & Islam 1996), 48.1% (Modi et al. 1997), 60.7% (Parasani et al. 2001), 56.3% (Lim et al. 2008). Such variations are likely influenced by geographic, climatic, and ecological factors that affect parasite transmission and host–parasite dynamics (Lalremruati & Solanki 2020; Moustafa et al. 2021; Anusha et al. 2025). Parasitic infections are known to be prevalent widely in warm and tropical climates where temperature, humidity, and light conditions favour parasite development and survival (Magona & Musisi 1999). These parasites, particularly trematodes and certain cestodes, require intermediate hosts for completion of their life cycles (Atanaskova et al. 2011). However, due to the limited scope of this study, life history parameters related to the identification of intermediate hosts were not examined.

Dampa Tiger Reserve hosts a rich diversity of carnivores (Singh et al. 2016; Singh & MacDonald 2017; Vandir et al. 2022), which rely on herbivores as their principal prey. This trophic relationship increases the potential for parasite transmission from herbivores to carnivores. Vandir et al. (2022) reported a gastrointestinal (GI) parasite prevalence rate of 90.47% among carnivores in DTR, with most parasite species corresponding to those identified in herbivores. Of the 13-parasite species in herbivores, 10 were common in carnivores in DTR. Frequent human-herbivore interactions also occur in and around the 12 villages adjacent to the reserve (Solanki et al. 2016), where bushmeat consumption poses a significant zoonotic risk (Keatts et al. 2021). The dependency of the local population (21%) on wild animals as sources of bushmeat and as ethnomedicines (Solanki et al. 2016) also increases the possibilities of cross-transmission of zoonotic diseases several-fold. Increasing human encroachment into wildlife habitats further heightens the risk of zoonotic disease transmission between wildlife and local communities

(Gibb et al. 2020; Recht et al. 2020). Agricultural fields surrounding protected areas often function as peri-habitats for several herbivores, increasing the likelihood of exposure to zoonotic pathogens. Increasing landscape modification, greater human intrusion into wilderness areas, habitat fragmentation, the presence of free-ranging domestic animals, and seasonal ecological changes further intensify interactions among wildlife, livestock, and humans. Consequently, zoonotic parasites may eventually breach existing ecological barriers, shifting to new hosts such as livestock and ultimately humans (Otranto et al. 2015; Gibb et al. 2020a,b; Keatts et al. 2021; Plowright et al. 2021).

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COMMUNICATION

Theileriosis in a captive Indian Gaur *Bos gaurus*: a rare encounter

Kaushal Kumar [1], Vishal Kumar Sinha [2], Deepak Kumar [3], Imran Ali [4], Ramesh Tiwary [5], Pankaj Kumar [6] & Amit Kumar [7]

[1–4] Department of Veterinary Pathology, [5] Department of Veterinary Suregry & Radiology,
Bihar Veterinary College, Bihar Animal Sciences University, Patna, Bihar 800014, India.
[6] Department of Veterinary Microbiology , Bihar Veterinary College, Bihar Animal Sciences University, Patna, Bihar 800014, India.
[7] Sanjay Gandhi Biological Park, Patna, Bihar 800001, India.
[1] drkaushal15@rediffmail.com (corresponding author), [2] vishalbvc17@gmail.com, [3] drdeepakpath@gmail.com,
[4] aliimran3373@gmail.com, [5] vettiwary@gmail.com, [6] pankajimmunol@gmail.com, [7] amit55vetindian@gmail.com

Abstract: This study describes fatal theileriosis in two captive Indian Gaurs *Bos gaurus* housed at Sanjay Gandhi Biological Park, Patna, Bihar, India. Both animals exhibited high fever, anorexia, lethargy, congested mucous membranes, subcutaneous haemorrhages and enlarged lymph nodes and subsequently succumbed to the disease. Post-mortem examination revealed enlarged lymph nodes, characteristic punched-out abomasal ulcers and petechial haemorrhages in multiple visceral organs. Diagnosis was confirmed by detection of Koch's blue bodies in lymph node smears, histopathological lesions consistent with Theileria infection and PCR analysis. The findings highlight the occurrence of severe, fatal theileriosis in captive gaur and emphasize the need for timely diagnosis and effective control measures in zoological settings.

Keywords: Abomasum, anorexia, histopathology, Koch blue bodies, liver, lymph node, lymphoadenopathy, petechial haemorrhages, polymerase chain reaction, zoo animal.

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Author details: Vishal Sinha is a postgraduate scholar in the Department of Veterinary Pathology. His current work focuses on wildlife pathology, histopathology and infectious diseases of animals. He is actively involved in diagnostic pathology, post-mortem examination and research related to disease investigation in domestic and captive wild animals. Dr. Kaushal Kumar is a professor in the Department of Veterinary Pathology. His areas of expertise include diagnostic pathology, histopathology, toxicopathology and infectious diseases of animals. He is actively engaged in teaching, research and pathological investigations related to domestic and wild animal diseases. Dr. Deepak Kumar is an associate professor in the Department of Veterinary Pathology. His professional interests include diagnostic veterinary pathology, histopathology and disease investigation in animals. He is actively involved in teaching, research and laboratory diagnosis of infectious and pathological conditions affecting domestic and wild animals. Dr. Imran Ali is a professor in the Department of Veterinary Pathology. His expertise includes veterinary diagnostic pathology, histopathology and infectious diseases of animals. He is actively engaged in teaching, research and disease diagnosis, with special interest in pathological investigations in domestic and wild animals. Dr. Ramesh Tiwary is an associate professor in the Department of Veterinary Surgery and Radiology. His areas of interest include veterinary surgery, diagnostic imaging and clinical management of animal diseases. He is actively involved in teaching, research and clinical practice related to surgical and radiological diagnosis in animals. Dr. Pankaj Kumar is a professor in the Department of Veterinary Microbiology. His areas of expertise include microbial diseases of animals, diagnostic microbiology and infectious disease research. He is actively involved in teaching, research and laboratory diagnosis, with special interest in bacterial pathogens affecting domestic and wild animals. Dr. Amit Kumar is a veterinary officer at Sanjay Gandhi Biological Park, Patna. His work involves health management, disease diagnosis and clinical care of captive wild animals. He is actively engaged in wildlife health monitoring, treatment and conservation-oriented veterinary practices in zoological settings.

Author contribution: VS, DK, KK—conception and design of the study. VS, DK—conducted post-mortem examination and sample collection. VS, DK, IA—histopathological examination and interpretation. PK—PCR analysis and microbiological investigations. RT, AK—clinical management and case investigation. VS—drafted the manuscript. DK, KK, IA—reviewed and finalized the manuscript.

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Patna Zoo
Government of Bihar

INTRODUCTION

Theileriosis is a tick-borne parasitic disease caused by protozoa of the genus *Theileria* primarily affecting cattle and buffaloes but also capable of infecting other wild animals including the Indian Gaur *Bos gaurus*. This haemoprotozoan disease transmitted by arthropods mainly impacts calves leading to significant illness, mortality and substantial economic losses in the livestock sector worldwide. Among the pathogenic species, *Theileria annulata* and *T. parva* are most notable, transmitted by *Hyalomma* and *Rhipicephalus* ticks, respectively.

The Indian Gaur, the largest bovid confined to the oriental biogeographic region has approximately 85% of its current global population occurring in India (Ashok et al. 2011) and is vulnerable to epidemic diseases such as foot & mouth disease, anthrax, and rinderpest. Although there is scanty representation of haemoprotozoan diseases like theileriosis and babesiosis yet theileriosis is an economically significant vector-borne disease spread by arthropods and blood protozoa in tropical and subtropical regions of India (Sitotaw et al. 2014). Although haemoprotozoan infections such as theileriosis are relatively under-reported in some regions, theileriosis, affects a range of domestic ruminants primarily cattle (bovine tropical theileriosis caused mainly by *Theileria annulata*), Water Buffalo *Bubalus bubalis*, sheep, and goats and it has also been detected in wild ungulates (like Sambar, Spotted Deer, and other cervids) in India.

Molecular and meta-analytic studies indicate *T. annulata* is the dominant pathogenic species in Indian cattle while *T. orientalis* and other *Theileria* spp. occur in both bovines and small ruminants (Krishnamoorthy et al. 2021). It infects many domestic and wild animals through ixodid ticks of the genera *Amblyomma*, *Haemaphysalis*, *Hyalomma*, and *Rhipicephalus* (Mans et al. 2015). With cattle, water buffalo, waterbucks, and African Buffalo susceptible to *T. parva* infection, although symptomatic illness is mainly observed in cattle and water buffalo (Spickler et al. 2010). Among the many species of *Theileria* infecting cattle, *T. parva* and *T. annulata* are the most pathogenic with economic impacts making them the most prevalent causes of bovine theileriosis worldwide (Kohli et al. 2014; Abdel-Rady et al. 2023).

A systematic review and meta-analysis of studies across India estimated an overall theileriosis prevalence of ~20% in cattle and buffaloes (Krishnamoorthy et al. 2021). Regionally, microscopy-based surveys recorded *Theileria* prevalence of 2.2% (Cauvery Delta, Tamil Nadu; Jayalakshmi et al. 2019) and ~13% (western Tamil Nadu; Velusamy et al. 2014) and sensitive molecular qPCR work from an endemic area in Odisha showed high *T. annulata* parasitaemia among clinical cases and detectable carriers (Sahoo et al. 2022).

Following attachment of infected ticks to the host, the incubation period ranges 4–14 days and in the acute phase, the disease duration can vary 3–4 days or extend up to 20 days (Bakor et al. 2008). The clinical signs include fever (>103°F), enlargement of superficial lymph nodes (acute form), anorexia, pale or congested mucous membranes, conjunctivitis, severe ocular congestion, excessive lacrimation, corneal opacity, respiratory symptoms such as serous nasal discharge, cough, purulent nasal discharge, dyspnea, weakness, and death (Mahmmod et al. 2011).

In wild animals, the prevalence of theileriosis varies significantly depending on species, geographical location, and surveillance methods.

These data suggest that while theileriosis is widely distributed among wild ungulates, its prevalence in Gaur appears to be rare, underreported or possibly underestimated due to limited surveillance.

Case Presentation

Two zoo-born Indian Gaurs *Bos gaurus* housed at Sanjay Gandhi Biological Park died within an interval of seven days. One animal was approximately five years and nine months old while the other was seven months old and both were males. The animals exhibited clinical illness for approximately two weeks prior to death, characterized by high fever, anorexia, lethargy, dyspnoea, weakness, congested mucous membranes, subcutaneous haemorrhages and marked enlargement of pre-scapular lymph nodes and eventually succumbed to the disease. Despite being maintained under generally well-managed conditions with adequate hygiene, accumulation of faecal material was observed in the surrounding area. At the time of clinical examination and necropsy, ticks were not prominently observed. No similar clinical signs or mortality were recorded among other wild ruminants housed in adjacent enclosures during this period. Both affected animals were confirmed to be zoo-born and maintained under captive conditions since birth. Necropsy was performed under aseptic conditions following standard procedures (Maxie 2015). External examination revealed enlarged pre-scapular lymph nodes, congested mucous membranes, subcutaneous haemorrhages, abdominal distension, and rigor mortis in the hind limbs.

During necropsy, impression smears were prepared from the cut surface of the lymph nodes, fixed in methanol for 2 minutes, air-dried and stained with Giemsa stain for 45 minutes for cytological examination. Tissue samples from the abomasum, lymph nodes, liver, and lungs were collected and fixed in 10% neutral buffered formalin for histopathological analysis. The tissues were processed using the standard paraffin embedding technique, sectioned at 4–6 µm thickness and stained with haematoxylin and eosin (H&E) following established protocols (Luna et al. 1968; Maxie 2015).

For molecular confirmation, genomic DNA was extracted from lymph node tissue using the HiPurA™ Multi-Sample DNA Purification Kit (MB553, HiMedia Laboratories, Mumbai, India) following the manufacturer's protocol and subsequently subjected to polymerase chain reaction (PCR) targeting the 18S rRNA gene of *Theileria* spp. using genus-specific primers. Genomic DNA extracted from a previously confirmed *Theileria* spp. positive sample was used as the positive control, while nuclease-free water served as the negative control in the PCR reaction. PCR amplification was carried out using genus-specific primers: forward primer 5'-CCTGAGAAACGGCTACCACATCT-3' and reverse primer 5'-GGACTACGACGGTATCTGATCG-3' as described by Yang et al. (2014). The thermal cycling conditions consisted of an initial denaturation at 95 °C for 5 min, followed by 35 cycles of denaturation at 95 °C for 45 s, annealing at 58 °C for 30 s and extension at 72 °C for 45 s, with a final extension at 72 °C for 10 min and the reaction was then held at 4 °C. PCR amplification yielded a distinct product of approximately 591 bp corresponding to the expected size for *Theileria* spp., which was visualized by agarose gel electrophoresis along with appropriate positive and negative controls.

Following confirmation of theileriosis, the remaining three adult Gaurs were treated with buparvaquone (Butalex™, MSD Animal Health, Pune, India) at a dose of 2.5 mg/kg body weight administered via dart gun. Supportive management and vector control measures were simultaneously implemented. Carcass disposal of deceased animals was carried out by deep burial with lime application in accordance with MoEFCC (2017) guidelines. Routine disinfection of the enclosure and contaminated materials was performed. The treated animals showed clinical improvement within 3-4 days post-administration, with resolution of fever, and improved appetite.

RESULT & DISCUSSION

Gross Findings and Interpretation

At necropsy, the abomasum exhibited prominent, well-demarcated punched-out ulcers characterized by discrete, circular mucosal defects (Image 2a,b), which are considered characteristic lesions of theileriosis and have been previously reported in bovines affected with *Theileria* infection (Omer et al. 2003). The spleen was markedly enlarged and congested with a mottled appearance and multifocal petechial to ecchymotic haemorrhages on the capsular surface (Image 2c), indicative of systemic vascular damage and haemolytic processes. The liver was mildly enlarged with diffuse congestion and multiple small pale focal areas (Image 2d), suggesting hepatocellular injury associated with systemic infection. Lymph nodes were markedly enlarged, edematous and congested, reflecting lymphoproliferative and inflammatory responses typical of theileriosis. The kidneys showed multifocal haemorrhages (Image 2e) while the lungs were congested, edematous and emphysematous, consistent with respiratory compromise. The heart exhibited petechial and ecchymotic haemorrhages on both epicardial and endocardial surfaces, further supporting a systemic haemorrhagic condition.

Cytological, histopathological and molecular findings

Impression smears from the pre-scapular lymph nodes stained with Giemsa revealed the presence of Koch's blue bodies, a diagnostic feature of *Theileria* infection.

Image 1. Indian Gaur during postmortem examination exhibiting clinical signs of theileriosis found in recumbent position. © Authors.

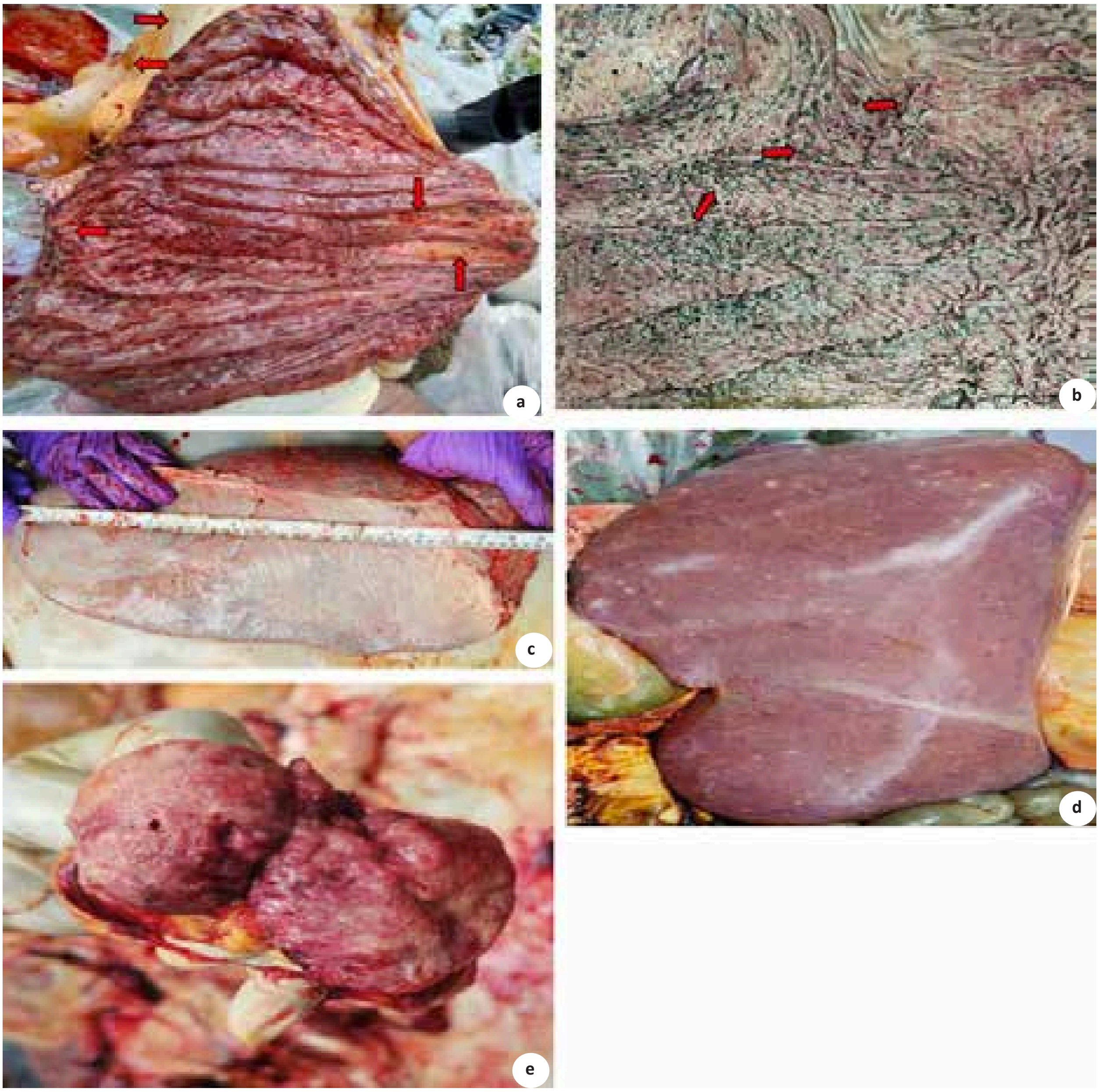

Image 2. a,b—Punched-out ulcerative lesions on the abomasal mucosa of and infected calf (left) and adult Indian Gaur (right) | c—Enlarged, congested spleen with mottled appearance and scattered multiple petechial to ecchymotic hemorrhages | d—Mildly enlarged liver with smooth capsule, and diffuse congestion along with multiple small pale focal lesions throughout the parenchyma | e—Markedly enlarge edematous and congested lymph nodes with a tense capsule and diffuse reddish discolouration. © Authors.

Histopathological examination of the abomasum (H&E, × 100) revealed focal to multifocal mucosal ulceration with epithelial necrosis, loss of mucosal architecture and infiltration of lymphocytes and macrophages (Image 3a), corresponding to the gross lesions. Lymph node sections showed lymphoid depletion with macrophage infiltration containing intracytoplasmic Koch's blue bodies (Image 3b), indicating active parasitic infection and immune response. The liver exhibited moderate hepatocellular vacuolar degeneration, sinusoidal congestion and mononuclear inflammatory infiltration with prominent Kupffer cell activation (Image 3c), reflecting systemic inflammatory insult. Lung sections revealed diffuse interstitial pneumonia with thickened alveolar septa due to mononuclear infiltration and vascular congestion, along with eosinophilic proteinaceous fluid in alveolar spaces suggestive of pulmonary edema (Image 3d). The myocardium showed focal myofibre degeneration with

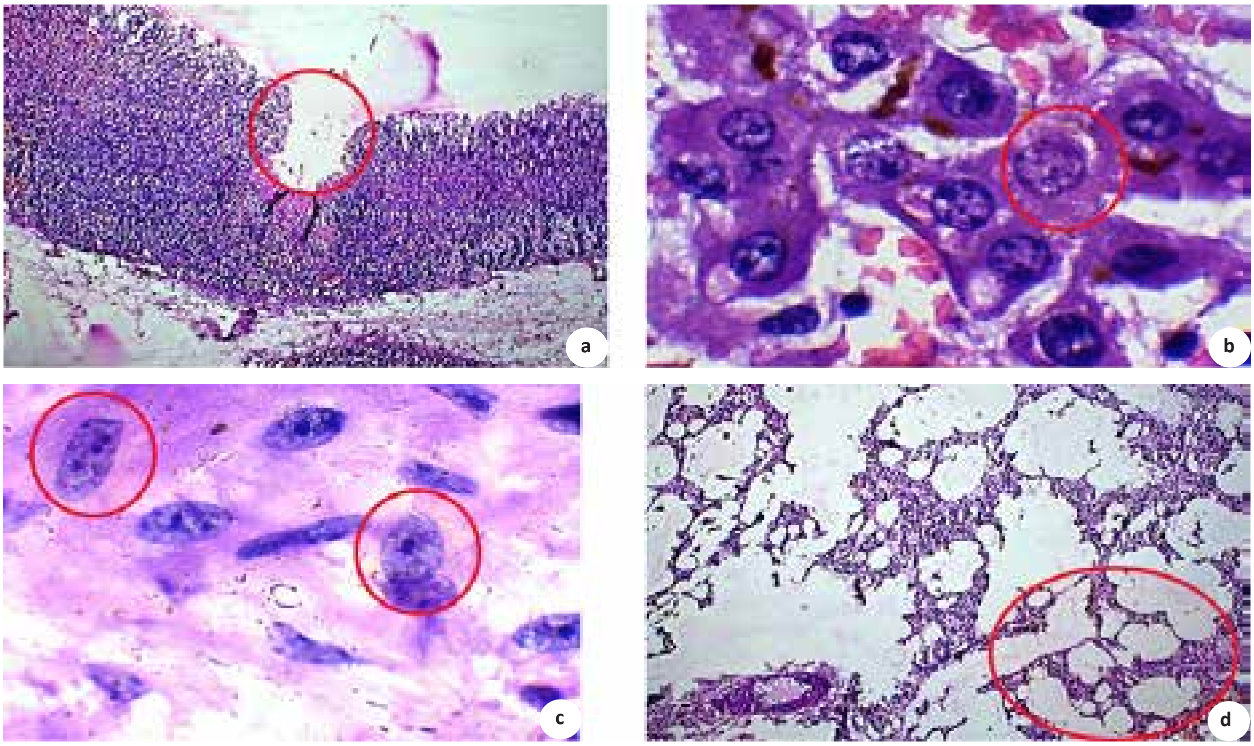

Image 3. a—Histological section of abomassum of Gaur (H&E, x100) demonstrates a punched out ulcerative lesion (circle) with surrounding chronic inflammation, epithelial necrosis and mucosal disruption | b—Histological section of Lymph node of Bison (H&E, x100) reveals lymphoid infiltration with macrophages containing Koch's blue bodies (circle) | c—Histological section of Liver of Bison (H&E, x 100) revealed moderate hepatocellular vacuolar degeneration with sinusoidal congestion, mononuclear inflammatory infiltration and prominent Kupffer cells (circle) | d—Histological section of Lungs of Bison (H&E, x 10) reveals diffuse interstitial pneumonia characterized by marked thickening of alveolar septa (circle) due to mononuclear inflammatory infiltration and vascular congestion. © Authors.

interstitial haemorrhage and lymphocytic infiltration while the kidneys exhibited mild interstitial nephritis with mononuclear cell infiltration, indicating multi-organ involvement.

PCR amplification targeting the 18S rRNA gene yielded a specific amplicon of approximately 591 bp (Image 4), confirming infection with *Theileria* spp. The use of 18S rRNA based PCR has been widely validated for detecting *Theileria annulata* and other *Theileria* spp. in bovines and field samples (Aktas et al. 2006; Prado et al. 2022). However, as the assay employed was genus-specific, species-level identification could not be achieved. Further confirmation using species-specific PCR or sequencing would be required to determine the exact *Theileria* species involved. These molecular findings support the gross and histopathological observations of theileriosis in the present case.

Outcome and Implications

No further mortality was observed during the 3-month follow-up period, indicating successful containment of the outbreak. These findings underscore the susceptibility of captive wild bovids to theileriosis and highlight the critical need for early diagnosis, continuous health monitoring, and effective disease management in zoological settings. Control of theileriosis in captive wildlife relies on integrated tick management, timely therapeutic intervention with buparvaquone, regular acaricide application, and strict quarantine measures. Strategic implementation of tick control using topical synthetic pyrethroids and macrocyclic lactones is essential to prevent recurrence.

CONCLUSION

This study highlights fatal theileriosis in captive Indian gaur *Bos gaurus*, emphasizing the vulnerability of wild bovids to tick-borne haemoprotozoan infections under captive conditions. Early diagnosis and timely therapeutic intervention are crucial to prevent mortality and control disease outbreaks in zoological settings.

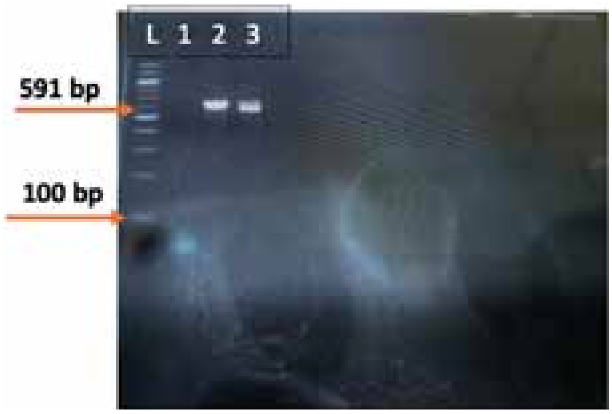

Image 4. PCR amplification showing 591 bp *Theileria* band: Lane 1–Negative control (nuclease free water), Lane 2–Positive control (*Theileria* spp. Positive DNA, 591 bp), Lane 3–Sample positive with 591 bp band. © Authors.

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COMMUNICATION

Avifaunal diversity in agroecosystems: a case study from Uttar Pradesh, India

Fatima Khan [1] & **Kaleem Ahmed** [2]

[1,2] Department of Wildlife Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India.
[1] fatima.amu01@gmail.com, [2] kahmed.wl@amu.ac.in (corresponding author)

Abstract: Birds play a crucial role as indicators of environmental health, making them valuable for conservation assessments. This study presents a systematic checklist of bird species composition, diversity patterns, and foraging guild structures in the Nautanwa agroecosystem of Maharajganj District, Uttar Pradesh. Field surveys were conducted using the point count method across agricultural fields, human settlements, rivers, and wetlands between April and May 2022. A total of 52 bird species, spanning 47 genera, 28 families, and 13 orders, were recorded. Passeriformes emerged as the dominant order, while Ardeidae and Sturnidae were the most represented families. The overall bird density was ~12 individuals per ha, with the highest density in human habitats and the lowest in agricultural fields, indicating the influence of habitat heterogeneity on avian abundance. Diversity and richness indices were highest in river habitats and lowest in wetlands, underscoring the importance of habitat mosaics for supporting avian communities. Six foraging guilds were identified, with omnivores (51%) and insectivores (19%) being the most prevalent, reflecting birds' adaptability to diverse food resources in agroecosystems. The presence of two 'Vulnerable' species—the Sarus crane *Antigone antigone* and the Lesser adjutant *Leptoptilos javanicus*—and one 'Near Threatened' species highlight the conservation value of these agricultural landscapes. The findings highlight the importance of considering agroecosystems in broader conservation strategies and emphasize the need for continued monitoring to protect vulnerable bird species in these dynamic environments.

Keywords: Birds, conservation, density, feeding guilds, insectivorous, point count, richness, status, vulnerable, wetlands.

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Author details: Fatima Khan completed her post-graduation from the Department of Wildlife Sciences at Aligarh Muslim University. Dr. Kaleem Ahmed serves as a faculty member in the Department of Wildlife Sciences at Aligarh Muslim University. His research interests cover multiple dimensions of wildlife ecology, with particular emphasis on leopard ecology in human–wildlife conflict areas of western Uttar Pradesh and the effects of heat stress on birds through the application of remote sensing and GIS techniques. He is also involved in research focusing on avian ecology in the Himalayan region.

Author contribution: FK: field work, first manuscript draft. KA: conceptualization, supervision, evaluation, editing and proof reading

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INTRODUCTION

India is home to many habitats and ecosystems, with a rich diversity of plants and animals. The agricultural frontier has rapidly expanded due to the growth of human populations (Velásquez et al. 2021) and one of the most frequent land-use changes has been the conversion of natural ecosystems to agricultural fields (Barral et al. 2015). Agricultural areas cover nearly 37% of the terrestrial surface of Earth, and provide many ecosystem services and is influenced by anthropogenic activities and natural cycles (FAO 2025).

Birds are key indicators of environmental conditions and are pivotal in conserving threatened vertebrates (Ikin et al. 2016). Birds are versatile in their ecological adaptations and respond swiftly to habitat changes. They are easily monitored and play crucial ecological roles such as seed dispersal, pest control, and pollination (Wenny et al. 2011). Agricultural landscapes provide a focused and predictable supply of bird food (Kumar & Sahu 2020). This food includes seeds, grains, fruits, grasses, weeds, arthropods, and rodents (Asokan et al. 2009).

Agriculturists benefit from birds as natural pest control agents, consuming harmful insects and pests within the agroecosystem (Dhindsa & Saini 1994; Bianchi et al. 2006; Asokan et al. 2010; Narayana et al. 2019). Although agriculture covers approximately 60.45% of the total land area (Anonymous 2021a), conservation efforts are concentrated on natural forests or protected areas, despite the global protected area coverage being only 15.40% (Anonymous 2021b). Agricultural ornithology studies in India have been limited, with a major focus on vulnerable species (Mukherjee et al. 2002). There is a growing shift towards conservation outside protected areas, acknowledging the significant impact of agricultural landscapes on bird habitats, as explored in research addressing habitat loss, fragmentation, and avifauna changes (Brock & Jarman 2000; Mac Nally et al. 2000; Woinarski et al. 2000).

Although less than 1% of the world's bird species are primarily associated with agricultural habitats, nearly one-third of all bird species use these landscapes at least occasionally (Sekercioglu et al. 2007). Such species play a crucial role in agroecosystems by providing key ecosystem services, including pest control, pollination, seed dispersal, and nutrient deposition (Sekercioglu 2006). Therefore, documenting and monitoring species assemblages in agroecosystems are essential for understanding birds' habitat and resource use in providing ecosystem services. This will also help in understanding of the changes in bird ecosystem services and ecological function in agricultural areas as a result of the declines or increases in predators, seed dispersers, pollinators, and other avian functional groups (Sekercioglu 2012).

Bird diversity in agricultural areas has been studied by many authors in different parts of India: Assam (Ahmed & Dey 2014; Gogoi et al. 2023), Chhattisgarh (Yashmita-Ulman et al. 2017), Haryana (Kiran et al. 2022; Kumar & Sahu 2020), Karnataka (Basavarajappa 2006; Athreya et al. 2010), Maharashtra (Abdar 2014), Punjab (Malhi 2006; Kler & Manoj 2015; Kaur & Sidhu 2022; Kler et al. 2022), Tamil Nadu (Jayasimhan & Padmanabhan 2019), Telangana (Narayana et al. 2019), and West Bengal (Hossain & Aditya 2016). Several studies have also been conducted in Uttar Pradesh agroecosystems (Iqubal et al. 2003; Sundar 2006; Sundar & Kittur 2012); few studies have focused on eastern Uttar Pradesh (Yashmita-Ulman & Singh 2021). It is hypothesized that the heterogeneous agricultural habitats of the Terai region support a high diversity of avifauna with distinct foraging guild structures, and that variations in crop composition, vegetation cover, and resource availability influence species composition and distribution within the agroecosystem. The present study addresses this gap by documenting species composition, diversity patterns, and foraging guild structure of avifauna in the Nautanwa agricultural landscape of Maharajganj District, Uttar Pradesh, thereby highlighting the ecological importance of Terai agroecosystems.

Study area

The town of Nautanwa, situated in the Maharajganj district of Uttar Pradesh, India, with geographical coordinates of around 27.424° N and 83.427° E (Figure 1). Nestled in the Terai region at the foothills of the Shivalik Himalaya, it has an average elevation of 89 m.

The study site consists of approximately 259 villages (Census of India 2011). The region experiences an oppressive, partly cloudy wet season and a mostly clear, hot dry season, with annual temperatures typically ranging 11–37 °C, and rare extremes below 8 °C or above 41 °C (Weather Spark 2024). The Danda Stream and Rohini River serve as the main water sources (Central Ground Water Board 2013). Agriculturally, Nautanwa follows the cultivation of Kharif and Rabi crops. The town hosts a variety of tree species, including Ashoka *Saraca asoca*, Neem *Azadirachta indica*, Shisham *Dalbergia sissoo*, Peepal *Ficus religiosa*, Burflower *Neolamarckia cadamba*, Banyan *Ficus benghalensis*, Eucalyptus *Eucalyptus grandis*, and Babool *Vachellia nilotica*. The fauna includes Indian Grey Mongoose *Urva edwardsii*, Asian Palm Civet *Paradoxurus hermaphroditu*, Golden Jackal *Canis aureus*, and Indian Fox *Vulpes bengalensis* (Fatima Khan pers. obs. 2022).

METHODS

Sampling sites were strategically selected across the diverse study area, including agriculture, human habitats, rivers, and wetlands. Bird surveys were conducted using point-count method (Ahmed 2010) from April to May 2022. Point count surveys were conducted by establishing an imaginary circular plot, with the observer positioned at the center. The observer recorded all detections in every direction for a fixed duration of 10 minutes (Persulessy & Putuhena 2020). During the survey, birds were sampled by monitoring 50 permanently established points. Each point was surveyed twice, resulting in a total sampling effort of 100 point counts. Surveys were conducted in the morning hours (0600–1030 h). The birds were recorded in a 50-m radius from the point count to cover maximum species in the data set and points were at least 200 m apart to avoid repetitive counting of the same individual multiple times (Ahmed et al. 2023). At every point count, a five minutes settling down time was given before recording the birds (Yashmita-Ulman & Singh 2021). On sighting the birds, the species name, number of individuals and habitat was recorded. Data on species presence on ground, stem, outer, middle or top canopy was also recorded (Ahmed 2010). Birds flying across were not counted. The opportunistic counts during the other time of the day were also included in the final checklist of birds to ensure a more comprehensive documentation of avifaunal diversity; however, these records were excluded from point count-based indices and statistical analysis. Field guides (Ali & Ripley 1987; Grimmett et al. 2011) were used for bird identification. The bird checklist was compiled following Praveen & Jayapal (2025). The species were also classified into major feeding guilds, i.e., insectivorous (I), carnivorous (C), granivorous (G), frugivorous (F), nectarivores (N), and omnivorous (O).

Analysis

Shannon-Wiener Index (H') was used for diversity and Margalef's Index (RI) for richness computations. The program DISTANCE (Thomas et al. 2010) was used to compare models, assess goodness-of-fit and determine estimates of bird density for the study period.

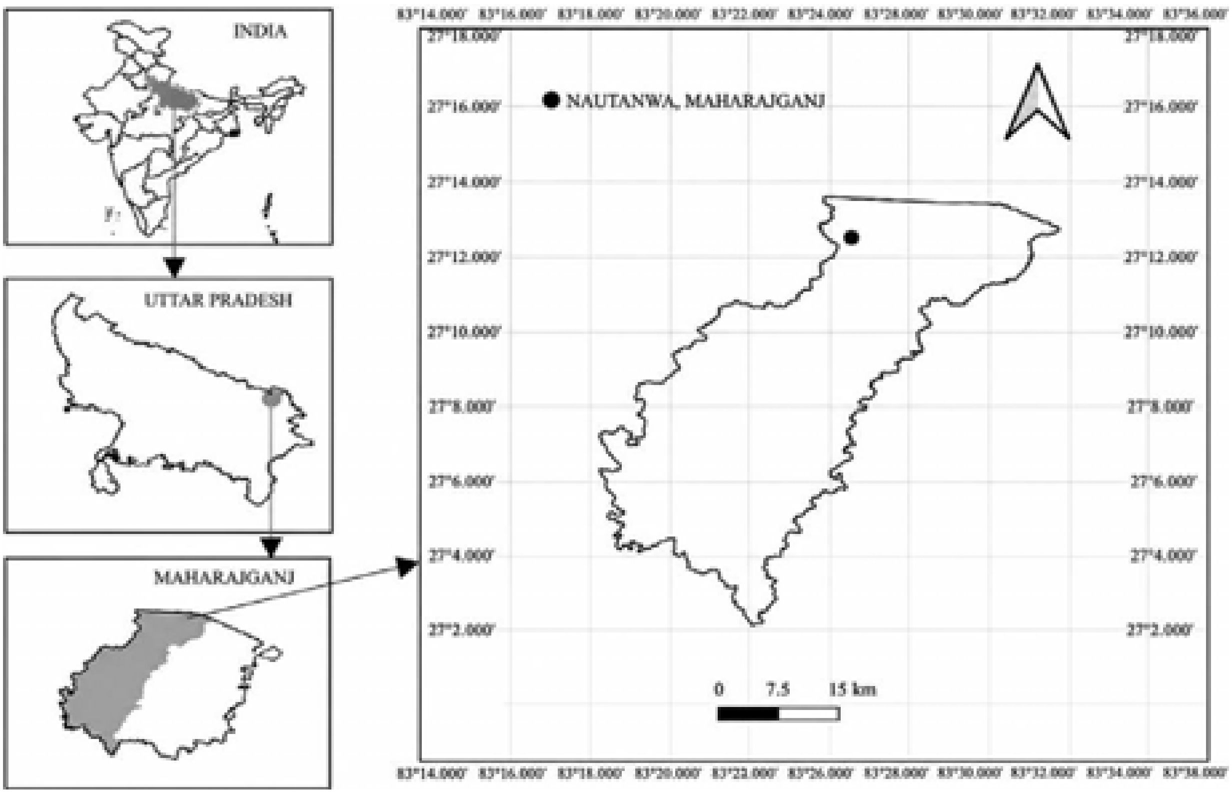

Figure 1. Map of study area of Nautanwa, Maharajganj, India.

The different models were compared using Akaike's information criteria (Anderson et al. 1998). A matrix was formed of bird species and their mean perch height and horizontal distance from trunk for each species. This data set was used to generate guilds. Single linkage cluster diagrams were generated using its nearest-neighbour method through statistical software BioDiversity Pro (McAleece et al. 1997).

RESULTS

The study recorded 52 bird species from the study area, representing 47 genera, 28 families, and 13 orders (Table 1). Among the recorded species, two were categorised as 'Vulnerable' (VU), one as 'Near Threatened' (NT), and the majority (49 species) were classified as 'Least Concern' (LC) on the IUCN Red List. Additionally, six species identified in the study are listed in Appendix II of the Convention on International Trade of Endangered Species (CITES), and 12 belong to Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS).

Bird density

Overall bird density in the study area was recorded as 11.74 ± 0.73 individuals per ha, with an average cluster size of 2.83 ± 2.65. The effective strip width (EDR) for bird observations was found to be 38.01 ± 1.79 (Table 2). Notably, bird density varied across different habitats, with the highest density observed in human habitats (16.43 ± 1.42) and the lowest in agricultural fields (9.68 ± 0.73). This difference in bird densities among habitats was significant ($t = 7.52$, $p < 0.005$).

Passeriformes was found to be the dominant order, encompassing 12 families and 22 species, followed by Pelecaniformes with one family and five species, while Strigiformes and Bucerotiformes are the least prevalent orders, each represented by one family and one species; the observed variation in order percentages in the study area was found to be significant ($t = 2.61$, $df = 12$, $p < 0.05$) (Table 3).

Among the 28 families recorded, Ardeidae and Sturnidae were identified as dominant, each with four species. This observed difference in dominance between these two families was found to be significant ($t = 10.55$, $df = 27$, $p < 0.05$) (Table 3).

Species diversity and richness

The study site's overall avian diversity and richness were found to be 4.39 and 13.74, respectively. Among diverse habitats, the river habitat showed the highest species richness (16.25) and diversity (4.13), while the wetland exhibited the lowest values (Figure 2). Analyzing various avian orders, Passeriformes demonstrated the highest species richness (27.12) and diversity (4.95), whereas Bucerotiformes exhibited the lowest (Figure 3). At the family level, Corvidae showed the highest species richness (10.79) and diversity (3.84), with the lowest values found in the family Strigidae (Figure 4).

Guild structure

Six foraging guilds were identified in the study site, with omnivores (O) being the most represented (27 species, 51%), followed by insectivores (I) (10 species, 19%), and nectarivores (N) being the least represented (one species, 1%) (Figure 5). A cluster analysis categorised the species into three distinct clusters (Figure 6).

Cluster 1 comprises species that typically forage on the ground, including, Little Egret *Egretta garzetta*, Cattle egret *Bubulcus ibis,* Red-wattled Lapwing *Vanellus indicus*, and White-breasted Waterhen *Amaurornis phoenicurus*. Cluster 2 includes species that share habitats characterised by open country in the plains with trees, wires, or other perches. Birds that belong to this cluster includes the House Crow *Corvus splendens*, Large-billed Crow *Corvus macrorhynchos*, Jungle Babbler *Argya striata*, Black Drongo *Dicrurus macrocercus*, Indian Pond Heron *Ardeola grayii*, and White-throated Kingfisher *Halcyon smyrnensis*. Cluster 3 consists of species that share the same stratum, whether found on the lower, middle, or top levels. This cluster includes Common Myna *Acridotheres tristis*, Bank Myna *Acridotheres ginginianus*, and Red-whiskered Bulbul *Pycnonotus jocosus*. Black Kite predominantly occupies the top canopy, mostly flying, even feeding on prey while airborne.

DISCUSSION

The present study offers a detailed assessment of avifaunal diversity in the Nautanwa agricultural landscape of Maharajganj District, Uttar Pradesh, and contributes baseline data for understanding the ecological role of agroecosystem in supporting bird communities. The documentation of 52 bird species, spanning 47 genera, 28 families, and 13 orders, with Passeriformes as the dominant order, highlights the ecological richness and complexity of this agroecosystem. In line with the broader trend in India, Passeriformes emerged as the most dominant order (Praveen et al. 2016). This order

Table 1. Checklist of bird species along with their conservation status recorded in the study area.

	Order	Family	Common name	Scientific name	Red List	CITES	CMS	Feeding guild
1	Columbiformes	Columbidae	Rock Pigeon	*Columba livia*	LC			G
2		Columbidae	Laughing Dove	*Streptopelia senegalensis*	LC			G
3		Columbidae	Spotted Dove	*Streptopelia chinensis*	LC			G
4	Cuculiformes	Cuculidae	Greater Coucal	*Centropus sinensis*	LC			O
5		Cuculidae	Asian Koel	*Eudynamys scolopaceus*	LC			F
6	Gruiformes	Rallidae	Common Moorhen	*Gallinula chloropus*	LC			O
7		Rallidae	White-Breasted Waterhen	*Amaurornis phoenicurus*	LC			O
8		Rallidae	Grey-headed Swamphen	*Porphyrio poliocephalus*	LC			O
9		Gruidae	Sarus Crane	*Antigone antigone*	VU	II	II	O
10	Charadriiformes	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	LC		II	O
11		Jacanidae	Bronze-winged Jacana	*Metopidius indicus*	LC			O
12		Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	LC		II	O
13	Ciconiiformes	Ciconiidae	Asian Openbill	*Anastomus oscitans*	LC			O
14		Ciconiidae	Lesser Adjutant	*Leptotilos javanicus*	VU			O
15	Suliformes	Phalacrocoracidae	Little Cormorant	*Microcarbo niger*	LC			O
16		Phalacrocoracidae	Indian Cormorant	*Phalacrocorax fuscicollis*	LC			O
17	Pelecaniformes	Ardeidae	Intermediate Egret	*Ardea intermedia*	LC			O
18		Ardeidae	Little Egret	*Egretta garzetta*	LC			O
19		Ardeidae	Eastern Cattle-Egret	*Ardea coromanda*	LC			O
20		Ardeidae	Indian Pond-Heron	*Ardeola grayii*	LC			O
21		Threskiornithidae	Red-naped Ibis	*Pseudibis papillosa*	LC			O
22	Accipitriformes	Accipitridae	Black-winged Kite	*Elanus caeruleus*	LC	II	II	C
23		Accipitridae	Black Kite	*Milvus migrans*	LC	II	II	C
24	Strigiformes	Strigidae	Spotted Owlet	*Athene brama*	LC	II		C
25	Bucerotiformes	Upupidae	Eurasian Hoopoe	*Upupa epops*	LC			O
26	Coraciiformes	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	LC			O
27		Alcedinidae	Pied Kingfisher	*Ceryle rudis*	LC			O
28		Meropidae	Asean Green Bee-eater	*Merops orientalis*	LC			I
29	Psittaciformes	Psittaculidae	Alexandrine Parakeet	*Psittacula eupatria*	NT	II		G
30		Psittaculidae	Rose-ringed Parakeet	*Psittacula krameri*	LC			G
31	Passeriformes	Dicruridae	Black Drongo	*Dicrurus macrocercus*	LC			I
32		Corvidae	Rufous Treepie	*Dendrocitta vagabunda*	LC			F
33		Corvidae	House Crow	*Corvus splendens*	LC			O
34		Corvidae	Large-billed Crow	*Corvus macrorhynchos*	LC			O
35		Cisticolidae	Ashy Prinia	*Prinia socialis*	LC	II		I
36		Cisticolidae	Zitting Cisticola	*Cisticola juncidis*	LC		II	I
37		Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	LC		II	I
38		Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	LC			F
39		Pycnonotidae	Red-whiskered Bulbul	*Pycnonotus jocosus*	LC			F
40		Leiothrichidae	Jungle Babbler	*Argya striata*	LC		II	I
41		Sturnidae	Indian Pied Starling	*Gracupica contra*	LC			O
42		Sturnidae	Brahminy Starling	*Sturnia pagodarum*	LC			O
43		Sturnidae	Common Myna	*Acridotheres tristis*	LC			O

	Order	Family	Common name	Scientific name	Red List	CITES	CMS	Feeding guild
44		Sturnidae	Bank Myna	*Acridotheres ginginianus*	LC			O
45		Muscicapidae	Oriental Magpie-Robin	*Copsychus saularis*	LC		II	I
46		Muscicapidae	Brown Rock Chat	*Oenanthe fusca*	LC		II	I
47		Nectariniidae	Purple Sunbird	*Cinnyris asiaticus*	LC			N
48		Estrildidae	Red Munia	*Amandav aamandava*	LC			G
49		Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	LC			G
50		Passeridae	House Sparrow	*Passer domesticus*	LC			G
51		Motacillidae	White-browed Wagtail	*Motacilla maderaspatensis*	LC		II	I
52		Motacillidae	Paddyfield Pipit	*Anthus rufulus*	LC		II	I

LC—Least Concern | NT—Near Threatened | VU—Vulnerable | C—Carnivorous | F—Frugivorous | G—Granivorous | I—Insectivorous | O—Omnivorous | N—Nectarivorous | CITES—Convention on International Trade in Endangered Species of Wild Fauna and Flora | CMS—Convention on the Conservation of Migratory Species of Wild Animals.

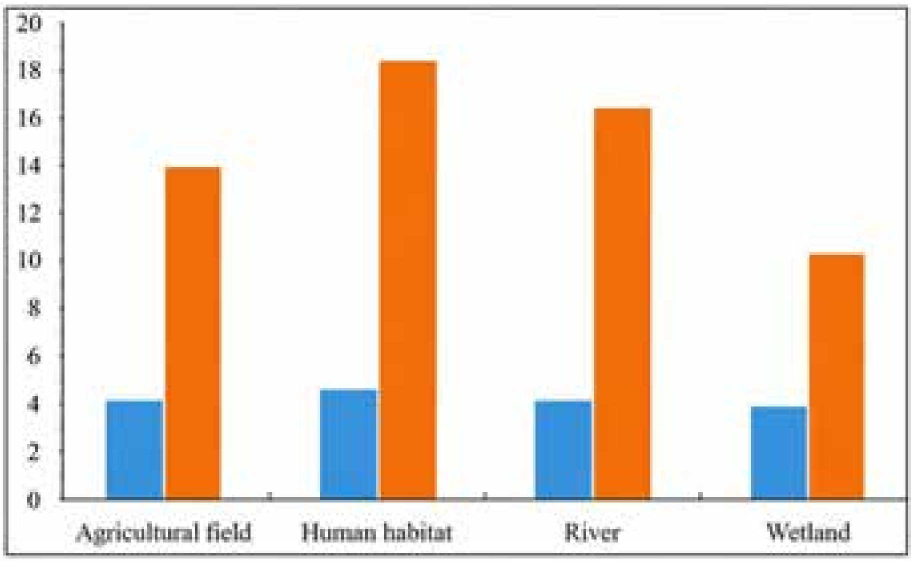

Figure 2. Habitat-wise diversity and richness of birds found in the study area.

was observed to be the most dominant in the study area, represented by 11 families. The dominance of Passeriformes is also consistent with findings from other Indian agricultural landscapes, such as those reported by Kumar & Sahu (2020) in Haryana and Hossain & Aditya (2016) in West Bengal, where Passeriformes also represented the largest proportion of the avifaunal community.

From the overall bird density, the highest density was found in human habitats and the lowest in agricultural fields which highlights the influence of habitat heterogeneity and human-modified environments on avian abundance. This pattern is in line with studies by Mukhopadhyay & Mazumdar (2017) and Chaube et al. (2018), who found that areas with greater structural complexity, such as those near human settlements or with a mix of trees, water bodies, and open fields, tend to support higher bird densities. Such habitat diversity in this area is crucial in supporting relatively high species richness (Mukhopadhyay & Mazumdar 2017). The relatively lower density in agricultural fields may be attributed to intensive farming practices, reduced vegetation cover, and limited availability of nesting and foraging sites, as also observed by Power (2010) and Barral et al. (2015) in agroecosystem studies.

The diversity (4.39) and richness (13.74) values observed in this study are comparable to those reported in other Indian agricultural and semi-urban landscapes, such as the Banda University of Agriculture and Technology Campus (Singh et al. 2018) and Haiderpur

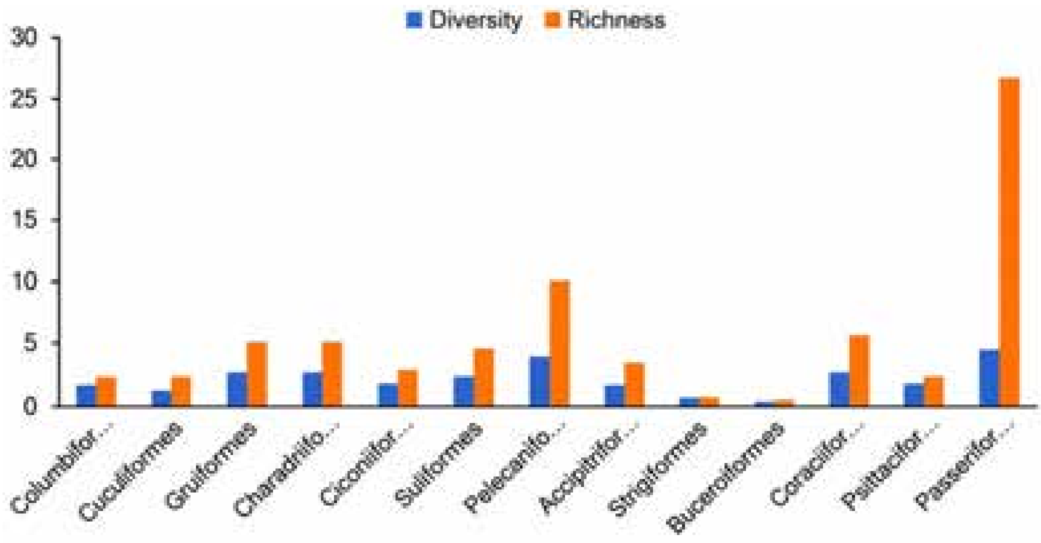

Figure 3. Diversity and richness of different orders found in the study area.

Table 2. Variation of bird density (D/ha), effective strip width (EDR), and average cluster size A(S) across different habitats.

Habitat	DS ± SE	95% CL	EDR ± SE	95% CL	A(S) ± SE	95% CL
Human habitat	16.43 ± 1.42	15.94–16.98	30.72 ± 6.27	27.14–34.79	7.09 ± 0.79	6.3–7.88
River	11.09 ± 1.31	10.51–11.67	45.19 ± 3.68	38.48–53.08	1.60 ± 0.56	0.81–3.17
Agricultural field	9.68 ± 0.73	1.52–20.88	36.27 ± 1.67	33.07–39.77	3.28 ± 0.40	2.50–4.19
Wetland	10.03 ± 1.64	8.45–11.61	4.81 ± 1.61	41.72–48.12	2.38 ± 0.76	1.27–4.47
Overall	11.74 ± 0.73	11.01–12.47	38.01 ± 1.79	34.65–41.70	2.83 ± 2.65	0.18–5.48

Wetland (Joshi et al. 2021). The highest species richness and diversity in river habitats, and the lowest in wetlands, further emphasize the importance of maintaining a mosaic of habitat types within the agroecosystem. This is attributed to the presence of water and strategically planted patch trees along the bounds, exerting a positive influence on bird diversity. The ecosystem's health is underscored by factors such as local abundance of food resources, appropriate water levels, and a well-structured habitat (Saygili et al. 2011). Wetland factors such as water level, size, habitat changes, and plant species also shape the diversity and richness of birds in this environment (Woldemariam et al. 2018).

The identification of six foraging guilds, with omnivores being the most represented (51%), followed by insectivores (19%), reflects the adaptability of birds to the diverse food resources available in agroecosystems. This is consistent with studies by Mukhopadhyay & Mazumdar (2017) who also found omnivorous and insectivorous birds to dominate in agricultural and suburban landscapes. The prevalence of omnivores suggests that these birds can exploit a wide range of food sources, including seeds, grains, insects, and anthropogenic waste, which may be abundant in agricultural and human-modified habitats. Insectivorous birds, on the other hand, play a crucial role in natural pest control, as highlighted by Asokan et al. (2009, 2010) and Bianchi et al. (2006), who documented the ecosystem service value of birds in regulating insect populations in crop fields. Black Kite *Milvus migrans* and House Sparrow *Passer domesticus* did not group into any cluster and were identified as outliers due to their unique foraging behaviour.

The finding of two VU species, the Sarus Crane *Antigone antigone* and Lesser Adjutant *Leptoptilos javanicus*, as well as one NT species, highlights the conservation value of the agroecosystem. This finding is supported by Mukherjee et al. (2002) and Sundar & Subramanya (2010), who emphasized the importance of rice fields and agricultural habitats for the survival of threatened waterbirds in India. The presence of species listed in CITES and CMS appendices further highlights the international conservation relevance of these habitats. These findings highlight the significance

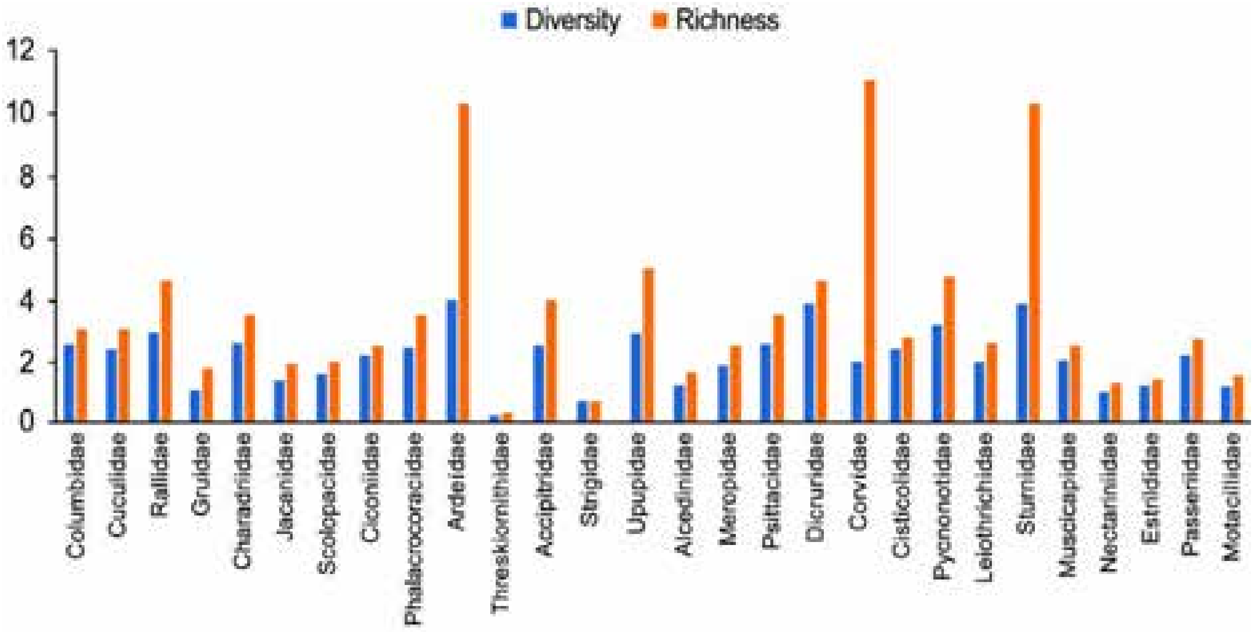

Figure 4. Diversity and richness of different families found in the study area.

Table 3. Percentage of orders and families of birds recorded from the study area.

	Order	%	Family	%
1	Columbiformes	5.76	Columbidae	5.76
2	Cuculiformes	3.84	Cuculidae	3.84
3	Gruiformes	7.69	Rallidae	5.76
4			Gruidae	1.92
5	Charadriiformes	5.76	Charadriidae	1.92
6			Jacanidae	1.92
7			Scolopacidae	1.92
8	Ciconiiformes	3.84	Ciconiidae	3.84
9	Suliformes	3.84	Phalacrocoracidae	3.84
10	Pelecaniformes	9.61	Ardeidae	7.69
11			Threskiornithidae	1.92
12	Accipitriformes	3.84	Accipitridae	3.84
13	Strigiformes	1.92	Strigidae	1.92
14	Bucerotiformes	1.92	Upupidae	1.92
15	Coraciiformes	5.76	Alcedinidae	3.84
16			Meropidae	1.92
17	Psittaciformes	3.84	Psittacidae	3.84
18	Passeriformes	42.3	Dicruridae	1.92
19			Corvidae	5.76
20			Cisticolidae	5.76
21			Pycnonotidae	3.84
22			Leiothrichidae	1.92
23			Sturnidae	7.69
24			Muscicapidae	3.84
25			Nectariniidae	1.92
26			Estrildidae	3.84
27			Passeridae	1.92
28			Motacillidae	3.84

of continuous monitoring efforts and further research to comprehensively understand and address the dynamic interactions within bird populations in the region for formulating effective conservation strategies.

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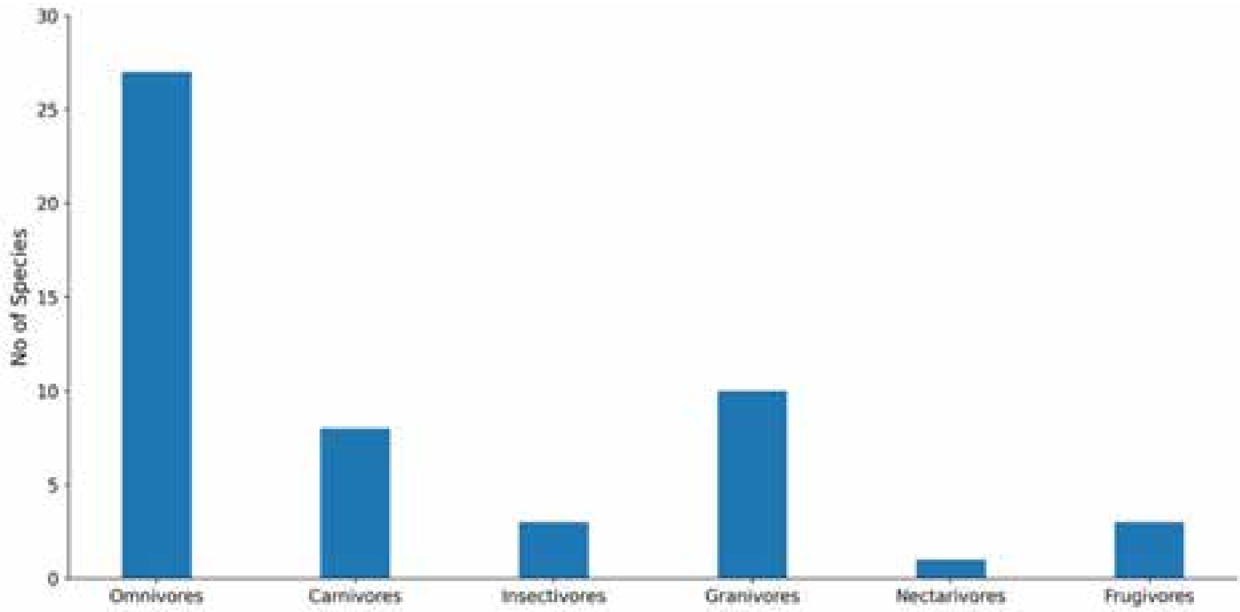

Figure 5. Number of bird species recorded under different feeding guilds in the study area.

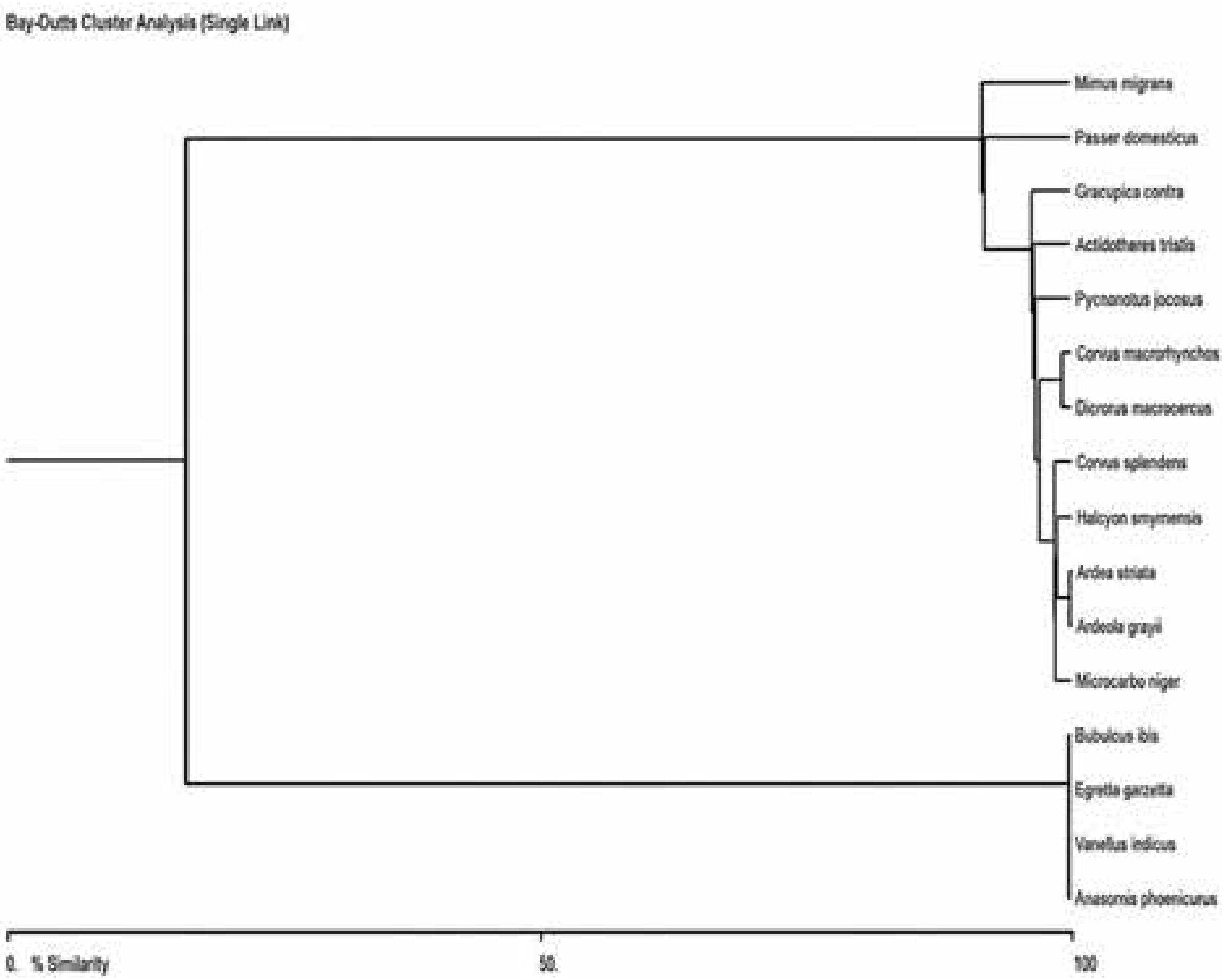

Figure 6. Cluster of birds based on feeding niche in the study area.

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COMMUNICATION

First record of the Sistan Sand Boa *Eryx sistanensis* Eskandarzadeh et al., 2020 (Reptilia: Serpentes: Erycidae) from India

Vivek Sharma [1] & Dharmendra Khandal [2]

[1] 393, Sanjeevni Nagar, Jabalpur, Madhya Pradesh 482003, India.
[2] Tiger Watch, Dhonk Farm, Ranthambhore Road, Sawai Madhopur, Rajasthan 322001, India.
[1] vrks1007@gmail.com (corresponding author), [2] dharmkhandal@gmail.com

Abstract: We report the presence of Sistan sand boa *Eryx sistanensis*, a species known from Iran and Pakistan, from northern parts of Thar desert of northwestern India by presenting detailed diagnosis of three live individuals from Rajasthan. Data obtained from the Indian individuals offers moderately updated definition of *E. sistanensis* and helps distinguishing it more effectively from its look-alike, *Eryx johnii* by comparing their morphology in life. Additionally, based on our past findings and sightings posted in social media and from wildlife colleagues from our network, we hint its wider presence in the low rainfall areas of three states of northwestern India, including Haryana and Punjab, apart from Rajasthan.

Keywords: *Eryx johnii*, farmlands, morphology, Pakistan, Rajasthan, sandy plains, trade, Thar Desert.

सार: हम उत्तर-पश्चिमी भारत के थार मरुस्थल के उत्तरी राजस्थान के भागों से सिस्तान सैंड बोआ *एरिक्स सिस्तानेंसिस* प्रजाति की उपस्थिति विस्तृत विवरण के साथ प्रस्तुत कर रहे हैं जो अब तक ईरान एवं पाकिस्तान से ज्ञात थी। भारत से प्राप्त साँपों के अवलोकन *एरिक्स सिस्तानेंसिस* की पहचान को अधिक स्पष्ट करते हैं जो जीवित अवस्था में इससे मिलती-जुलती दिखने वाली प्रजाति रैड सैंड बोआ *एरिक्स जोह्नी* की पहचान से अंतर करने में सहायता करते हैं। इसके अतिरिक्त, हमारे पूर्व अवलोकनों, सोशल मीडिया में उपलब्ध अवलोकनों एवं वन्यजीवों पर कार्यरत सहयोगियों से प्राप्त सूचनाओं आधार पर हम उत्तर-पश्चिमी भारत के कम वर्षा वाले तीन राज्यों में इस प्रजाति की व्यापक उपस्थिति का संकेत देते हैं जिनमें राजस्थान के अतिरिक्त हरियाणा एवं पंजाब सम्मिलित हैं।

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Author details: Vivek Sharma is a freelance conservation biologist working on snakes and snakebite matters of India. He is co-founder of Indiansnakes and founder of Snakehub mobile app. He serves as data gatherer and admin of both platforms. His prime interest is taxonomy, natural history and distribution of snakes of India. Dr. Dharmendra Khandal has been working with Tiger Watch since 2003 and has served as executive director since 2011. A conservation biologist, his work spans anti-poaching, wildlife monitoring, research, and community-based conservation in Ranthambhore and beyond.

Author contribution: VS: conducted fieldwork, gathered taxonomic data, conceptualized and wrote manuscript. DK: collected initial data of species, conducted fieldwork with VS to examine latest specimens, participated in designing manuscript.

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INTRODUCTION

The boid snake genus *Eryx* Daudin, 1803, comprises a group of short and robust-bodied boas of burrowing habits. The known geographic expansion of this genus is from Indian subcontinent, Middle East, southeastern Europe to northern Africa (Whitaker & Captain 2004; Pyron et al. 2014). Since the description of *Eryx whitakeri* Das, 1991, the number of *Eryx* species in India has remained unchanged at three (Whitaker & Captain 2004). The other two species, *Eryx conicus* (Schneider, 1801) and *Eryx johnii* (Russell, 1801), are widespread in the Indian subcontinent, whereas *E. whitakeri* is endemic to the western coastal versant of the Western Ghats (Whitaker & Captain 2004).

The Sistan Sand Boa *Eryx sistanensis* Eskandarzadeh, Rastegar-Pouyani, Rastegar-Pouyani, Zargan, Hajinourmohamadi, Nazarov, Sami, Rajabizadeh, Nabizadeh & Navaian, 2020 was described from Sistan in Balochistan Province of Iran (Eskandarzadeh et al. 2020). Prior to its formal description, although distinguishable based on colour and patterns, it remained taxonomically overlooked or misinterpreted for more than a century. The taxon was either considered *E. johnii* or treated as a regional morph in its western range due to similarities in head, body, and tail type as well as overlapping pholidosis, which likely offered less motivation for further work on it (Wall 1911; Minton 1966). Alternatively, it was classified and treated as a subspecies, *Eryx johnii persicus* Nikolsky, 1907 (see Stull 1935; Constable 1949; Biswas & Sanyal 1977). Subsequent studies (Tokar 1991; Ananjeva in Wagner et al. 2016) re-evaluated its taxonomic status and confirmed *E. persicus* as a junior synonym of *Eryx jaculus* (Linnaeus, 1758), with no taxonomic affinity to *E. johnii*. This arrangement of *E. persicus* provided the basis for Eskandarzadeh et al. (2020) to revise the western morph/population of *E. johnii* with a new approach and assign new name to this innominate population as, *E. sistanensis*.

Hussain et al. (2024) recently reported *E. sistanensis* from multiple localities from the Cholistan Desert, a northwestern extension of the Thar Desert in Pakistan. The present study builds on the existing literature and confirms the presence of *E. sistanensis* in the Indian Thar Desert, representing first confirmed record from India.

MATERIAL AND METHODS

This study is based on live individuals of the Sistan Sand Boa *E. sistanensis* that were documented in Ramgarh-Shekhawati Tehsil of Sikar District, Rajasthan. Additionally, we revisited past uncollected sightings of *E. sistanensis* from our own and colleague's collections to get further information on distribution of this species in India. Also, morphological data of uncollected live and road-killed individuals of *E. johnii*, mainly from Rajasthan (Ajmer, Jaipur, Jodhpur, Kota, and Phalodi), Madhya Pradesh (Jabalpur) and from Tamil Nadu (Madurai, 250 km south west off the type locality Tranquebar, now Tharangambadi) was gathered to compare these two species in live or freshly dead states.

No live individual was harmed or kept in long captivity for study, and no road-killed individual was collected for preservation. All individuals were photographed with the help of DSLR cameras; mounted with macro lenses. Body and tail length were measured with the help of unstretchable thread and measuring tape, whereas other body characters were measured with the help of Mitutoyo digital caliper with the accuracy of 0.1 mm. Eleven meristic and seven morphometric characters were documented which are presented in Table 1. Except last two, all characters and their definitions were taken from Eskandarzadeh et al. (2020) and their abbreviations are: SVL—Snout-ventral length, TaL—Tail length, TL—Total length, V—Ventrals, SC—Subcaudals, BE—Scales falling in shortest distance between eyes, SE—Scales around eyes, SL—Number of supralabials, PIN—Scales posterior to internasals, NE—Scales between eyes and nasals, IO—Interocular distance, EM—Distance between posterior edge of eye and corner of mouth, DH—Dorsal scale rows one head—length after head, DM—Dorsal scale rows at mid body, DP—Dorsal scale rows one head-length before anal, TR—Scale rows taken at the middle of tail, CB—Breadth of tail base at cloaca region, TB—Breadth of tail at the middle of tail. Head characters in which data is shown in pair, data from left side of head is written first.

RESULTS

Three live individuals of *Eryx sistanensis* were documented from the outskirts and farmlands of Ramgarh Shekhawati, viz., near Goshala (28.163° N, 74.957° E, 320 m) on 19 August 2025 at 2130 h inside cowshed, Sunda ki Dhani (28.131° N, 75.042° E, 334 m) on 12 September 2025 at 0930 h from a local boy who caught it from his courtyard and playing with it sometime before it was taken for safe release, and outskirts of Rukansar (28.142° N, 74.964° E, 324 m) on 21 September at 1230 h from brick pile of under construction house near farmland. All locations are situated in Ramgarh-Shekhawati Tehsil of

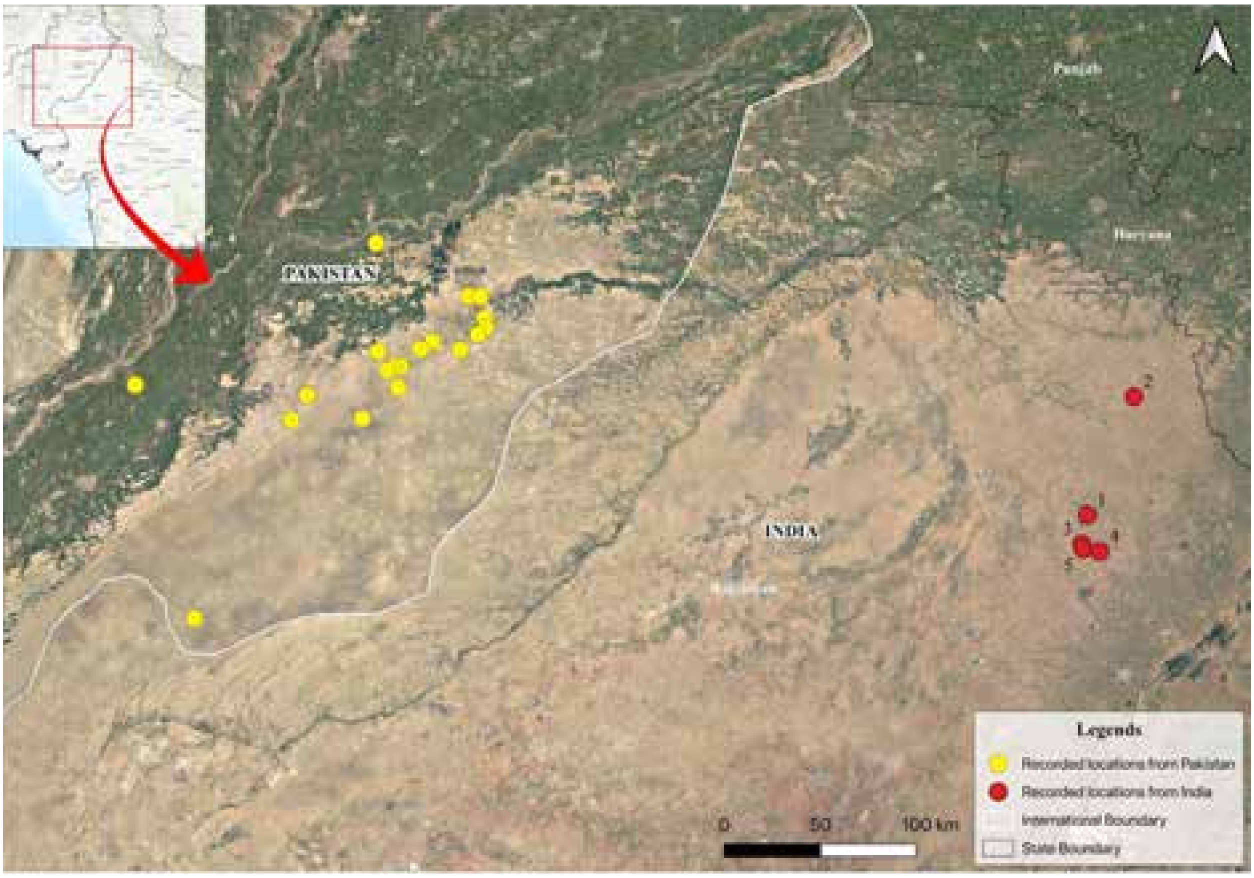

Image 1. Map of northwestern Indian subcontinent showing published and new records of *Eryx sistanensis* from Pakistan (yellow dots) and India (red dots) respectively. Indian localities in Rajasthan state are chronologically numbered: 1—Churu city outskirts (Churu District) | 2—Leelki Beed (Churu District) | 3—Outskirt of Ramgarh Shekhawati (Sikar District) | 4—Sunda ki Dhani, Ramgarh Shekhawati (Sikar District) | 5—Rukansar, Ramgarh Shekhawati (Sikar District).

Sikar District (Image 1), Rajasthan, India.

The Indian individuals (A–C in both Images 2 & 3) had the following morphological characteristics: Dorsal scales in 44–50 (neck): 52–57 (midbody): 34–38 (before tail) rows. Ventrals 187–197, subcaudals 30–31. The body was robust and cylindrical from the posterior of the head to starting of the tail, which gently tapered and terminated in an obtusely pointed tip made from large shield (Image 4). Dorsal scales were superficially subequal, although the first two rows bordering ventral scales were larger than the rows on the upper body. Upper dorsal rows were keeled, whereas the scales on the anterior part of the body were weakly keeled, and pronounced toward the posterior one-third of the body and tail. Dorsal body colour was buff in juvenile, whereas tan in subadult and adult. Both individuals, the juvenile and the adult, had distinct 14 and 15 sooty dorsal bands from neck to cloaca respectively, while the subadult had around six obscure and mutually fused bands on the posterior half of the body hence made posterior vertebral region of body obscurely striped with sooty colour. All individuals had various degrees of sooty edges on random scales, hence made the overall dorsal surface speckled with sooty colour on tan/buff ground colour. All individuals had distinct three or four bands (including band over cloaca region) on tail which were noticeably darker than body bands, with upper interspace orange/tangerine coloured. The underside was distinctly paler than dorsal surface, with pale colouration extending across nine or ten scale rows and could be seen from lateral view when individuals were resting on flat surface. The underside patterns were variable, juvenile exhibited predominantly creamy ventrals with minimal number of black patches; subadult showed moderate black mottling on sunset orange-colored ventrals of subadult; and adult displayed heavy black mottling on sunset orange ventrals and lower dorsal rows. The underside of the tail in juvenile and subadult was creamy white and patternless, resembling the lower dorsal rows; in adult, however, it was speckled with small black patches and appeared slightly lighter

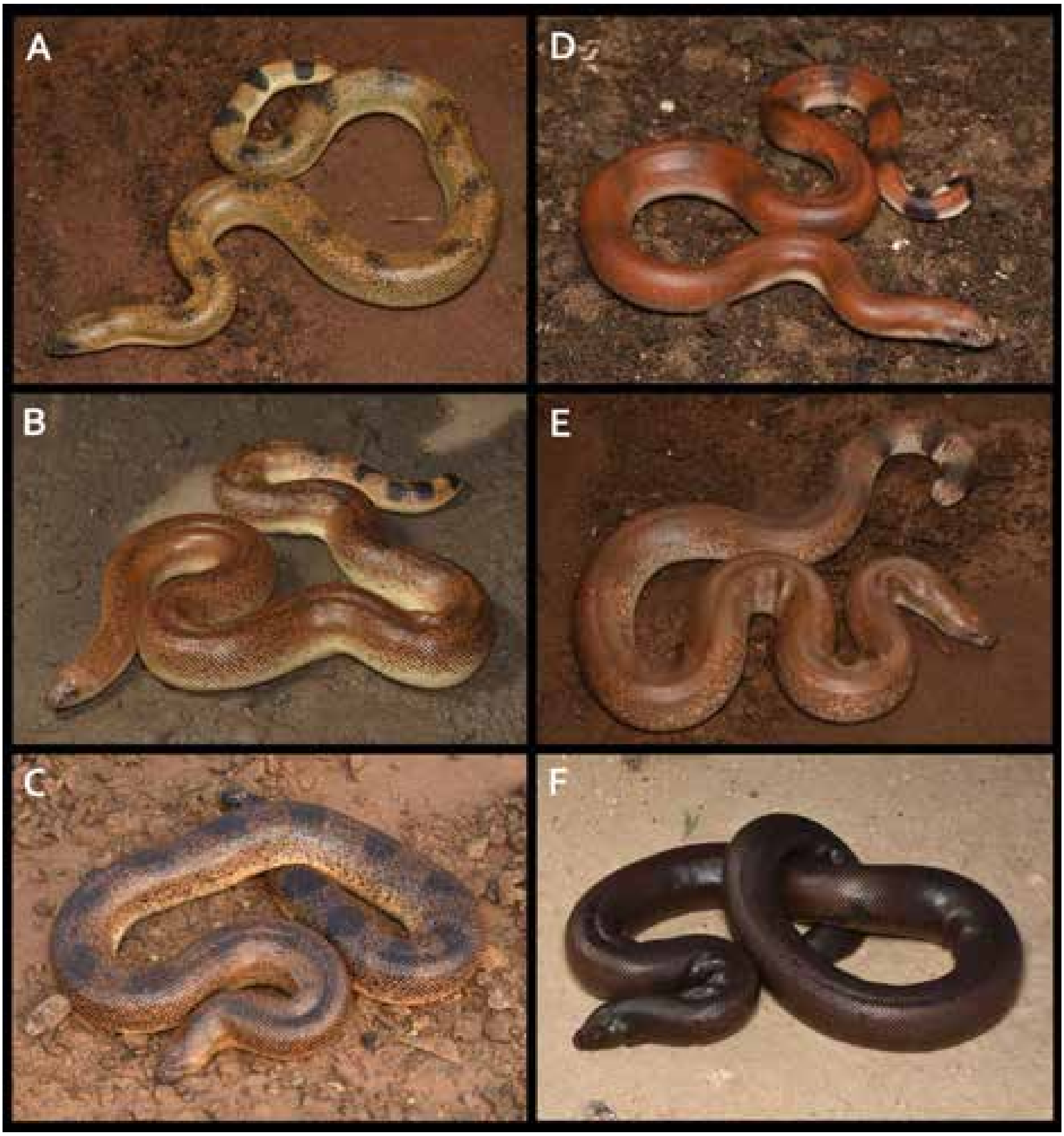

Image 2. Comparison of dorsal colour pattern of three different life stages of *Eryx sistanensis* (A–C): A—juvenile | B—subadult | C—adult, all from Sikar District. *Eryx johnii* (D–F): D—juvenile | E—subadult, both from Ajmer District | F—adult from Phalodi District. © Vivek Sharma.

than the ventral surface. Meristic and morphometric data is presented in Table 1.

In India, sightings of wild *E. sistanensis* were not from typical sand dune-laden part of Thar desert but from human-influenced desert lands like suburban gardens, farmlands and other plantations. The area has a mosaic of natural scrub patches, grasslands, crop fields, and fallow land. It is characterized by firm sandy plains rather than loose dunes, with soils that are often a mix of sand and loam. These northern districts of Rajasthan form an important connectivity corridor between desert fauna of Rajasthan and the plains of Punjab-Haryana. The sand here is relatively compact and retains slight moisture, creating suitable conditions for many burrowing species. The region is also a prey-rich environment, with a high density of rodents. Notably, populations of the Desert

Table 1. Comparison of live individuals of *Eryx sistanensis* from India with previous works.

Characters	Eskandarzadeh et al. 2020 (Iran)	Hussain et al. 2024 (Pakistan)	This study (India)		
			Juvenile	Subadult	Adult
SVL (in cm)	22.0–85.5	*	39.3	55.1	95.0
TaL (in cm)	3.0–8.5	*	4.9	6.8	9.0
TL (in cm)	25.0–94.0	*	44.2	61.9	104.0
V	190–201	191–200	187	189	197
SC	26–31	11–12**	30	31	30
BE	6–7	6–7	8	8	8
SE	10–12	9–11	10, 10	9, 10	10, 10
SL	11–12	11–12	10, 11	11, 11	11, 10
PIN	2	–	2	2	2
NE	3	–	3, 3	3, 3	3, 3
IO/EM	1.2–1.4	–	1.3	1.2	1.3
DH	43–51	–	44	48	50
DM	43–56	44–55	52	57	56
DP	38–45	–	34	38	36
TR	–	–	27	28	25
TB/CB	–	–	0.9	0.8	0.7

* Length data provided in table in cited work is mathematically suspicious. Also, there is no information on minimum and maximum lengths in studied specimens by those authors.
** Possibly erroneous range data or typing error because overall subcaudal range is unusually low in large sample size claimed by authors.

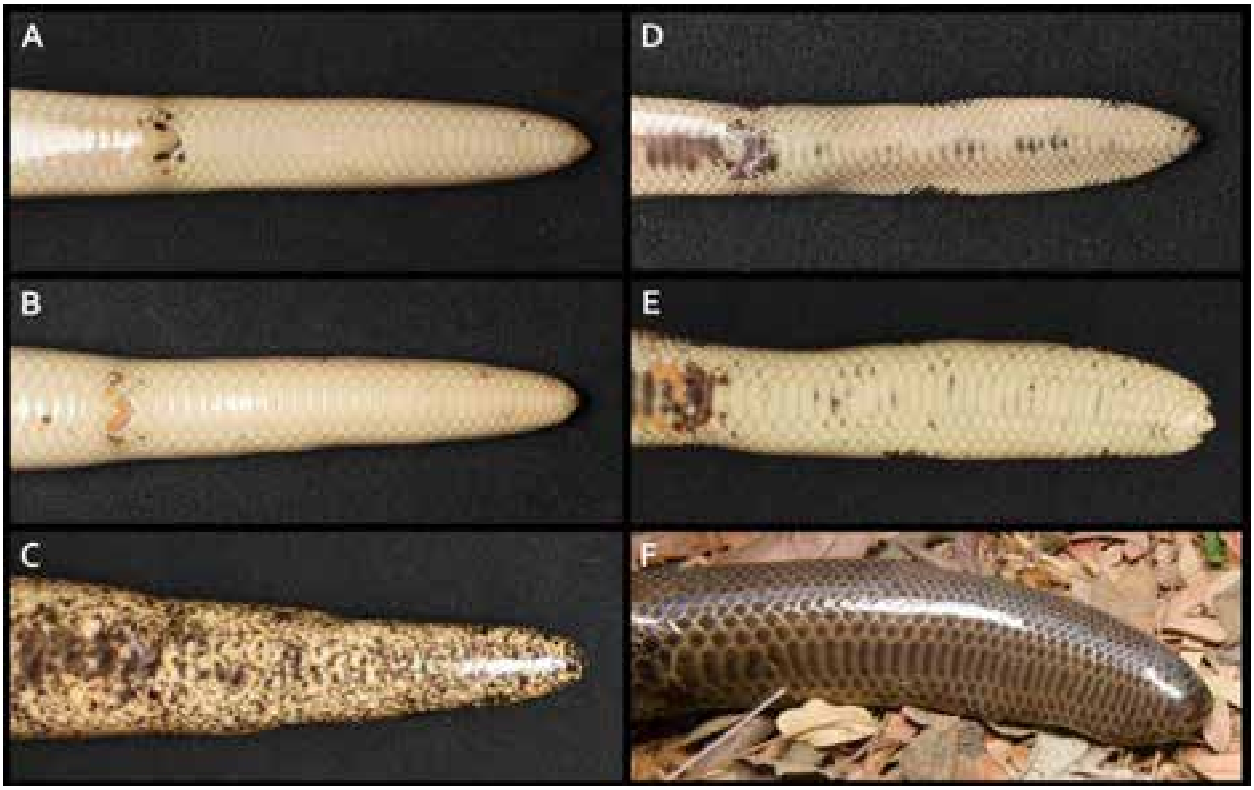

Image 3. Comparison of subcaudal colour pattern and tail shape of three different life stages of *Eryx sistanensis* (A–C): A—juvenile | B—subadult | C—adult, all from Sikar District. *Eryx johnii* (D–F): D—juvenile | E—subadult, both from Ajmer District | F—adult from Jabalpur District. © Vivek Sharma.

Jird *Meriones hurrianae* are particularly abundant in this landscape. Subadult *E. sistanensis* was found at late night, whereas other two were found at day time, indicating this species can show activity at day and night both.

Dharmendra Khandal (author) photographed two undiagnosed subadults (Image 5A, B) from Churu District, first one approximately 50 cm in total length from Churu city outskirts (28.282° N, 74.984° E; 310 m) on 20 August 2003 and second one approximately 70 cm in total length from Leelki Beed (28.761° N, 75.201° E; 242 m) on 29 April 2006. We have documented one subadult (Image 5C) being demonstrated by a boy in regionally celebrated Goga Mela in Churu on 17 August 2025. In this annual event, dozens of live individuals of various locally collected snake species are carried and demonstrated by devotees of a deity Gogaji.

DISCUSSION

Individuals of *E. sistanensis* examined in the present study agree with the characters provided by Eskandarzadeh et al. 2020 and Hussain et al. 2024 with some minor extensions (see Table 1) in meristic and morphometric characters. Our observation on colour and patterns correspond with both of previous works where individuals in all life forms tend to maintain sooty blotches or bands on buff or tan dorsal body. However, subadult examined by us had obscure and difficult to count bands only on posterior half of body. Tail description provided by Eskandarzadeh et al. (2020) was observed in individuals examined by us where all individuals had obtusely pointed tail tip. However, we noticed tail tip of juvenile and subadult of the examined individuals did not show any noticeable difference from live individuals of *E. johnii* in similar length range. Unfortunately, both Eskandarzadeh et al. (2020) and Hussain et al. (2024) have not provided any photographic comparison of tail or tail tip, hence relying upon this character is currently not possible until larger sample size of related taxa is compared. However, we noticed tail from base gradually tapered until it ended in conical tip in *E. sistanensis* whereas in case of *E. johnii*, it maintained the same thickness on most of the length except its end. We have found TB/CB 0.7–0.9 in *E. sistanensis*, indicating the middle of tail was always thinner than base of the tail. Also, TB/CB was lowest in largest individual (0.7) which suggests adult's body gains more girth than tail and the latter remains thinner than body. In three individuals of *E. johnii*, TB/CB were found 1–1.1, indicating observed individuals maintained same thickness for at least half of their tail lengths. This character appears to have taxonomic value if large sample size is analyzed.

After combining our data (of uncollected live individuals of both species; also check Image 2–5) with existing works on *E. sistanensis* (Eskandarzadeh et al. 2020; Hussain et al. 2024), we observed that *E. sistanensis* is different from *E. johnii* in having: 1) lower mid body rows (43–57) in former vs higher up to 66 (in our observation) or 53–67 (fide Whitaker & Captain 2004) in latter; 2) tan or tan brown dorsal body in most of the life stages in former vs reddish-brown or brick red in juveniles, reddish-brown, brown or chocolate brown in subadults and plain brown, dark chocolate brown or black in adults; 3) sooty black bands visible in all life forms in former vs blackish bands in juveniles (sometimes on whole body), present only on tail in subadults or can be entirely absent, and entirely absent in adults; and 4) tail gradually tapers till end in former vs tail maintains same thickness for most of the length in latter.

Our observations with live individuals match with some of past works where authors have been able to recognize "adult form with bands" in few *E. johnii* or recognized them as *E. j. persicus* and were able to describe such specimens. Wall (1911) noted three specimens of *E. johnii* from Duki and Hanna (Balochistan, Pakistan) had black bars throughout the body and tail, lower number of dorsal rows (47–53), lower number of ventral scales (190–200) and heavily mottled black underbody, fitting with the description of *E. sistanensis*. Constable (1949) reported a subadult female of *E. j. persicus* from "within 100 miles of Ambala", in present day's northern India. This single specimen's pholiodosis falls within range of data obtained by us from three individuals in Rajasthan. Minton (1966) mentioned two different colour forms of *E. johnii* in western Pakistan and noted both forms were sympatric. Without providing pholidosis, he was able to observe ontogenic trends in both forms where reddish coloured juveniles tend to grow darkest, whereas the other form fits with description of *E. sistanensis*. Our finding of three individuals of three different life stages confirms Minton's observation.

Our current records of *E. sistanensis* from Ramgarh Shekhawati in Sikar are approximately 290 km from the nearest published locality Haider Wali, Bahawalnagar District in Cholistan Desert of Pakistan (Hussain et al. 2024). Our most recent findings from Ramgarh Shekhawti are not the foremost sightings from India. Constable (1949) reported a subadult female of *E. j. persicus* (now *E. sistanensis*) from "within 100 miles of Ambala", south-west of this locality broadly corresponds to present-day Haryana and Punjab states from where we have gathered

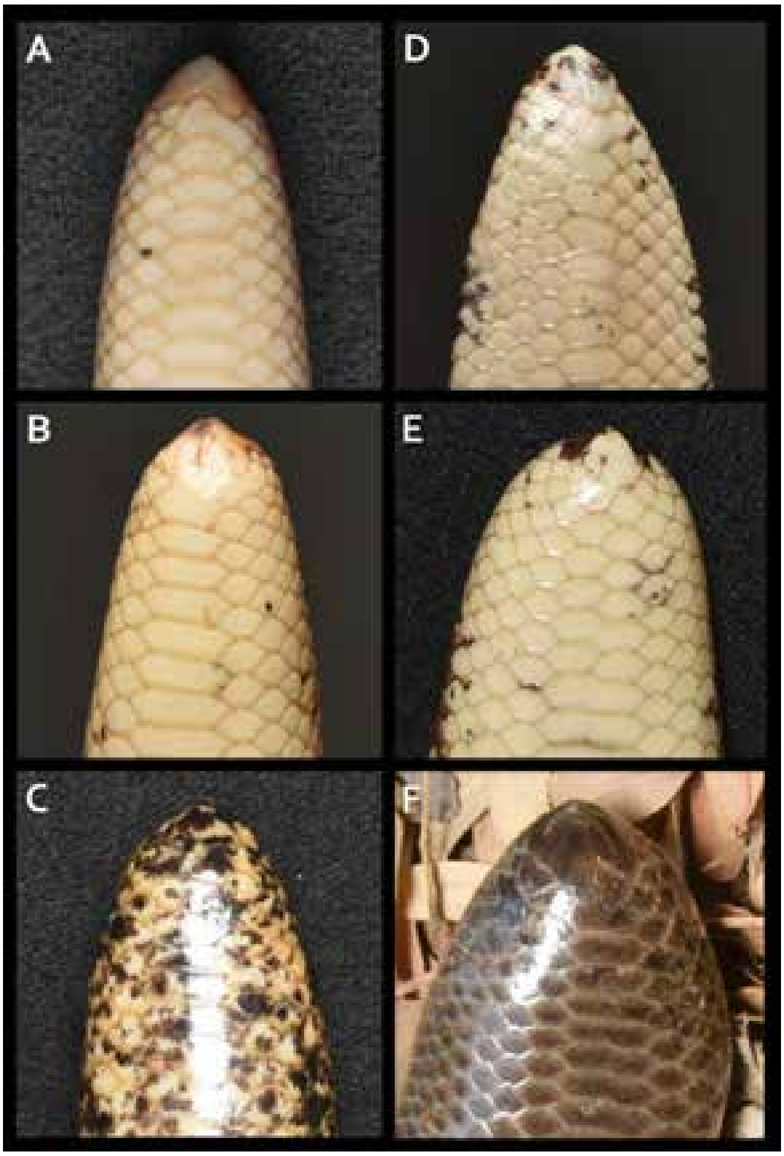

Image 4. Comparison of tail tip profiles of three different life stages of *Eryx sistanensis* (A–C): A—juvenile | B—subadult | C—adult, all from Sikar District. *Eryx johnii* (D–F): D—juvenile | E—subadult, both from Ajmer District | F—adult from Jabalpur District. © Vivek Sharma.

photographic records of locally rescued *E. sistanensis* from the outskirts of Fatehabad and Bathinda respectively. Both of these localities fall between Ambala (Punjab), and Sikar and Churu (Rajasthan), from where we have obtained total six personally observed live individuals. Apart from these above-mentioned observations, we have noticed presence of this species in the outskirts and the rural parts of Bikaner, Hanumangarh, and Jaisalmer District headquarters of Rajasthan. Despite being able to identify them as *E. sistanensis* on the basis of tan or buff coloured dorsal body marked with sooty bands, we refrain ourselves from drawing any conclusion with these sightings because we were unable to personally document and diagnose all such specimens from these three states. We leave this task for future biologists to gather morphological data to report them formally. Nevertheless, all these photographic records hint wider presence of *E. sistanensis* in sandy plains of Thar region and its northern edges.

Eryx johnii is a conservation-significant species that is heavily targeted in illegal wildlife trade such as black magic and demonstration in snake charming (Vyas 2012; Parmar & Kaiser 2022; Wildlife Conservation Society, India 2023), and its inclusion in Schedule I of the Wildlife (Protection) Act, 1972 reflects the serious threats it faces. In our data collection, we have noticed at least three cases (one each from Hoshiarpur in Punjab State, Sarguja in Chhattisgarh State and Siliguri in West Bengal

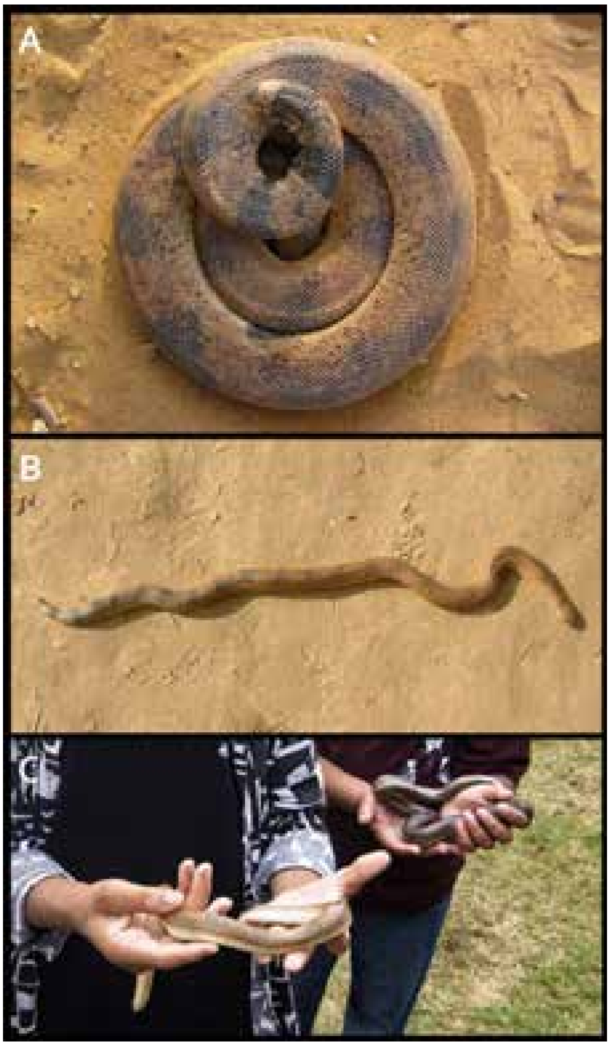

Image 5. Observations of undiagnosed live individuals of *Eryx sistanensis* from Churu District of Rajasthan, India. A—from Churu City outskirts | B—from Leelki Beed | C—live subadult of *E. sistanensis* (left) and *E. johnii* (right) demonstrated by two boys in regionally celebrated Goga Mela from Churu City outskirts. © Dharmendra Khandal.

State) of *E. sistanensis* being used as two-headed snake or "Do-muh-wala saanp" (a popular Hindi name of *E. johnii* in snake charming practices) by snake charmers due to similar appearance and inoffensive nature. Also, live individual of *E. sistanensis* and *E. johnii* were used by local boys in Goga Mela in Churu for annual religious event. With such examples in our knowledge, we believe *E. sistanensis*, with much restricted distribution and sightings in India, may be at even greater risk of being exploited in various cultural and religious activities, also can face pressure of local population decline due to habitat alteration (Hussain et al. 2024). The lack of data on its population and trade status further increases concern. As of now, it is 'Not Evaluated' (NE) according to IUCN and comes under Schedule-II of Indian Wildlife (Protection) Amendment Act, 2022. Given this, there is an urgent need for precautionary assessment and possible elevation of its protection status, as such species may be facing greater threats than *E. johnii*, a species reckoned to face several anthropogenic direct threats. Also, live individual of E. sistanensis and E. johnii were used by local boys in Goga Mela in Churu for annual religious event, within a week before we started getting live individuals from Sikar District.

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COMMUNICATION

Population dynamics and habitat assessment of Indian Flapshell Turtle *Lissemys punctata vittata* (Reptilia: Testudines: Trionychidae) in Chawandiya, Rajasthan, India

Mahaveer Prasad Vaishnav [1] & **Amol Arora** [2]

[1,2] Department of Zoology, Vidya Professional and Technical College, Palri, Bhilwara, Rajasthan 311001, India.
[1] research.mpvaishnav@gmail.com (corresponding author), [2] research.amolarora@gmail.com

Abstract: Freshwater turtles are increasingly threatened by habitat degradation, pollution, and other human disturbances, particularly in small urban and semi-urban wetlands. In the present study, the Indian Flapshell Turtle *Lissemys punctata vittata* was monitored in Chawandiya Pond, Rajasthan, northwestern India, to understand changes in population dynamics in relation to habitat conditions and water quality. Weekly field observations using fixed transects were conducted from January 2023 to March 2025, and seasonal water-quality parameters were analysed following APHA (2017) standard methods. Observations showed a noticeable increase (~33–38 %) in turtle density during the breeding season, while a further 13–15 % rise during non-breeding periods may be linked to immigration into the pond under suitable ecological conditions. Stable hydrology, comparatively low pollution, adequate dissolved oxygen, and food availability appear to favour the persistence of the population. However, increasing anthropogenic activities and mild detergent-related pollution could become potential threats if left unmanaged. The study highlights the conservation value of semi-protected wetlands such as Chawandiya Pond and stresses the importance of continued habitat and population monitoring for freshwater turtle conservation and also proposes Chawandiya Pond as a candidate conservation site for this species.

Keywords: Anthropogenic disturbance, habitat suitability, hydrological stability, population monitoring, semi-protected wetland, softshell turtle, turtle conservation, water quality.

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Ethics statement: All research was conducted through non-invasive in situ observation, in compliance with the Wildlife Protection Act, 1972. No animals were harmed or captured during this study.

Author details: Mahaveer Prasad Vaishnav is the assistant professor and HoD of Department of Zoology,Vidya Prof. & Tech. College, Palri, 311001, Rajasthan, India, with research interests focused on biodiversity conservation. His work primarily involves field-based ecological monitoring and conservation-oriented studies of ecosystems. Amol Arora is his student, pursuing B.Sc.-B.Ed.(final year- CBZ) in the same college. His interests also include ecological monitoring, and conservation awareness related to ecosystems.

Author contribution: MPV—conceptualization, field work, ecological analysis, data interpretation, manuscript preparation. AA—field work, data collection and analysis.

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INTRODUCTION

Freshwater wetlands are increasingly being threatened from urbanization, pollution, overexploitation, and unsustainable agricultural practices (Rao 1986; Reid et al. 2019). These pressures alter hydrology, reduce water quality, and destroy nesting and basking sites, which are critical for the survival of freshwater turtles. The disappearance of turtles from degraded wetlands and unmanaged water bodies has been documented across India and other parts of Asia (Rao et al. 2018; Singh & Rao 2019).

Turtles decline serves as a sensitive indicator of wetland health, since even moderate habitat disturbances can lead to rapid local extinctions (Moll 1983; Moll & Moll 2004). Monitoring turtle populations, therefore, provides important insights into both species-level conservation needs and broader ecosystem stability. Without regular monitoring, declines often go unnoticed across India (Krishnakumar et al. 2009; Vasava et al. 2021; Abinesh et al. 2022; Dubey et al. 2025; Mandal & Mallick 2025; Mandal et al. 2025; Sunny et al. 2025) and also bordering countries (Kashmi et al. 2025; Safi et al. 2025).

In a pond in Rajasthan, such impacts were observed in Nehru Talai, where flapshell turtles were initially recorded in 2022 but disappeared entirely by early 2023. Possible causes included pollution, poor habitat conditions, and the absence of protective measures. In contrast, Chawandiya Pond, a semi-protected wetland with partial cultural safeguarding, has continued to support turtles. The present study monitored the population dynamics of *L. p. vittata* and analyzed how ecological factors contribute to observed trends.

MATERIALS AND METHODS

Field Surveys

Population monitoring of *Lissemys punctata vittata* (Image 1) was conducted from January 2023 to March 2025. The observational method included 1–2 field visits weekly, increasing to 2–3 times per week during the breeding season (May–August). Observations were conducted during early morning and late afternoon when basking behaviour made turtles more visible. Data were collected visually using fixed transects of 100 m² (20 × 5 m) along the shore per sampling area. All observations were conducted in situ, with no direct interaction or disturbance to the turtles. Research adhered strictly to the provisions of the Indian Wildlife Protection Act, 1972.

Image 1. Indian Flapshell Turtle *Lissemys punctata vittata* basking along the shore of Chawandiya Pond, Rajasthan, India.

Water Quality Test

Monthly water samples were collected and analyzed in the laboratory (of Vidya Professional and Technical College, Paldi, Bhilwara) according to the APHA (2017) standard procedures. Parameters included: total dissolved solids (TDS), pH, dissolved oxygen (DO), biological oxygen demand (BOD), nitrate and phosphate concentrations, and general pollution indicators. Equipment used for water analysis included: Thermometer — Thermocare-ST9283B; pH meter — Metzer-METZ-202M; TDS meter — Aquasol Digital AM-P-EC; Nephelometer (Deluxe turbidity meter) — PSAW-LT-34; DO meter — Metzer-METZ-902M, BOD Incubator — D.D.R.INT and Colorimeter OPTEC Instrumentation-910 /211231019.

Study Species

The Indian Flapshell Turtle, a trionychid species distributed across the Indian subcontinent, is one of the 22 species of turtles found in India and comprises three recognized subspecies: *Lissemys punctata punctata*, *L. p. vittata*, and *L. p. andersonii* (Das 1985; Bhupathy et al. 2000; Gramentz 2011). Among these, *L. p. vittata* is known for its adaptability to a variety of freshwater environments. Owing to its 'Vulnerable' status under IUCN Red List (Rahman et al. 2021; IUCN 2025, Appendix II of CITES(CITES 2025)) and Schedule I of the Wildlife Protection Act, 1972, India (Government of India 1972), which affords it the highest level of national legal protection, *Lissemys punctata* faces significant threats due to poaching, habitat degradation, and pollution (CITES CoP17 Doc 73 2016).

Study Area

The study was carried out in Chawandiya Pond (25.331° N, 74.775° E; 375–402 m) in Bhilwara District of Rajasthan that spans nearly 48 ha. It is situated in the periphery of the Bhilwara City outskirts, just 15 km east of the city. The climatic conditions include hot and dry summers (32–37 °C), cooler winters (10–15 °C), with an overall average of 23–28 °C temperature annually and an average annual rainfall of 600–700 mm (Ground Water Department Rajasthan 2013, Sharma et al. 2021; Climate-Data.org 2023). The pond has recently been recognized as a protected area under the Rajasthan State Wetland Conservation framework (Chawandiya Wetland Gazette Notification 2021), highlighting its ecological and cultural importance. Chawandiya Pond serves as an important freshwater wetland system, supporting both permanent and migratory fauna. Its ecological profile includes varied shoreline vegetation, submerged aquatic plants, and stable hydrological conditions for most of the year (Sharma et al. 2023).

RESULTS

Initial sightings (January–April 2023) averaged 10–12 turtles per 100 m² (Figure 1). During the breeding season (mid-June to early July) numbers increased to 14–15, which continued to increase, peaking at 16–17 by August with the onset of heavy monsoon. Density stabilized after rains and plateaued until March 2024, rising again during the 2024 breeding season. After the seasonal stabilization, by June 2024, 20–22 turtles were observed per transect, reaching 23–24 from August

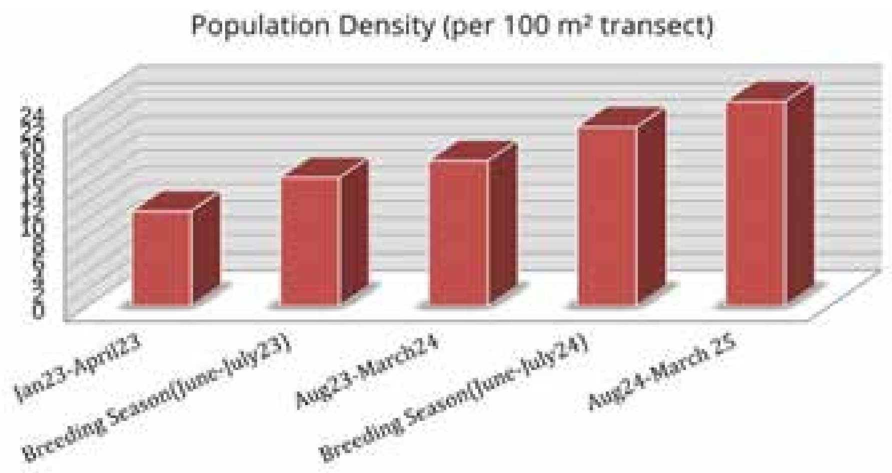

Figure 1. Breeding vs. non-breeding seasons variations in sighting frequencies of *Lissemys punctata vittata* in Chawandiya Pond, across the transects sampled during 2023–25.

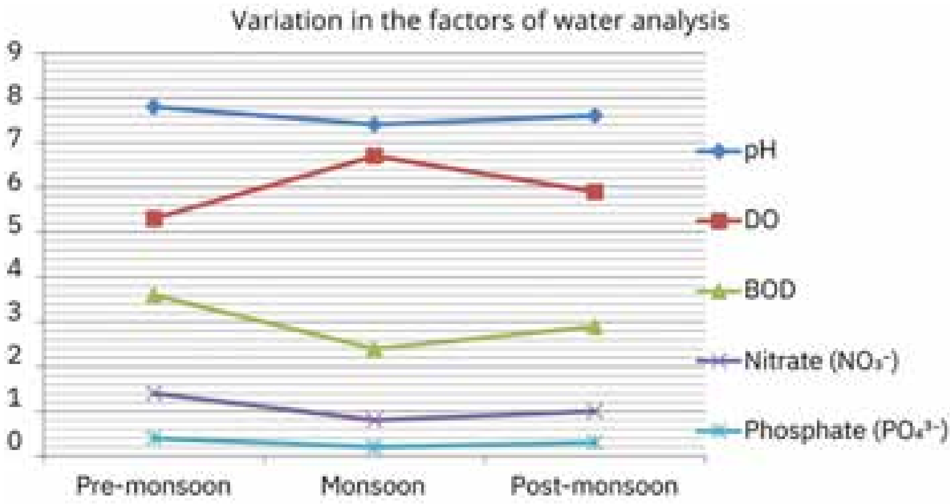

Figure 2. Seasonal break-up of chemical water quality parameters of Chawandiya Pond.

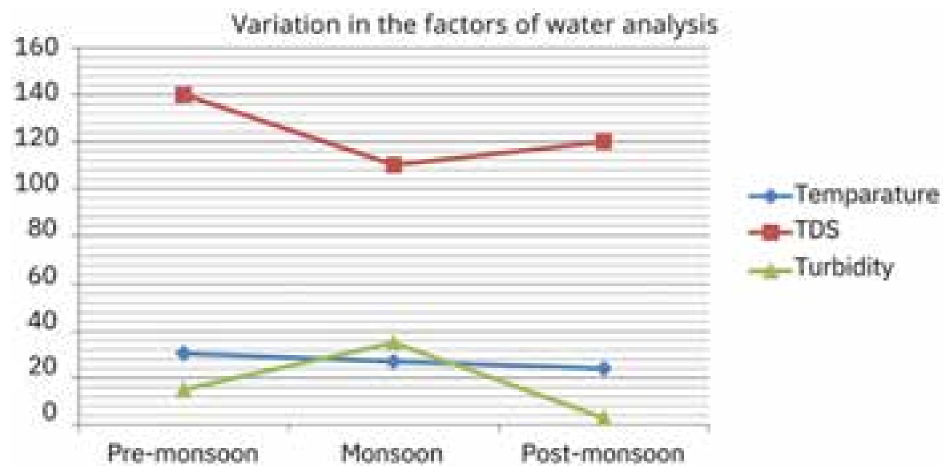

Figure 3. Seasonal break-up of physical water quality parameters of Chawandiya Pond.

2024–March 2025, i.e., there was a rise of ca. 33–38 % in the population of turtles in the breeding period. Further, there was a rise of 13–15 % after the breeding season.

From the above observations it may be inferred that, in the recent years, there has been a significant rise in the population dynamics of the Indian Flapshell Turtle in the Chawandiya Pond. Approximately a 33–38 % rise can be reported during the breeding season. In this study it was found that the mating occurs in mid to late May, nesting occurs in July–August and the hatchlings emerged in May after an incubation period of approximately 235–250 days, which is in accordance with the common behaviour. (Affunberg 1981; Gramentz 2011). Thus, the mating and hatchlings emerging season is almost the same during May. An additional slight rise of approximately 13–15 % after the breeding season is also observed by the study.

The recent sightings (March 2025) have recorded the presence of approximately 23–24 turtles in the shore region of around 100 m². By this it can be estimated that a total of nearly 580–600 *Lissemys punctata vittata* are present in the Chawandiya Pond. By seasonal and year-round study of the wetland habitat (Figures 2, 3), it can be inferred that, Chawandiya Pond is a stagnant freshwater body providing a perennial source of water for the turtles that has favourable conditions accounting for the persistence of turtle populations and their prey base. Moreover, the less turbid water, with very mild pollution, adequate amounts of dissolved oxygen, slightly alkaline pH, and low TDS, indicates favourable habitat conditions for the freshwater fauna, especially the turtles. The good ecological conditions of the habitat

Table 1. Seasonal break-up of water quality parameters of Chawandiya Pond.

Parameter	Unit	Pre-monsoon (avg ± SD)	Monsoon (avg ± SD)	Post-monsoon (avg ± SD)
Temperature	°C	30.5 ± 0.5	27.0 ± 0.5	24.0 ± 0.5
pH	—	7.8 ± 0.2	7.4 ± 0.2	7.6 ± 0.2
TDS	mg/L	140 ± 10	110 ± 10	120 ± 10
Turbidity	NTU	15 ± 5	35 ± 5	20 ± 5
Dissolved Oxygen (DO)	ppm	5.3 ± 0.5	6.7 ± 0.5	5.9 ± 0.5
BOD	ppm	3.6 ± 0.5	2.4 ± 0.5	2.9 ± 0.5
Nitrate (NO_3^-)	mg/L	1.4 ± 0.2	0.8 ± 0.2	1.0 ± 0.2
Phosphate (PO_4^{3-})	mg/L	0.4 ± 0.1	0.2 ± 0.1	0.3 ± 0.1

are the reason for the increase in the migrant population of the turtles.

Another ecological benefit of the Chawandiya Pond habitat is that since it is an eco-religious tourist spot, the tourists and devotees visiting here feed the organisms with grains and other food items, creating an abundance of food for the organisms. As the result of it, both intraspecific and interspecific competition between the organisms is reduced, and more or less there's a positive or neutral interaction between the organisms, especially for the food, making it a good freshwater ecosystem. All these ecological conditions support and push forward the rise in the population density of the *Lissemys punctata vittata* in the Chawandiya Pond. Mildly elevated phosphate concentrations during the pre-monsoon season, along with moderate BOD, indicate a mild degree of organic and detergent-based pollution, likely linked to in-pond washing and other human activities which might serve as a possible future ecological threat.

DISCUSSION

The increase in *Lissemys punctata vittata* population at Chawandiya Pond clearly shows that the wetland offers highly suitable ecological conditions. Breeding-season rises were strongly tied to the onset of monsoon rains, which is consistent with earlier reports linking rainfall with reproduction in softshell turtles (Gramentz 2011). The rise in density during the breeding months (33–38 %) is similar to observations from post-monsoon increase recorded in the Banni grasslands of Gujarat (Bhupathy et al. 2000). This parallel suggest that rainfall and associated hydrological changes are key drivers of breeding success in this species.

An additional rise of 13–15 % after the breeding season can be accounted for the tendency of the turtle to immigrate into the pond because of improved habitat conditions. Water-quality analysis also supports this trend, with generally low pollution, sufficient dissolved oxygen, and balanced nutrient levels. At the same time, certain human activities influence habitat conditions. Feeding of aquatic fauna by visitors' increases food availability and may reduce competition, while washing activities add mild detergent loads, reflected in slightly elevated phosphate concentrations. Similar pollution-related impacts on turtle nesting and hatching have been reported from wetlands in West Bengal and Bangladesh (Hossain et al. 2020). Although concentrations at Chawandiya remain below critical thresholds, continued monitoring is essential to prevent long-term impacts.

The delayed hatching pattern (235–250 days) recorded in this study aligns with regional climatic cycles and earlier findings from other southern Asian populations (Singh & Rao 2019). Such delayed emergence likely enhances hatchling survival under uncertain pre-monsoon conditions. When compared with other regional studies, turtle density at Chawandiya Pond stands out. The observed average of 23–24 individuals per 100 m² (ecological density) was substantially higher than the 0.86 (direct count) to 1.05 (capture–mark–recapture) per 100 m² reported by Yousaf (2017) from Pakistan's Pothwar Plateau. Although methodological differences between studies should be considered, but this contrast highlights the exceptional concentration of *L. p. vittata* at Chawandiya Pond, possibly associated with hydrological stability, food availability, and partial cultural protection.

Studies from other regions demonstrate that freshwater turtle populations are highly vulnerable to a range of anthropogenic threats. Illegal exploitation and trade continue despite legal protection (Vijaya 1982; Choudhury & Bhupathy 1993; Uttara 2017), as documented for *Lissemys punctata* in Kerala wetlands (Krishnakumar et al. 2009) and through long-term confiscation records in West Bengal (Mandal et al. 2025). Infrastructure-related mortality, such as turtle deaths along railway tracks, has also been reported in southern India (Abinesh et al. 2022). In Bangladesh's largest wetland, extensive habitat degradation, pollution, and loss of nesting sites have resulted in significant conservation challenges for *L. punctata* (Kashmi et al. 2025). At the same time, positive roles of indigenous beliefs in reducing exploitation have been reported from parts of eastern India (Mandal & Mallick 2025), supporting the importance of cultural protection, especially in sacred temple ponds. Broad regional reviews further emphasize that habitat loss, exploitation, pollution, and hydrological alterations remain the dominant threats to southern Asian trionychid turtles (Safi et al. 2025). Field-based studies also show that wetlands with stable water levels and lower disturbance support healthier populations (Sunny et al. 2025), consistent with observations from Chawandiya Pond.

Although Chawandiya Pond currently supports a growing population, increasing human pressure could pose future risks. Regular habitat and population monitoring is essential to ensure the steady growth of *L. p. vittata*, as the absence of such oversight may result in sudden and unexplained mortalities, as reported from Gujarat wetlands (Vasava et al. 2021). Controlled access during the breeding season, regulation of detergent use, and community-based awareness programs represent low-cost but effective conservation measures. Similar community-involved conservation approaches have proven successful in other Indian wetlands (Rao et al. 2018) and could be applied here. By focusing on breeding patterns, seasonal changes, water quality, and human interactions, the research aims to establish a foundation for conservation-oriented policy recommendations. Given its population status and official wetland recognition, Chawandiya Pond merits consideration as a site of local conservation importance for *Lissemys punctata vittata*.

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COMMUNICATION

A preliminary checklist of dragonflies and damselflies (Insecta: Odonata) of Kanyakumari District, Tamil Nadu, India

V. Muthukrishnan [1], Anand Shibu [2], Vinod Sadhasivan [3] & R. Amirtha Balan [4]

[1,2] Kanyakumari District Forest Office, Vadasery, Nagercoil, Tamil Nadu 629001, India.
[3] 7/1d, Vini Nivas , Moovendhar Nagar, Holy Cross College Road, Nagercoil, Tamil Nadu 629004, India.
[4] Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India.
[1] avmkrish07@gmail.com (corresponding author), [2] anandshibu12@gmail.com, [3] svinod@gmail.com, [4] amirthabalanrs13@gmail.com

Abstract: This study documents the Odonata diversity in Kanyakumari District, Tamil Nadu, covering forested regions, wetlands, reservoirs, and saltpans from September 2024 to January 2025. A total of 82 species were recorded, including 47 dragonflies and 35 damselflies. The highest diversity was observed at Mukkadal Dam, followed by Mambazhathurayar Reservoir and Kannimaranthoppu stream. In contrast, Puthalam Saltpan exhibited the lowest diversity likely due to high salinity levels. Forested regions supported the greatest species richness, possibly due to their relatively undisturbed, less polluted nature. This study contributes to the documentation of regional biodiversity and supports the Biological Diversity Act (2002) of India. The findings are expected to assist in local conservation efforts and provide insights into Odonata habitat preferences in Kanyakumari District.

Keywords: Anisoptera, Balamore, Coenagrionidae, endemic, Libellulidae, Puthalam saltpan, Theroor wetland, Western Ghats, wetland, Zygoptera.

Tamil: இந்த ஆய்வு தமிழ்நாட்டின் கன்னியாகுமரி மாவட்டத்தில் உள்ள வனப் பகுதிகள், ஈரநிலங்கள், நீர்த் தேக்கங்கள் மற்றும் உவர்நிலங்களில் உள்ள தும்பிகளின் பல்வகைத் தன்மையைப் பதிவு செய்கிறது. இந்த ஆய்வு செப்டம்பர் 2024 முதல் ஜனவரி 2025 வரை நடைபெற்றது. மொத்தமாக 82 இனங்கள் கண்டறியப்பட்டன. இதில் 47 தட்டான் பூச்சி இனங்களும், 35 ஊசித் தட்டான் இனங்களும் அடங்கும். இந்த ஆய்வில், முக்கடல் அணையில் அதிகமான இனப் பல்வகைத் தன்மை காணப்பட்டது. அதற்கு அடுத்ததாக மாம்பழத் துறையார் நீர்த் தேக்கம் மற்றும் கன்னிமாரத்தோப்பு ஓடைப் பகுதிகள் உள்ளன. இதற்கு மாறாக, புத்தளம் உப்பளத்தில் உப்புத்தன்மை அதிகமாக இருப்பதால், அங்கு மிகவும் குறைவான இனங்கள் மட்டுமே காணப்பட்டன. காடுகள் அதிகமாக உள்ள பகுதிகளில் உயிரினங்களின் செழுமை அதிகமாக இருந்தது. இது குறைந்த மாசு மற்றும் மனிதர் ஏற்படுத்தும் இடையூறுகள் குறைவாக இருப்பதாலாக இருக்கலாம். இந்த ஆய்வு, உள்ளூர் பல்லுயிர் பதிவுகளை மேம்படுத்துவதோடு, இந்தியாவின் உயிரியல் பல்வகைத் தன்மை சட்டம் (2002) ஆதரிக்கிறது. மேலும், இந்த கண்டுபிடிப்புகள் உள்ளூர் பாதுகாப்பு முயற்சிகளுக்கு உதவுவதோடு, தும்பிகள் எந்த வகை வாழ்விடங்களை விரும்புகின்றன என்பதை புரிந்துகொள்ளவும் உதவும் என எதிர்பார்க்கப்படுகிறது.

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INTRODUCTION

The order Odonata, encompassing dragonflies and damselflies, is primarily associated with freshwater wetlands and adjacent landscapes. It represents one of the most ancient insect lineages, with fossil evidence indicating its origin dating back to the Permian period. The term *Odonata* is derived from the Greek word *odontos*, meaning "toothed", referring to the characteristic dentition of their mandibles. It comprises hemimetabolous insects with a semi-aquatic life cycle (Corbet 1962; Stoks & Córdoba-Aguilar 2012). They rely on freshwater ecosystems for reproduction, with aquatic larval stages and terrestrial/aerial adult stages. Due to this dependence, odonates serve as key bioindicators of both aquatic and terrestrial habitats (Monteiro-Junior et al. 2014; Rocha-Ortega et al. 2019). Although freshwater ecosystems cover only 0.8% of Earth's surface and account for merely 0.01% of the global water volume (Gatti 2016), they play a crucial role in sustaining biodiversity (Previsic et al. 2014; Ivković & Plant 2015) and support over 1,00,000 species (Gatti 2016).

Globally, the order Odonata comprises 6,392 extant species distributed across 46 families (Paulson et al. 2026) and is found worldwide, except in polar regions. In India, the order is represented by 506 species and 44 subspecies belonging to 157 genera, 17 families, and three suborders (Kalkman et al. 2020; Subramanian & Babu 2024; Chandran et al. 2025). Tamil Nadu comprises 147 species, of which 55 are endemic (Subramanian & Babu 2024).

Odonates, being habitat specialists, are primarily associated with primary forests, open plains, and tropical streams (Villanueva & Mohagan 2010; Koparde et al. 2014, 2015). Notably, dragonflies and damselflies exhibit differential responses to habitat modifications, with damselflies being more sensitive to microhabitat changes (Koparde 2016). Due to their ecological roles, odonates are regarded as key components of aquatic ecosystems and serve as biological indicators of environmental conditions (Clark & Samways 1996; Samways et al. 1989). Subramanian (2007) reported 178 species of odonates from the Western Ghats with 68 endemic species. Emiliyamma (2014) reported 169 species of odonates from southern Western Ghats with 66 endemic species.

Kanyakumari District, formerly part of the Travancore State before India's independence, was historically known as South Travancore District (Menon & Padmanabha 1929) and later integrated into Tamil Nadu. While historical faunal records from Travancore exist, many lack precise locality data. This study represents one of the first dedicated surveys on Odonata diversity in Kanyakumari District in nearly a century, contributing valuable insights into the region's unique Odonata assemblages.

Given the significance of regional biodiversity documentation for long-term conservation and management, a systematic study was conducted across varied habitats of Kanyakumari District, Tamil Nadu, southern India, from September 2024 to January 2025. The findings of this research are presented herein.

Study area

The present study was conducted across multiple sites in Kanyakumari District, encompassing both forested regions (natural plantation with rich canopy) (Kannimaranthoppu scrub forest elevation ranges 100–140 m, Mahendragiri Reserve Forest; Balamore Estate elevation ranges 400–480 m, with fragmented moist evergreen forest; Kothayar elevation ranges 200–250 m, with moist deciduous forest), Freshwater wetlands (Mambazhathurayar Reservoir located in Villukuri, with dry deciduous forest elevation 99 m; Mukkadal Dam built across the Vambaru River, with dry deciduous forest elevation 57 m; Thovalai Checkdam built across Thovalai Canal, elevation 53 m; Putheri lake receives water from a canal outlet of Pechiparai Dam, elevation 17 m; Periyakulam near the town of Manavalakurichi, elevation 10 m; Theroor wetland receives water from Thovalai Channel, elevation 32 m; Thirunanthikarai receives water source from Nandhiaaru River (Kodayar left bank canal), elevation 92 m, and Puthalam Saltpan receives water from the Manakkudy Estuary, elevation 8 m). Forests cover approximately 30% of the district, extending over 40,000 ha, situated between 8.076°–8.578° N and 77.100°–77.590° E. This survey aimed to assess Odonata richness across diverse habitat types, including forest streams (Kannimaranthoppu—KMT, Balamore Estate—BE, & Kothayar—KTF), reservoirs (Mambazhathurayar—MTY & Mukkadal dam—MD), selected wetlands (Thovalai Checkdam—TCD, Putheri lake—PL, Periyakulam—PK, Theroor wetland—TW, & Thirunanthikarai–TNK), and saltpans (Puthalam Saltpan–PSP) (Table 1; Figure 1; Image 1). The study was conducted from September 2024 to January 2025.

MATERIALS AND METHODS

The Odonata survey was conducted primarily during daylight hours using the line transect & visual encounter

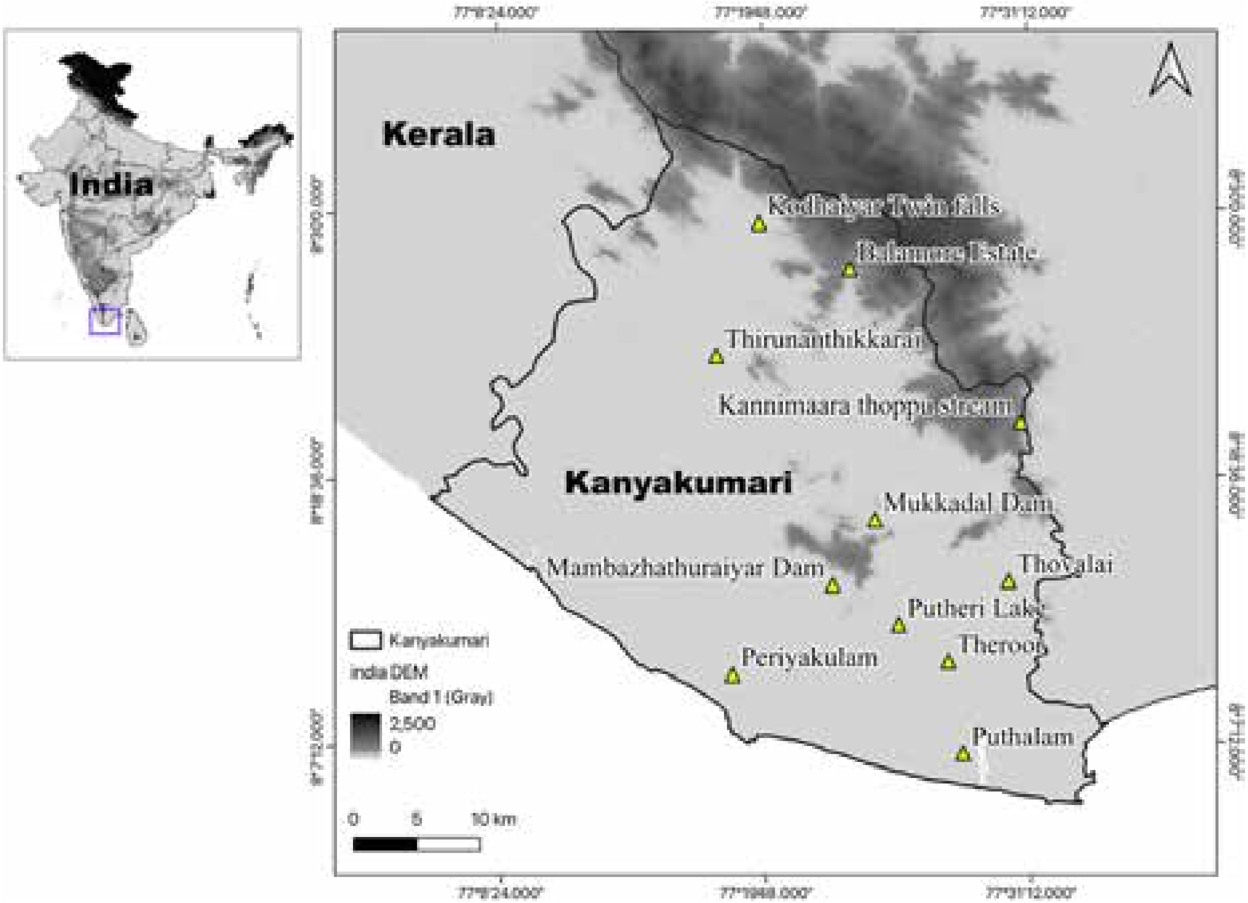

Figure 1. Map showing the study area in Kanyakumari District.

survey method, everyday from 0600 to 1000 h, from September 2024 to January 2025. The study relied predominantly on photographic documentation rather than specimen collection, due to the Tamil Nadu Forest Department's stringent regulations on faunal collection. This policy contrasts with those of the neighbouring states, Kerala and Karnataka, and has contributed to the scarcity of faunal records from this region of the Western Ghats.

Digital photographs were captured using a Nikon D7000 camera equipped with a 300 mm lens. Species identification was performed using available reference literature, including Subramanian (2009) and Kiran & Raju (2013).

RESULTS

During the study period, a total of 82 Odonata species were recorded, comprising 47 dragonfly (Anisoptera) and 35 damselfly (Zygoptera) species (Table 2, Images 2–6) belonging to 13 families and 57 genera. Of the 82 species, 18 species are endemic. Species richness varied across the surveyed locations. The highest number of species was observed at Mukkadal Dam, where 37 dragonfly species and 17 damselfly species were recorded, followed by Mambazhathurayar Reservoir with 31 dragonfly species and 13 damselfly species. The Kannimaranthoppu Stream habitat also exhibited a high number of species, with 29 dragonfly species and 15 damselfly species.

In contrast, Puthalam Saltpan, a high-salinity habitat, exhibited the lowest number of species, with 15 dragonfly species and six damselfly species, as elevated salinity levels are generally unsuitable for most Odonata species, except for a few salinity-tolerant species. Further study is required to understand the species habitat preference.

Other surveyed locations recorded moderate species richness: Kothayar Twin Falls (38 species), Periyakulam (37 species), Thirunanthikarai (35 species), Theroor Wetland (33 species), Putheri Lake (31 species), Balamore

Image 1. Study stations: A,B—Puthalam Saltpan | C—Balamore Estate | D—Thovalai Check Dam | E—Kodayar Twin Falls. © Muthukrishnan.

Table 1. List of study site across Kanyakumari District.

	Study site	Elevation (m)	Location
1	Kannimaranthoppu, Mahendragiri Reserve Forest	100–140	08.348° N, 77.514° E
2	Balamore Estate	400–480	08.458° N, 77.392° E
3	Kothayar Twin Falls	200–250	08.491° N, 77.327° E
4	Mambazhathurayar Reservoir, Villukuri	99	08.233° N, 77.378° E
5	Mukkadal Dam	57	08.280° N, 77.409° E
6	Thovalai Checkdam	53	08.235° N, 77.505° E
7	Putheri Lake	17	08.205° N, 77.426° E
8	Periyakulam, Manavalakurichi	10	08.170° N, 77.306° E
9	Theroor Wetland, Thovalai Channel	32	08.178° N, 77.461° E
10	Thirunanthikarai	92	08.397° N, 77.296° E
11	Puthalam Saltpan	8	08.112° N, 77.471° E

Estate (30 species), and Thovalai checkdam (25 species). Survey efforts at Balamore Estate were limited to three replicates, as the region falls largely within a protected area where research activities were restricted due to lack of permission and other constraints (Figure 2).

The documented species are classified under various IUCN Red List categories, with the 'Least Concern' (LC) category comprising 42 species of dragonflies (Anisoptera) and 27 species of damselflies (Zygoptera). Additionally, one dragonfly *Heliogomphus promelas* is categorized as 'Near Threatened' (NT), while one damselfly *Protosticta sanguinostigma* falls under the 'Vulnerable' (VU) category. Furthermore, eight species (*Gynacantha dravida*, *Macrogomphus wynaadicus, Hylaeothemis apicalis* and *Idionyx travancorensis* dragonflies and *Caconeura ramburi*, *Caconeura risi*, *Esme mudiensis* and *Protosticta rufostigma* damselflies) are classified as 'Data Deficient' (DD), while two damselflies

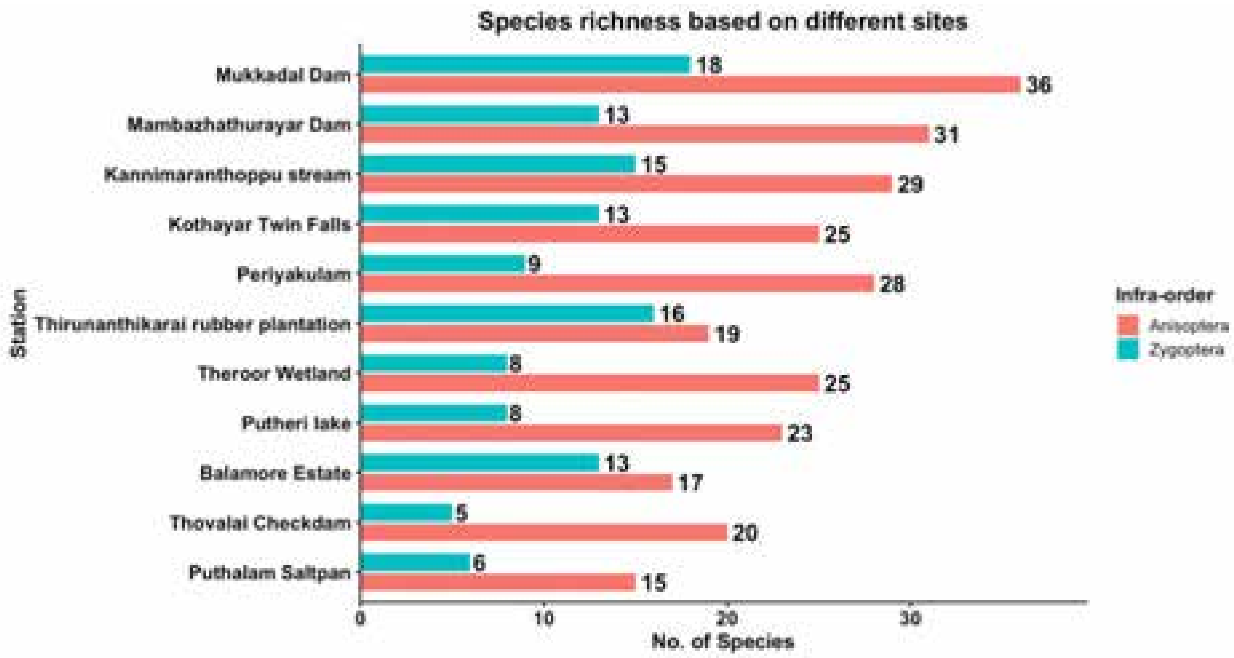

Figure 2. Site-wise Odonata species richness in Kanyakumari District.

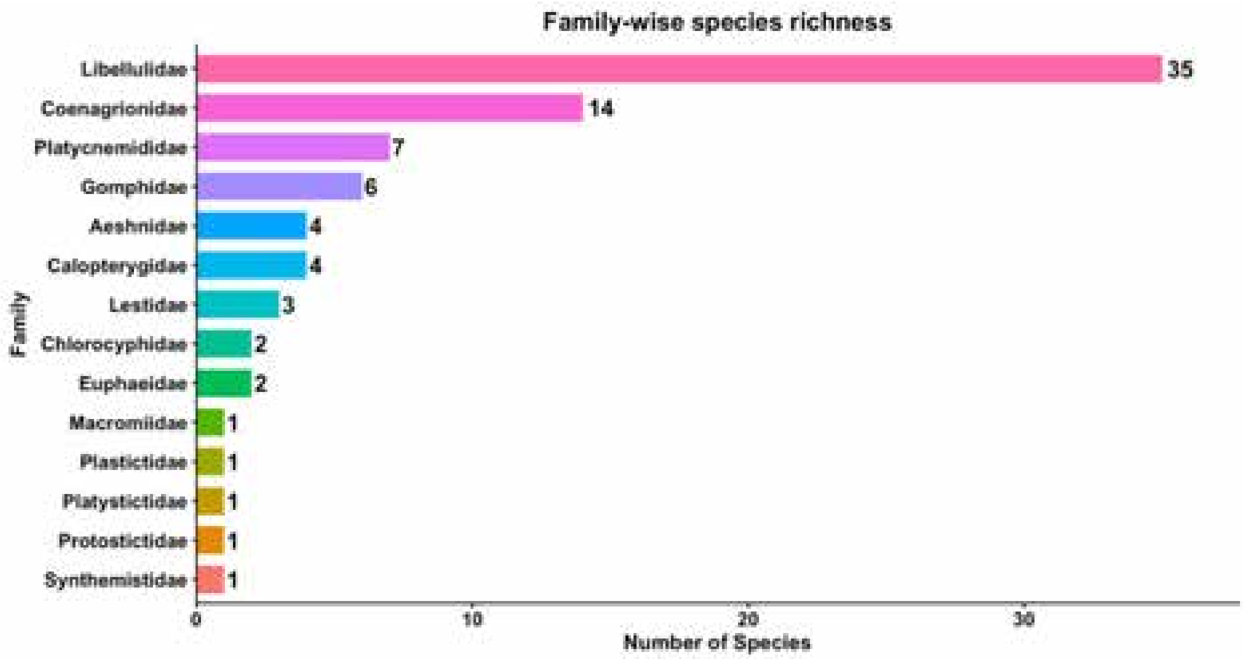

Figure 3. Family-wise species richness.

Vestalis submontana and *Indolestes gracilis davenporti* and one dragonfly *Merogomphus tamaracherriensis* remain 'Not Evaluated' (NE) (Table 2). Platycnemididae and Gomphidae have the highest number of DD and NE species, respectively, on the IUCN Red List.

Libellulidae is the most species-rich family, comprising 35 species, followed by Coenagrionoidea with 14 species, and Platycnemididae with seven species, which are considered moderate in terms of species-rich families. Several families, including Macromiidae, Platystictidae, Protostictidae, and Synthemistidae, are represented by one species each. The distribution of species richness

Table 2. A checklist of dragonflies and damselflies of Kanyakumari District, Tamil Nadu.
IUCN—International Union for Conservation of Nature | LC—Least Concern | DD—Data Deficient | NT—Near Threatened | VU—Vulnerable | NE—Not Evaluated | BE—Balamore Estate | KMT—Kannimaranthoppu | KTF—Kothayar Twin Falls | MTY—Mambazhathurayar Reservoir | MD—Mukkadal Dam | PK—Periyakulam | PS—Puthalam Saltpan | PL— utheri Lake | TW—Theroor Wetland | TNK—Thirunanthikarai | TCD—Thovalai Check Dam | "✓"— Presence | "—"—Absence. * Endemic Taxa.

	Scientific name	Common name	IUCN Red List status	BE	KMT	KTF	MTY	MD	PK	PS	PL	TW	TNK	TCD
	Suborder Anisoptera Selys, 1854													
	Family: Aeshnidae Leach, 1815													
1	*Anax guttatus* (Burmeister, 1839)	Lesser Green Emperor	LC	-	—	—	—	—	✓	✓	✓	✓	—	—
2	*Anax immaculifrons* Rambur, 1842	Magnificient Emperor	LC	✓	—	✓	—	✓	—	—	—	—	—	✓
3	*Anax indicus* Lieftinck, 1942	Elephant Emperor	LC	—	✓	—	✓	✓	✓	✓	—	✓	—	—
4	*Gynacantha dravida* Lieftinck, 1960	Indian Duskhawker	DD	—	—	—	✓	✓	—	—	—	—	✓	—
	Family: Gomphidae Rambur, 1842													
5	*Heliogomphus promelas* (Selys, 1873)*	Indian Lyrtail	NT	—	—	✓	—	—	—	—	—	—	—	—
6	*Ictinogomphus rapax* (Rambur, 1842)	Indian Common Clubtail	LC	✓	✓	✓	✓	✓	✓	—	—	✓	✓	—
7	*Macrogomphus wynaadicus* Fraser, 1924*	Wyanad Bowtail	DD	✓	—	—	—	—	—	—	—	—	—	—
8	*Merogomphus tamaracherriensis* Fraser, 1931*	Malabar Long-legged Clubtail	NE	—	—	✓	—	—	—	—	—	—	—	—
9	*Microgomphus souteri* Fraser, 1924*	Pygmy Clubtail	LC	—	—	✓	—	✓	—	—	—	—	—	—
10	*Paragomphus lineatus* (Selys, 1850)	Lined Hooktail	LC	—	✓	✓	✓	✓	—	—	—	—	—	—
	Family: Libellulidae Leach, 1815													
11	*Acisoma panorpoides* Rambur, 1842	Trumpet-Tail	LC	—	✓	—	✓	✓	✓	—	✓	✓	—	✓
12	*Aethriamanta brevipennis* (Rambur, 1842)	Scarlet Marsh Hawk	LC	—	—	—	✓	—	✓	—	✓	—	—	✓
13	*Brachydiplax chalybea* Brauer, 1868	Rufous-backed Marsh Hawk	LC	—	✓	—	✓	✓	✓	—	✓	—	—	—
14	*Brachydiplax sobrina* (Rambur, 1842)	Little Blue Marsh Hawk	LC	—	—	—	✓	✓	✓	—	✓	✓	—	✓
15	*Brachythemis contaminata* (Fabricius, 1793)	Ditch Jewel	LC	—	✓	—	✓	✓	✓	✓	✓	✓	✓	✓
16	*Bradinopyga geminata* (Rambur, 1842)	Granite Ghost	LC	✓	✓	✓	✓	—	—	—	—	—	—	✓
17	*Cratilla lineata* (Brauer, 1878)	Emerald-Banded Skimmer	LC	✓	—	✓	—	—	—	—	—	—	—	—
18	*Crocothemis servilia* (Drury, 1770)	Scarlet Skimmer	LC	—	✓	—	✓	✓	✓	✓	✓	✓	—	—
19	*Diplacodes trivialis* (Rambur, 1842)	Blue Ground Skimmer	LC	—	—	—	✓	✓	✓	✓	✓	✓	—	—
20	*Hydrobasileus croceus* (Brauer, 1867)	Amber-winged Marsh Glider	LC	—	✓	✓	✓	✓	✓	—	✓	✓	—	—
21	*Hylaeothemis apicalis* Fraser, 1926*	Blue Hawklet	DD	✓	—	✓	—	—	—	—	—	—	—	—
22	*Indothemis carnatica* (Fabricius, 1798)	Light-tipped Demon	LC	—	✓	—	—	—	—	—	—	—	—	—

	Scientific name	Common name	IUCN Red List status	BE	KMT	KTF	MTY	MD	PK	PS	PL	TW	TNK	TCD
23	*Lathrecista asiatica* (Fabricius, 1798)	Asiatic Blood-Tail	LC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
24	*Macrodiplax cora* (Brauer, 1867)	Estuarine Skimmer	LC	–	–	–	–	✓	✓	✓	✓	✓	–	–
25	*Neurothemis tullia* (Drury, 1773)	Pied Paddy Skimmer	LC	–	✓	–	✓	✓	✓	–	✓	✓	✓	–
26	*Onychothemis testacea* Laidlaw, 1902	River Hawker	LC	–	–	✓	–	✓	–	–	–	–	✓	–
27	*Orthetrum chrysis* (Selys, 1891)	Brown-Backed Marsh Hawk	LC	–	✓	✓	–	✓	–	–	–	–	✓	✓
28	*Orthetrum glaucum* (Brauer, 1865)	Blue Marsh Hawk	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
29	*Orthetrum luzonicum* (Brauer, 1868)	Tri-coloured Marsh Hawk	LC	–	✓	✓	✓	✓	✓	–	–	–	✓	✓
30	*Orthetrum pruinosum* (Burmeister, 1839)	Crimson-tailed Marsh	LC	–	✓	✓	✓	✓	–	–	–	–	✓	✓
31	*Orthetrum sabina* (Drury, 1770)	Green Marsh Hawk	LC	–	✓	–	✓	✓	✓	✓	✓	✓	✓	✓
32	*Pantala flavescens* (Fabricius, 1798)	Wandering Glider	LC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
33	*Potamarcha congener* (Rambur, 1842)	Yellow-tailed Ashy Skimmer	LC	–	✓	✓	✓	✓	✓	–	–	✓	–	✓
34	*Rhodothemis rufa* (Rambur, 1842)	Rufous Marsh Glider	LC	–	–	–	✓	✓	✓	–	✓	✓	–	–
35	*Rhyothemis variegata* (Linnaeus, 1763)	Common Picturewing	LC	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
36	*Tetrathemis platyptera* Selys, 1878	Pygmy Skimmer	LC	–	–	✓	–	–	–	–	–	–	–	–
37	*Tholymis tillarga* (Fabricius, 1798)	Coral-tailed Cloudwing	LC	–	✓	–	✓	✓	✓	–	✓	✓	✓	–
38	*Tramea basilaris* (Palisot de Beauvois, 1805)	Red Marsh Trotter	LC	✓	✓	–	–	✓	✓	✓	✓	✓	–	✓
39	*Tramea limbata* (Desjardins, 1832)	Black Marsh Trotter	LC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
40	*Trithemis aurora* (Burmeister, 1839)	Crimson Marsh Glider	LC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
41	*Trithemis festiva* (Rambur, 1842)	Black Stream Glider	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	✓
42	*Trithemis pallidinervis* (Kirby, 1889)	Long-legged Marsh Glider	LC	–	✓	–	✓	✓	✓	✓	✓	✓	–	✓
43	*Urothemis signata* (Rambur, 1842)	Greater Crimson Glider	LC	✓	✓	–	✓	✓	✓	✓	✓	✓	–	✓
44	*Zygonyx iris* Selys, 1869	Emerald Cascader	LC	✓	✓	✓	–	✓	–	–	–	–	✓	–
45	*Zyxomma petiolatum* Rambur, 1842	Long-tailed Dusk Darter	LC	–	–	–	✓	✓	✓	–	✓	✓	–	–
	Family: Macromiidae Needham, 1903													
46	*Epophthalmia vittata* Burmeister, 1839	Common Torrent Hawk	LC	✓	✓	✓	✓	✓	✓	–	–	✓	✓	–
	Family: Synthemistidae Tillyard, 1911													
47	*Idionyx travancorensis* Fraser, 1931	-	DD	✓	–	–	–	–	–	–	–	–	–	–
	Zygoptera Selys, 1854													
	Family: Chlorocyphidae Cowley, 1937													

	Scientific name	Common name	IUCN Red List status	BE	KMT	KTF	MTY	MD	PK	PS	PL	TW	TNK	TCD
48	*Heliocypha bisignata* (Hagen in Selys, 1853)*	Stream Ruby	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
49	*Libellago indica* (Fraser, 1928)*	Southern Heliodor	LC	–	–	–	✓	✓	–	–	–	–	✓	–
	Family: Calopterygidae Selys, 1850													
50	*Neurobasis chinensis* (Linnaeus, 1758)	Stream Glory	LC	✓	✓	✓	–	–	–	–	–	–	✓	–
51	*Vestalis apicalis* Selys, 1873	Black-tipped Forest Glory	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
52	*Vestalis gracilis* (Rambur, 1842)	Clear-winged Forest Glory	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
53	*Vestalis submontana* Fraser, 1934*	Montane Forest Glory	NE	–	–	✓	–	–	–	–	–	–	–	–
	Family: Coenagrionidae Kirby, 1890													
54	*Aciagrion approximans* (Selys, 1876)	Indian Violet Dartlet	LC	✓	–	–	–	–	–	–	–	–	–	–
55	*Agriocnemis pygmaea* (Rambur, 1842)	Pygmy Dartlet	LC	–	–	–	✓	✓	✓	✓	✓	✓	✓	✓
56	*Agriocnemis splendidissima* Laidlaw, 1919	Splendid Dartlet	LC	–	–	–	–	✓	–	–	–	–	–	–
57	*Ceriagrion cerinorubellum* (Brauer, 1865)	Orange-tailed Marsh Dart	LC	–	–	–	–	–	✓	–	–	–	–	–
58	*Ceriagrion coromandelianum* (Fabricius, 1798)	Coromandel Marsh Dart	LC	–	✓	–	✓	✓	✓	–	✓	✓	✓	✓
59	*Ischnura rubilio* Selys, 1876	Western Golden Dartlet	LC	–	✓	–	–	–	–	✓	✓	–	–	–
60	*Ischnura senegalensis* (Rambur, 1842)	Senegal Golden Dartlet	LC	–	✓	–	✓	✓	✓	✓	✓	✓	–	✓
61	*Paracercion malayanum* (Selys, 1876)	Malayan Lily-Squatter	LC	–	–	–	–	–	✓	✓	✓	✓	–	–
62	*Pseudagrion decorum* (Rambur, 1842)	Three-lined Sprite	LC	–	✓	–	–	–	✓	–	–	–	–	–
63	*Pseudagrion indicum* Fraser, 1924*	Yellow-striped Sprite	LC	–	–	–	–	✓	–	–	–	–	–	–
64	*Pseudagrion microcephalum* (Rambur, 1842)	Blue Sprite	LC	–	✓	–	✓	✓	✓	✓	✓	✓	✓	–
65	*Pseudagrion rubriceps* Selys, 1876	Saffron-faced Blue Sprite	LC	–	✓	–	✓	✓	✓	–	✓	✓	✓	✓
	Family: Euphaeidae Yakobson & Bainchi, 1905													
66	*Dysphaea ethela* Fraser, 1924*	Black Torrent Dart	LC	✓	–	✓	–	✓	–	–	–	–	–	–
67	*Euphaea fraseri* (Laidlaw, 1920*)	Malabar Torrent Dart	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
	Family: Lestidae Calvert, 1907													
68	*Indolestes gracilis davenporti* Fraser, 1930*	Davenport's False Spreadwing	NE	✓	–	–	–	–	–	–	–	–	–	–
69	*Lestes concinnus* Hagen in Selys, 1862	Dusky Spreadwing	LC	–	✓	–	–	–	–	–	–	–	–	–
70	*Lestes elatus* Hagen in Selys, 1862	Emerald Spreadwing	LC	–	–	–	–	✓	–	✓	–	✓	–	✓
71	*Lestes praemorsus* Hagen in Selys, 1862	Scalloped Spreadwing	LC	–	–	–	✓	✓	–	–	–	–	–	–
	Family: Coenagrionoidea Kirby, 1890													

	Scientific name	Common name	IUCN Red List status	BE	KMT	KTF	MTY	MD	PK	PS	PL	TW	TNK	TCD
72	*Agriocnemis pieris* Laidlaw, 1919	Indian White Dartlet	LC	–	–	–	–	–	–	–	–	–	✓	–
	Family: Platycnemididae Yakobson & Bainchi, 1907													
73	*Copera marginipes* (Rambur, 1842)	Yellow Bush Dart	LC	–	✓	✓	✓	✓	✓	–	✓	✓	✓	–
74	*Caconeura ramburi* (Fraser, 1922)*	Indian Blue Bambootail	DD	–	✓	–	–	–	–	–	–	–	–	–
75	*Caconeura risi* (Fraser, 1922)*	Wayanad Bambootail	DD	✓	–	✓	–	–	–	–	–	–	✓	–
76	*Copera vittata* Selys, 1863	Blue Bush Dart	LC	–	–	–	–	–	–	–	–	–	✓	–
77	*Esme mudiensis* Fraser, 1931*	Travancore Bambootail	DD	✓	–	✓	–	–	–	–	–	–	–	–
78	*Prodasineura verticalis* (Selys, 1860)	Red-striped Black Threadtail	LC	✓	✓	✓	✓	✓	–	–	–	–	✓	–
79	*Onychargia atrocyana* (Selys, 1865)	Black Marsh Dart	LC	–	–	–	–	✓	–	–	–	–	–	–
	Family: Platystictidae Kennedy, 1920													
80	*Protosticta gravelyi* Laidlaw, 1915*	Pied Shadow Damsel	LC	✓	–	✓	–	–	–	–	–	–	✓	–
81	*Protosticta rufostigma* Kimmins, 1958*	-	DD	✓	–	–	–	–	–	–	–	–	–	–
82	*Protosticta sanguinostigma* Fraser, 1922*	Red Spot Reedtail	VU	–	–	✓	–	–	–	–	–	–	–	–

among these families reflects differential patterns of abundance and taxonomic representation within the Odonata order across Kanyakumari District (Figure 3).

DISCUSSION

The study on Odonata in Kanyakumari District recorded 82 species, representing about 55.78% of Tamil Nadu's total (147 species). It notably documented 18 endemic species, making up 32.73% of the state's known endemics (Subramanian & Babu 2024). The findings, with 47 dragonflies and 35 damselflies, surpass other regional surveys, such as the Madurai District (28 species), the Mettur Dam region in Salem (40 species), Coimbatore (69 species), and the Vellore District (30–37 species) (Muhil & Pramod 2017; Ganeswari & Rajendran 2025) establishing Kanyakumari as a biodiversity hotspot. This richness is attributed to its proximity to the Western Ghats, a global biodiversity hotspot with 176 Odonata species, 68 of which are endemic (Subramanian 2008; Subramanian et al. 2009).

The variation in species richness across the study sites highlights the importance of habitat heterogeneity. High diversity at Mukkadal Dam and Kannimaranthoppu Stream aligns with previous studies showing that forest streams and permanent water bodies support high Odonata species richness (Muhil & Pramod 2017). These environments offer stable conditions and complex microhabitats crucial for larval development and adult territoriality (Subramanian 2005; Vignesh & Manivannan 2021). In contrast, the low species count at Puthalam Saltpan indicates Odonata's sensitivity to high salinity, reinforcing their role as bioindicators of environmental health and water quality (Kunte 2000; Tiple 2020).

Taxonomically the Libellulidae family, with 35 species, dominates Odonata assemblages in Tamil Nadu and India (Koli et al. 2015; Tiple 2020; Ganeswari & Rajendran 2025) attributed to their shorter life cycles, adopt to a wide range of habitat (Gentry et al. 1975; Samways 1989), high dispersal capacity, and habitat adaptability (Ganeswari & Rajendran 2025). Similarly, Coenagrionidae, the second most speciose group with 14 species, also shows a similar prevalence, reflecting their tolerance for diverse wetland types and preference for areas with emergent vegetation.

The odonates documented from Kanyakumari District conservation profile features several species with specialized requirements. Most are classified as LC, but the VU damselfly *Protosticta sanguinostigma* and NT dragonfly *Heliogomphus promelas* highlight

Image 2. A—*Anax immaculifrons* | B—*Acisoma panorpoides* | C—*Microgomphus souteri* | D—*Aethriamanta brevipennis* | E—*Cratilla lineata* | F—*Paragomphus lineatus* | G—*Tholymis tillarga* | H—*Tramea basilaris*. © Muthukrishnan & Shibu.

Image 3. A—*Anax indicus* | B—*Hydrobasileus croceus* | C—*Ictinogomphus rapax* | D—*Rhodothemis rufa* | E—*Urothemis signata* | F—*Brachydiplax sobrina* | G—*Lathrecista Asiatica* | H—*Bradinopyga geminata*. © Muthukrishnan & Shibu.

Image 4. A—*Aciagrion approximans* | B—*Dysphaea ethela* | C—*Onychargia atrocyana* | D—*Lestes concinnus* | E—*Paracercion malayanum* | F—*Protosticta rufostigma*. © Muthukrishnan & Shibu.

the region's ecological importance (Muhil & Pramod 2017). *Protosticta sanguinostigma* thrives in specialized forest habitats, which face threats from fragmentation and land-use changes (Paray & Mir 2023; Samanta et al. 2023). Additionally, many species are categorized as DD or NE, reflecting a wider issue in Indian odonatology regarding limited taxonomic and distributional data. Members of the Gomphidae family are fast-moving insects, with some being crepuscular and many considered rare, making them difficult to detect during surveys (Tiple & Koparde 2015).

The study examined various aquatic habitats in the district but did not include forest areas, particularly within the Kanyakumari Wildlife Sanctuary. Challenges at Balamore Estate, due to its protected status, hindered a comprehensive biodiversity census. The findings highlight the need for strict protection of Kanyakumari's freshwater resources, as urbanization (Sánchez-Bayo & Wyckhuys 2019), pollution (Tiple et al. 2013; Tiple & Koparde 2015), and wetland loss threaten Odonata

Image 5. A—*Heliocypha bisignata* | B—*Lestes praemorsus* | C—*Ischnura rubilio* | D—*Protosticta sanguinostigma* | E—*Pseudagrion indicum* | F—*Caconeura ramburi*. © Muthukrishnan & Shibu.

species, emphasizing the importance of conserving both common and endangered taxa.

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Author details: Muthukrishnan, V. is an independent researcher with a primary focus on biodiversity conservation and wildlife research. His work mainly emphasizes mammalian ecology, field-based biodiversity assessments, and conservation monitoring. He is skilled in conducting mammalian research using ecological survey techniques and contributes toward understanding and conserving wildlife populations and their habitats. Anand Shibu is a wildlife enthusiast with a strong passion for wildlife photography and biodiversity documentation. His interests focus on capturing and documenting wildlife diversity through visual narratives and field observations. He is also associated with local forest departments in supporting biodiversity documentation and wildlife-related conservation activities. Vinod Sadasivan is a dedicated wildlife enthusiast with a strong interest in biodiversity conservation, wildlife photography, and ecological documentation. His work focuses on biodiversity documentation and conducting wildlife awareness campaigns to promote conservation among the public. He is also associated with local forest departments in supporting wildlife monitoring and conservation-related activities. Amirtha Balan, R. is pursuing a Ph.D. at the Wildlife Institute of India, focusing on wildlife conservation. His research emphasizes herpetofaunal diversity, turtle ecology, biodiversity profiling, and ecological monitoring. He is particularly interested in understanding ecological patterns and contributing to science-based conservation strategies for threatened wildlife species and habitats.

Author contribution: Conceptualization & Study Design: Muthukrishnan, Vinod Sadasivan, Amirtha Balan; Data collection & analysis: Muthukrishnan, Anand Shibu, Amirtha Balan; Manuscript writing: Muthukrishnan, Amirtha Balan; Reviewed manuscript: Muthukrishnan, Anand Shibu, Vinod Sadasivan, Amirtha Balan R. All authors reviewed and approved the final manuscript.

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COMMUNICATION

Documentation of dicotyledonous angiosperm diversity of Kanakamala, Kerala, India

Marunnoli Umaiba Fitha [1] & Puravannoor Edakkad Sreejith [2]

[1,2] Postgraduate & Research Department of Botany, The Zamorin's Guruvayurappan College, Kozhikode, Kerala 673014, India.
[1] umaibafitha@gmail.com, [2] sreejithzgc@gmail.com (corresponding author)

Abstract: The present study deals with identification and documentation of dicotyledonous angiosperm plants in Kanakamala, Kannur District, Kerala. The survey was conducted during March 2024 to March 2025 and documented 182 dicotyledonous angiosperms belonging to 152 genera under 57 families. Out of the reported plants, 17 species are endemic, one is 'Vulnerable', and one is 'Endangered'. Names of plants and status are also provided.

Keywords: Angiosperm plants, endangered, endemic, herbarium, flora, Kannur District, lateritic plateau, tropical moist deciduous, vulnerable.

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Author details: Umaiba Fitha is a M.Sc. Botany graduate and 4th rank holder under the University of Calicut from The Zamorin's Guruvayurappan College. Her research focused on the dicot flora of Kanakamala. Her interests include plant taxonomy, floral diversity, ecology, and biodiversity conservation. Dr. Sreejith P.E., is assistant professor in the Post Graduate and Research Department of Botany at The Zamorin's Guruvayurappan College, Kozhikode, affiliated with the University of Calicut. His academic and research interests include plant taxonomy, angiosperm systematics, floristics, biodiversity conservation, and banana taxonomy. He has published more than 23 research papers in national and international journals and has contributed to several books and book chapters related to plant diversity and taxonomy. He is also actively involved in editorial and review activities of scientific journals and has guided multiple postgraduate research projects in botany and biodiversity studies.

Author contribution: The present work was carried out as part of the M.Sc. project of the first author under the supervision and guidance of the second author. Field exploration and specimen collection were conducted by the first author, while identification and all other aspects of the study were completed jointly by both the student and the supervisor.

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INTRODUCTION

India is well-known for its rich biodiversity and vast landscapes. Globally, it accounts for only 2.3% of the total land area. One of the major contributors to India's biodiversity is the Western Ghats, which harbors numerous habitats due to its high range of variation in latitude, altitude, and climate. It also exhibits a high level of endemism, which is attributed to the long period of isolation from similar habitats in the Indian subcontinent (ATREE & CEPF 2013). Lateritic plateau is an important area that has rich species contribution. This plateau thus possesses different endemic and habitat specific species due to special environmental conditions (Drisya et al. 2023). However, these plateaus have received less conservation awareness compared to forests of Western Ghats (Pramod & Pradeep 2021). Present work is an attempt to document the diversity of dicotyledonous angiosperms in Kanakamala, Chokli of Kannur District of Kerala, southern India. It is more over a lateritic plateau and so this work is crucial for understanding the importance of lateritic plateau in biodiversity and conservation.

STUDY AREA

The study was conducted on the Kanakamala, located in Panoor Municipality in Kannur District of Kerala, India (Image 1). It is a lateritic hill spread around 0.4 km^2. It is geographically located between 11.719° N and 75.581° E with an average elevation of 118 m. It is a part of Western Ghats and located appropriately 6 km away from Chokli town, 10 km away from Mahe, and 12 km away from Thalassery Town.

Vegetation

The vegetation of Kanakamala, Kannur represents a tropical moist deciduous to secondary scrub landscape influenced by monsoonal climate and anthropogenic disturbances. The floristic composition, based on the recorded dicotyledonous species, shows dominance of Fabaceae, Rubiaceae, Lamiaceae, Asteraceae, and Malvaceae, indicating a well-developed herb and shrub layer. Tree species such as *Terminalia paniculata*, *Syzygium caryophyllatum*, *Holigarna arnottiana*, *Memecylon umbellatum*, *Bridelia retusa*, and *Ficus* spp. reflect remnants of forest vegetation, while shrubs and herbs like *Clerodendrum infortunatum*, *Lantana camara*, *Chromolaena odorata*, *Ageratum conyzoides*, and *Euphorbia hirta* characterize secondary growth and disturbed habitats. Climbers including *Cyclea peltata*, *Gymnema sylvestre*, *Hemidesmus indicus*, and *Ipomoea* spp. contribute to structural complexity along forest margins. The presence of Western Ghats endemic and conservation-significant species highlights the ecological importance of the area, and overall, the vegetation can be described as secondary moist deciduous vegetation with scrub and weed elements.

MATERIALS AND METHODS

An extensive and repeated field survey was carried out from March 2024 to March 2025. Frequent explorations helped document the diverse flora across different seasons. Frequent collection trips were conducted in every weekend to ensure maximum collection. Plant samples were collected for laboratory studies and herbarium preparation. Simultaneously, photographs of the plants were taken against a black cloth with a scale placed beside them. The photographs were captured using mobile phone cameras (Vivo V20 and Oppo A10). The herbarium specimens were prepared using the dry method (Jain & Rao 1977) and were mounted on standard-sized herbarium sheets and deposited in the Zamorin's Guruvayurappan College Herbarium (ZGC). Identification of plants was carried out using Gamble (1925) and Pramod & Pradeep (2020), along with online resources (eFlora of Kerala https://www.eflorakerala.com; Indian Biodiversity Portal https://indiabiodiversity.org; IPNI https://www.ipni.org). Maximum efforts were taken to use the latest nomenclature and were treated according to the latest APG systems of classification. The threat category was gathered from IUCN Red List of Threatened Species (https://www.iucnredlist.org/).

RESULTS AND DISCUSSION

The present study was undertaken to document the diversity of dicotyledonous angiosperms in Kanakamala, Chockli, Kannur. A total of 182 plant species, belonging to 152 genera under 57 families were collected, identified, and documented (Table 1). Among these, 85 species (46.70%) are herbs, 43 (23.63%) are shrubs, 28 (15.38%) are trees, and 26 (14.29) are climbers (Figure 1a). The dominant family is Fabaceae (Leguminosae) comprising 23 genera and 26 species. It is followed by Rubiaceae with 14 species, Malvaceae, and Lamiaceae with 13 species, Asteraceae and Acanthaceae with nine species each, Apocynaceae and Phyllanthaceae with seven species each, and Convolvulaceae and Amaranthaceae with six species each, among others.

Image 1. The study area - Kanakamala, Kannur, Kerala: a–c—Lateritic plateau and vegetation | d & e—Google images of the study area. a–c © Umaiba.

Table 1. Dicot angiosperms of Kanakamala, Kannur, Kerala.

	Binomial name	Family	Distribution	Endemism	Red List status
1.	*Peperomia pellucida* (L.) Kunth	Piperaceae	E		
2.	*Uvaria narum* (Dunal) Wall. ex Hook.f. & Thomson	Annonaceae	N		
3.	*Cassytha filiformis* L.	Lauraceae	N		
4.	*Cyclea peltata* (Burm.f.) Hook.f. & Thomson	Menispermaceae	N		
5.	*Alysicarpus bupleurifolius* (L.) DC.	Fabaceae	N		LC
6.	*Alysicarpus vaginalis* (L.) DC.	Fabaceae	N		
7.	*Centrosema molle* Mart. ex Benth.	Fabaceae	E		
8.	*Crotalaria pallida* Aiton	Fabaceae	N		
9.	*Dalbergia horrida* (Dennst.) Mabb.	Fabaceae	N		LC
10.	*Desmodium scorpiurus* (Sw.) Desv.	Fabaceae	E		
11.	*Geissaspis tenella* Benth.	Fabaceae	N	SI	LC
12.	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	Fabaceae	E		
13.	*Grona heterocarpa* (L.) H.Ohashi & K.Ohashi var. *heterocarpa*	Fabaceae	N		
14.	*Grona triflora* (L.) H.Ohashi & K.Ohashi	Fabaceae	N		LC
15.	*Indigofera prostrata* Willd.	Fabaceae	N		
16.	*Stylosanthes hamata* (L.) Taub.	Fabaceae	E		
17.	*Tadehagi triquetrum* (L.) H.Ohashi	Fabaceae	N		LC
18.	*Tephrosia pulcherrima* (Wight ex Baker) Gamble	Fabaceae	N	SI	LC
19.	*Vigna trilobata* (L.) Verdc.	Fabaceae	N		
20.	*Zornia gibbosa* Span.	Fabaceae	N		
21.	*Bauhinia acuminata* L.	Fabaceae	E		
22.	*Bauhinia purpurea* L.	Fabaceae	E		
23.	*Chamaecrista kleinii* (Wight & Arn.) V.Singh	Fabaceae	N		
24.	*Hultholia mimosoides* (Lam.) Gagnon & G.P.Lewis	Fabaceae	N		LC
25.	*Libidibia coriaria* (Jacq.) Schltdl.	Fabaceae	E		
26.	*Peltophorum pterocarpum* (DC.) Backer ex K.Heyne	Fabaceae	E		
27.	*Tamarindus indica* L.	Fabaceae	E		
28.	*Acacia auriculiformis* A.Cunn. ex Benth.	Fabaceae	E		
29.	*Adenanthera pavonina* L.	Fabaceae	E		
30.	*Mimosa pudica* L.	Fabaceae	E		
31.	*Polygala glaucoides* L.	Polygalaceae	N		
32.	*Casuarina equisetifolia* L.	Casuarinaceae	E		
33.	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Rhamnaceae	N		LC
34.	*Ziziphus oenopolia* (L.) Mill.	Rhamnaceae	N		LC
35.	*Ziziphus rugosa* Lam.	Rhamnaceae	N		LC
36.	*Ficus benghalensis* L.	Moraceae	N		
37.	*Ficus hispida* L.f.	Moraceae	N		LC
38.	*Pilea microphylla* (L.) Liebm.	Urticaceae	E		
39.	*Pouzolzia zeylanica* (L.) Bennett	Urticaceae	N		
40.	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	N		
41.	*Cucumis maderaspatanus* L.	Cucurbitaceae	N		
42.	*Connarus paniculatus* Roxb	Connaraceae	N		LC
43.	*Rourea minor* (Gaertn.) Alston	Connaraceae	N		
44.	*Biophytum sensitivum* (L.) DC.	Oxalidaceae	N		
45.	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	N		LC

	Binomial name	Family	Distribution	Endemism	Red List status
46.	*Euphorbia hirta* L.	Euphorbiaceae	E		
47.	*Euphorbia thymifolia* L.	Euphorbiaceae	E		
48.	*Macaranga peltata* Müll.Arg.	Euphorbiaceae	N		
49.	*Microstachys chamaelea* (L.) Müll.Arg.	Euphorbiaceae	N		
50.	*Campylospermum serratum* (Gaertn.) Bittrich & M.C.E.Amaral	Ochnaceae	N		LC
51.	*Breynia vitis-idaea* (Burm.f.) C.E.C.Fisch.	Phyllanthaceae	N		LC
52.	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae	N		LC
53.	*Bridelia stipularis* (L.) Blume	Phyllanthaceae	N		LC
54.	*Flueggea leucopyrus* Willd.	Phyllanthaceae	N		LC
55.	*Phyllanthus amarus* Schumach. & Thonn.	Phyllanthaceae	E		
56.	*Phyllanthus urinaria* L.	Phyllanthaceae	N		
57.	*Phyllanthus virgatus* G.Forst. var. *virgatus*	Phyllanthaceae	N		
58.	*Passiflora foetida* L.	Passifloraceae	E		
59.	*Flacourtia indica* (Burm.f.) Merr.	Salicaceae	N		LC
60.	*Pigea enneasperma* (L.) P.I.Forst.	Violaceae	N		
61.	*Hugonia mystax* L.	Linaceae	N		
62.	*Getonia floribunda* Roxb.	Combretaceae	N		
63.	*Terminalia paniculata* Roth	Combretaceae	N	PI	LC
64.	*Rotala malampuzhensis* R.V.Nair ex C.D.K.Cook	Lythraceae	N	WG	LC
65.	*Ludwigia hyssopifolia* (G.Don) Exell	Onagraceae	E		
66.	*Syzygium caryophyllatum* (L.) Alston var. *caryophyllatum*	Myrtaceae	N		VU
67.	*Melastoma malabathricum* L.	Melastomataceae	N		
68.	*Memecylon randerianum* S.M.Almeida & M.R.Almeida	Melastomataceae	N	SWG	
69.	*Memecylon umbellatum* Burm.f.	Melastomataceae	N		LC
70.	*Osbeckia muralis* Naudin	Melastomataceae	N		
71.	*Anacardium occidentale* L.	Anacardiaceae	E		
72.	*Holigarna arnottiana* Hook.f.	Anacardiaceae	N	SWG	LC
73.	*Mangifera indica* L.	Anacardiaceae	E		
74.	*Glycosmis pentaphylla* (Retz.) DC.	Rutaceae	N		LC
75.	*Azadirachta indica* A.Juss.	Meliaceae	E		
76.	*Naregamia alata* Wight & Arn.	Meliaceae	N	PI	
77.	*Hibiscus rosa-sinensis* L.	Malvaceae	E		
78.	*Hibiscus surattensis* L.	Malvaceae	N		
79.	*Sida acuta* Burm.f.	Malvaceae	N		
80.	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	N		
81.	*Sida cordifolia* L.	Malvaceae	N		
82.	*Sida rhombifolia* L. ssp. *alnifolia* (L.) Ugbor.	Malvaceae	E		
83.	*Urena lobata* L. ssp. *lobata* Mast.	Malvaceae	N		LC
84.	*Urena lobata* L. ssp. *sinuata* (L.) Borss.Waalk.	Malvaceae	N		
85.	*Melochia corchorifolia* L.	Malvaceae	N		LC
86.	*Sterculia guttata* Roxb. ex DC.	Malvaceae	N		LC
87.	*Waltheria indica* L.	Malvaceae	E		
88.	*Microcos paniculata* L.	Malvaceae	N		LC
89.	*Triumfetta rhomboidea* Jacq.	Malvaceae	N		
90.	*Cleome rutidosperma* DC. var. burmanni (Wight & Arn.) Siddiqui & S.N.Dixit	Cleomaceae	N		
91.	*Cleome viscosa* L.	Cleomaceae	N		

	Binomial name	Family	Distribution	Endemism	Red List status
92.	*Santalum album* L.	Santalaceae	E		
93.	*Dendrophthoe falcata* (L.f.) Etting.	Loranthaceae	N		
94.	*Drosera indica* L.	Droseraceae	N		LC
95.	*Polycarpaea aurea* Wight & Arn.	Caryophyllaceae	N	SI	
96.	*Rivina humilis* L.	Petiveriaceae	E		
97.	*Achyranthes aspera* L. var. *aspera*	Amaranthaceae	N		
98.	*Aerva lanata* (Linn.) Juss.	Amaranthaceae	N		
99.	*Alternanthera bettzickiana* (Regel) G.Nicholson	Amaranthaceae	E		
100.	*Alternanthera brasiliana* (L.) Kuntze	Amaranthaceae	E		
101.	*Alternanthera sessilis* (L.) R.Br. ex. DC.	Amaranthaceae	N		LC
102.	*Cyathula prostrata* (L.) Blume	Amaranthaceae	N		
103.	*Boerhavia diffusa* L.	Nyctaginaceae	N		
104.	*Trigastrotheca pentaphylla* (L.) Thulin	Molluginaceae	N		
105.	*Impatiens minor* (DC.) Bennet	Balsaminaceae	N	WG	
106.	*Chrysophyllum oliviforme* L.	Sapotaceae	E		
107.	*Mimusops elengi* L.	Sapotaceae	N		LC
108.	*Benkara malabarica* (Lam.) Tirveng.	Rubiaceae	N		
109.	*Canthium coromandelicum* (Burm.f.) Alston	Rubiaceae	N		
110.	*Chassalia curviflora* (Wall. ex Kurz) Thwaites	Rubiaceae	N		
111.	*Exallage auricularia* (L.) Bremek.	Rubiaceae	N		
112.	*Ixora coccinea* L.	Rubiaceae	N		
113.	*Mitracarpus hirtus* (L.) DC.	Rubiaceae	E		
114.	*Mussaenda frondosa* L.	Rubiaceae	N		LC
115.	*Neanotis subtilis* (Miq.) Govaerts ex Punekar & Lakshmin.	Rubiaceae	N		
116.	*Oldenlandia corymbosa* L.	Rubiaceae	N		
117.	*Oldenlandia herbacea* (L.) Roxb.	Rubiaceae	N		
118.	*Spermacoce articularis* L.	Rubiaceae	N		
119.	*Spermacoce latifolia* Aubl.	Rubiaceae	E		
120.	*Spermacoce ocymoides* Burm.f.	Rubiaceae	N		
121.	*Spermacoce pusilla* Wall.	Rubiaceae	N		
122.	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	Gentianaceae	N		
123.	*Canscora perfoliata* Lam.	Gentianaceae	N	WG	
124.	*Strychnos nux-vomica* L.	Loganiaceae	N		LC
125.	*Catharanthus pusillus* (Murr.) G.Don	Apocynaceae	N		
126.	*Ichnocarpus frutescens* (L.) W.T.Aiton	Apocynaceae	N		
127.	*Tabernaemontana alternifolia* L.	Apocynaceae	N	SWG	
128.	*Gymnema sylvestre* (Retz.) R.Br. ex Sm.	Apocynaceae	N		
129.	*Hemidesmus indicus* (L.) R.Br.	Apocynaceae	N		
130.	*Stephanotis volubilis* (L.f.) S.Reuss	Apocynaceae	N		
131.	*Vincetoxicum indicum* (Burm.f.) Mabb.	Apocynaceae	N		
132.	*Euploca marifolia* (J. Koenig ex Retz.) Ancy & P.Javad	Boraginaceae	N		
133.	*Camonea vitifolia* (Burm.f.) A.R.SimÃµes & Staples	Convolvulaceae	E		
134.	*Evolvulus alsinoides* (L.) L., var. *alsinoides*	Convolvulaceae	N		
135.	*Hewittia malabarica* (L.) Suresh	Convolvulaceae	N		
136.	*Ipomoea quamoclit* L.	Convolvulaceae	E		
137.	*Ipomoea triloba* L.	Convolvulaceae	E		
138.	*Xenostegia tridentata* (L.) D.F.Austin & Staples	Convolvulaceae	N		

	Binomial name	Family	Distribution	Endemism	Red List status
139.	*Jasminum malabaricum* Wight	Oleaceae	N	WG	
140.	*Tetrapilus dioicus* (Roxb.) L.A.S.Johnson	Oleaceae	N		
141.	*Mecardonia procumbens* (Mill.) Small	Plantaginaceae	E		
142.	*Scoparia dulcis* L.	Plantaginaceae	E		
143.	*Bonnaya ciliata* (Colsm.) Spreng.	Linderniaceae	N		LC
144.	*Torenia bicolor* Dalzell	Linderniaceae	N	WG	LC
145.	*Torenia crustacea* (L.) Cham. & Schltdl.	Linderniaceae	N		LC
146.	*Clerodendrum infortunatum* L.	Lamiaceae	N		LC
147.	*Clerodendrum paniculatum* L.	Lamiaceae	N		
148.	*Gmelina arborea* Roxb.	Lamiaceae	N		LC
149.	*Holmskioldia sanguinea* Retz.	Lamiaceae	E		
150.	*Holmskioldia sanguinea* Retz. forma *sanguinea*	Lamiaceae	E		
151.	*Premna serratifolia* L.	Lamiaceae	N		
152.	*Rotheca serrata* (L.) Steane & Mabb.	Lamiaceae	N		
153.	*Leucas aspera* (Willd.) Link	Lamiaceae	N		
154.	*Mesosphaerum suaveolens* (L.) Kuntze	Lamiaceae	E		
155.	*Ocimum tenuiflorum* L.	Lamiaceae	N		
156.	*Platostoma hispidum* (L.) A.J.Paton	Lamiaceae	N		
157.	*Pogostemon purpurascens* Dalzell	Lamiaceae	N	WG	
158.	*Pogostemon quadrifolius* (Benth.) F.Muell.	Lamiaceae	N		DD
159.	*Parasopubia hofmannii* var. *albiflora* Pradeep & Pramod	Orobanchaceae	N	SI	
160.	*Striga angustifolia* (D.Don) Saldanha	Orobanchaceae	N		
161.	*Utricularia cecilii* P.Taylor	Lentibulariaceae	N	WG	EN
162.	*Andrographis paniculata* (Burm.f.) Wall. ex Nees	Acanthaceae	N		
163.	*Asystasia dalzelliana* Sant.	Acanthaceae	N		
164.	*Asystasia gangetica* (L.) T.Anderson	Acanthaceae	N		
165.	*Phaulopsis dorsiflora* (Retz.) Sant.	Acanthaceae	N		
166.	*Rostellularia procumbens* (L.) Nees	Acanthaceae	N		
167.	*Ruellia prostrata* Poir.	Acanthaceae	N		
168.	*Rungia pectinata* (L.) Nees	Acanthaceae	N		
169.	*Staurogyne zeylanica* (Nees) Kuntze	Acanthaceae	N		
170.	*Thunbergia erecta* (Benth.) T.Anderson	Acanthaceae	E		
171.	*Tecoma stans* (L.) Juss.	Bignoniaceae	E		
172.	*Stachytarpheta jamaicensis* (L.) Vahl	Verbenaceae	E		
173.	*Lantana camara* L.	Verbenaceae	E		
174.	*Ageratum conyzoides* L.	Asteraceae	E		
175.	*Blumea laevis* (Lour.) Merr.	Asteraceae	N		
176.	*Centratherum punctatum* Cass.	Asteraceae	E		
177.	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	E		
178.	*Cyanthillium cinereum* (DC.) H.Rob.	Asteraceae	N		
179.	*Emilia sonchifolia* (L.) DC.	Asteraceae	N		
180.	*Mikania micrantha* Kunth	Asteraceae	E		
181.	*Synedrella nodiflora* (L.) Gaertn.	Asteraceae	E		
182.	*Tricholepis amplexicaulis* C.B.Clarke	Asteraceae	N	WG	

N—Native | E—Exotic | PI—Peninsular India | SI—Southern India | WG—Western Ghats | SWG—Southern Western Ghats | LC—Least Concern | DD—Data Deficient | EN—Endangered | VU—Vulnerable | Blank—Not Evaluated.

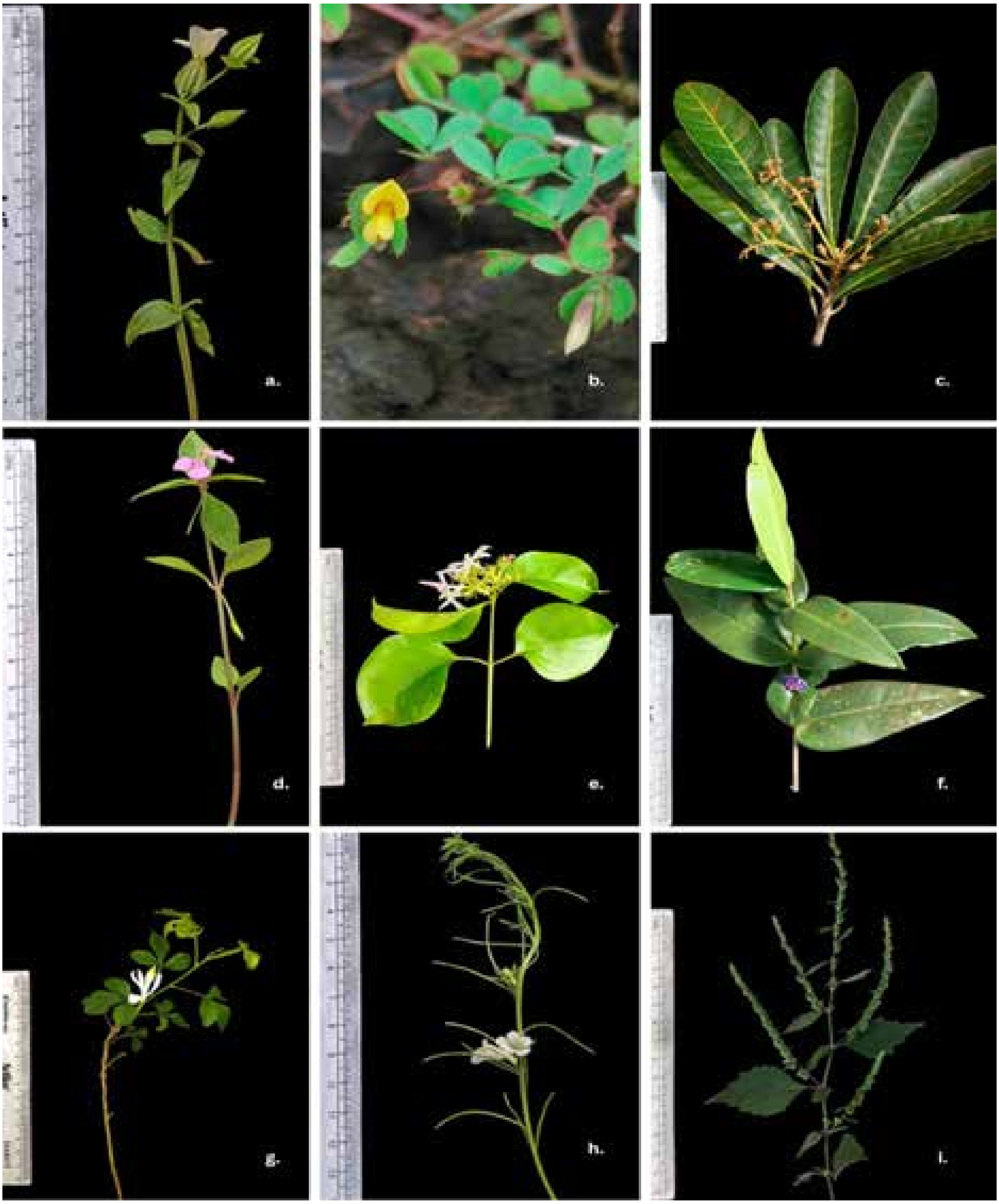
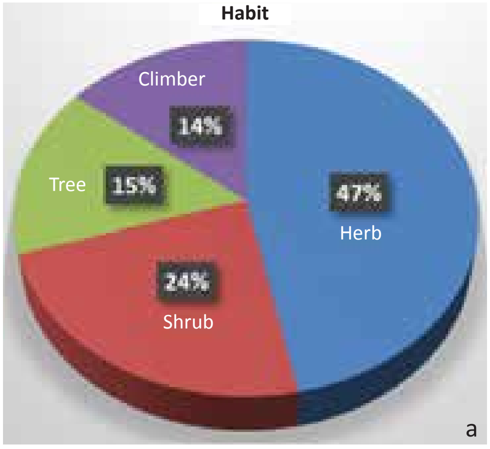


Image 2. Endemic species at Kanakamala: a—*Canscora perfoliata* | b—*Geissaspis tenella* | c—*Holigarna arnottiana* | d—*Impatiens minor* | e—*Jasminum malabaricum* | f—*Memecylon randerianum* | g—*Naregamia alata* | h—*Parasopubia hofmannii* var. *albiflora* | i—*Pogostemon purpurascens*. © Umaiba.

Sida and *Spermacoce* are the most abundant genera, with four species each. They are followed by *Phyllanthus* and *Alternanthera* with three species each. Furthermore, *Cleome*, *Hibiscus*, *Urena*, *Alysicarpus*, *Grona*, *Bauhinia*, *Memecylon, Oldenladia, Canscora, Ipomoea, Torenia, Asystasia, Clerodendron, Holmskioldia, Pogostemon,*

Image 3. Endemic species at Kanakamala: a—*Polycarpaea aurea* | b—*Rotala malampuzhensis* | c—*Tabernaemontana alternifolia* | d—*Tephrosia pulcherrima* | e—*Terminalia paniculata* | f—*Torenia bicolor* | g—*Tricholepis amplexicaulis* | h—*Utricularia cecilii*. © Umaiba.



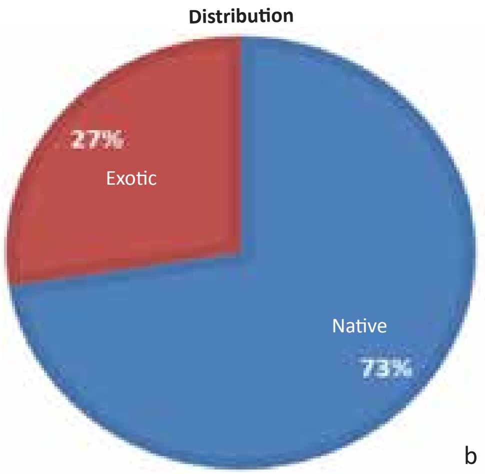


Figure 1. a—Habit distribution | b—Percentage distribution of native/exotic plants.

Bridelia, Euphorbia and *Ficus* contribute two species each. Additionally, this study also identifies nine monotypic genera including *Naregamia*, *Rivina*, *Hewittia*, *Hemidesmus*, *Ichnocarpus*, *Synedrella*, *Centratherum*, *Getonia*, and *Hultholia*.

The identified plants include 132 native and 50 exotic taxa as per the latest records in Plants of the World Online (https://powo.science.kew.org) (Figure 1b). According to the IUCN Red List Version 2025-1, a total of 62 plant species has been classified into various categories. Among these, two species are categorized as 'Data Deficient', another two fall under different threat categories. These include one 'Vulnerable' species, *Syzygium caryophyllatum* and one 'Endangered' species, *Utricularia cecilii*.

Among the plants obtained, 17 species are endemic (Table 1, Image 2 & 3). Out of which eight species are endemic to Western Ghats, four are endemic to southern India, three are endemic to southern Western Ghats and two are endemic to peninsular India. This plateau shows a relatively high rate of endemism.

CONCLUSION

Kanakamala exhibited a diverse range of angiosperms, especially dicots, and it can be considered a repository of endemic and rare plant taxa. A preliminary analysis revealed the presence of 182 dicot plants, of which 17 are endemic and three are threatened. That represents 9.3 percent of the total dicot flora (Table 1). Notably, many of the plant species collected from the area possess medicinal properties and are commonly used for various ailments (Jamsheena & Abdussalam 2018; Sukhadev et al. 2022). Although the area is frequently visited for birdwatching and other recreational activities, systematic documentation of plant diversity has been limited. The present floristic inventory highlights the need for further studies, particularly those incorporating rapid threat assessment and habitat-level evaluations, to better understand conservation priorities of the laterite plateau. Such focused assessments would complement floristic surveys and support informed management and conservation planning for the area.

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COMMUNICATION

Diversity of dye-yielding plants traditionally used by ethnic communities of Assam, India

Bhuban Chandra Chutia [1], **Hena Parbin** [2], **Abhijit Chandra Roy** [3], **Krishna Kanta Medhi** [4] & **Utpal Bora** [5]

[1,2,3] Department of Zoology, , Nagaon University, Nagaon, Assam 782001, India.
[4] Department of Botany, Nagaon University, Nagaon, Assam 782001, India.
[5] Department of Biosciences and Bioengineering, Indian Institute of Technology Guwahati, Guwahati, Assam 781039, India.
[1] bhuban78@gmail.com (corresponding author), [2] henaparbin12@gmail.com, [3] abhichroy@gmail.com, [4] medhikrishnc@gmail.com, [5] ubora@iitg.ac.in

Abstract: Many plant species contain natural colouring matter in their leaves, seeds, fruits, roots or bark, suitable for use as dyes. This paper deals with the diversity of traditional dye-yielding plants used by ethnic communities in Assam, India. Field investigation was carried out in villages of upper, middle, and lower Assam, and information was collected based on a semi-structured questionnaire, interviews, and discussions among the major ethnic communities. We report a checklist of 45 plant species used by 13 ethnic communities, including vernacular names and plant parts used. Women in every ethnic group of Assam have rich traditional knowledge of colouring textiles and other objects with dyes extracted from locally available plants, and of fixing them to different bases. Natural dye-yielding plants have immense significance in the socio-economic and socio-cultural life of these ethnic communities. Proper documentation and exploration of dye-yielding plants will help to preserve traditional knowledge.

Keywords: Biodiversity, bio-resources, community, documentation, exploration, ethnic community, mordents, natural dye, scientific approach, textile industry, traditional knowledge.

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Author details: Dr. Bhuban Chandra Chutia, associate professor & head, Department of Zoology, Nagaon University, Nagaon, Assam, India. Dr. Hena Parbin, guest faculty, Department of Zoology, Nagaon University, Nagaon, Assam, India. Abhijit Chandra Roy, research scholar, Department of Zoology, Nagaon University, Nagaon, Assam, India. Dr. Krishna Kanta Medhi, associate professor (retired 2021), Department of Botany, Nowgong College (Autonomous). Prof. Utpal Bora, professor & head, Department of Biosciences and Bioengineering, Indian Institute of Technology Guwahati, Assam, India

Author contribution: This work was carried out in cooperation among all authors. All the authors contributed to the design of the study. Hena Parbin and Abhijit Chandra Roy have done all the collection work, extraction of dye and wrote the first draft of the manuscript. Author Krishna Kanta Medhi identified plant samples and authors Bhuban Chandra Chutia and Utpal Bora contributed to the management and execution of the study and supervised the whole work. All authors read and approved the final manuscript.

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INTRODUCTION

Natural sources have long been widely used for dyeing. Plant-based natural dyes were first recorded around 2600 BC in China. The Indus Valley Civilization also used dyes from plant sources (Siva 2007). Plant and animal products are used for dyeing (Gupta 1999), and leaves, fruits, barks, seeds, and roots of many plant species are used for extracting colour. Natural resources endemic to a particular region are used in different parts of the world for their own natural dyeing tradition. In the second half of the 19th Century with the invention of synthetic dyes, the use of natural dyes started declining (Saravan & Chandramohan 2011). Synthetic dye has replaced natural dye for the rapid industrialization of textile production due to its easy availability and simple application process in ready-to-apply form. The beauty of natural dyes, however, has survived among specific communities that traditionally pass the knowledge to their next generation without proper documentation. Various research across the world has revealed the toxic effect of synthetic dyes. They release harmful chemicals, causing health hazards and degrading nature's ecological balance. The effluents of synthetic dyes contain carcinogenic and mutagenic chemicals, which pose a serious threat to living organisms (Novotny et. al. 2006; Mathur & Bhatnagar 2007; Uddin et al. 2014). Due to growing awareness on health and the environment, the use of natural dye is revived because of its eco-friendly and biodegradable nature (Prusty et al. 2010). Throughout the world, textile industries have shown dynamism in terms of growth and export performance of natural dye (Cautisicos 2006). Applications of natural dye on natural fibers not only have high compatibility with the environment but also provide health benefits to the wearer (Sarkar 2004; Singh et al. 2005). Despite the several advantages of natural dyes over synthetic, the present international consumption of natural dye is only 1% of the synthetic. This limitation is caused by a lack of scientifically validated information on dye-yielding sources, along with technical drawbacks related to dye extraction and a standardization process (Patil et al. 2012).

Natural dye-yielding plants are one of the most important natural resources found in Assam. The ethnic people are only now exploring its high potential for commercial and industrial expansion. Women in every ethnic group of Assam have perfected ways of colouring textiles and other objects with dyes extracted from locally available plants and fixing them to different bases. The state of Assam has a large number of major tribes and sub-tribes broadly belonging to the Indo-Mongoloid racial stock, including ethnic groups like Tai Ahom, Kacharis, Rabhas, Chutias, Bodos, Tiwas, SaraniaKacharis, MechKacharis, Thengal-Kacharis, and Deoris, with varied composition of cultural diversity. The information regarding dye-yielding plant in Northeast India is meager (Borthakur 1990; Ahmed & Borthakur 2005; Mahanta & Tiwari 2005; Sharma et al. 2005). Kar & Borthakur (2007) reported 47 dye-yielding plants from Assam. Akimpou et al. (2005) reported 25 dye-yielding plants used by Karbis of Assam. Hence, the present study has been undertaken to investigate and explore the availability of natural dye-yielding plant species in Assam and gather information on traditional knowledge associated with the use of natural dyes. A need of the hour is a proper exploration of dye-yielding plants traditionally used by the ethnic communities of Assam to generate a database of natural dyes, which will significantly help augment the textile industry.

MATERIALS AND METHODS

Study area

For the exploration of natural dye-yielding plants, the entire region of Assam is considered. Assam is one of the states of northeastern India, located at 26.2006° N, 92.9376° E, covering an area of 78,438 km^2 with diverse ecological conditions.

Biodiversity exploration of dye-yielding plants

The survey was started in April 2019 and completed in March 2021. Extensive surveys were conducted in eight districts of upper Assam, two districts of middle Assam, and one district of lower Assam. Rural artisans from 13 different communities were interviewed, and a structured questionnaire was provided pertaining to various information regarding the traditional use of dye-yielding plants and preparation methods. A list of dye-yielding plants was compiled, comprising 45 species used by 13 communities in Assam.

Sample collection

The surveyed plants were photographed, and various parts of the plants, such as roots, seeds, leaves, and bark, used for dye extraction, were collected for preparation of a herbarium using a standard herbarium technique (Jain & Rao 1977). The collected plant samples were identified in consultation with plant taxonomist, monographs and relevant literature.

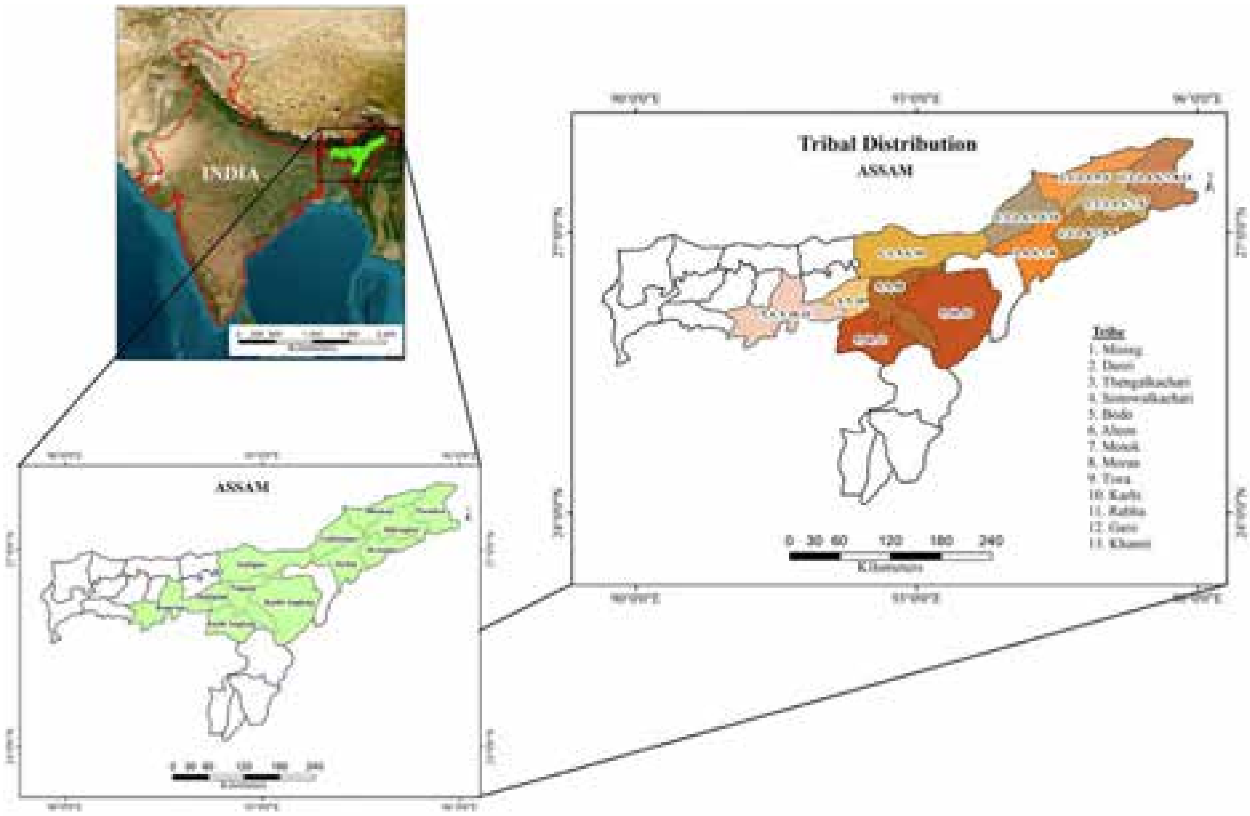

Figure 1. Study area of dye yielding plants used by 13 different communities of Assam.

RESULTS

Plant-based natural dyes are used for traditional dyeing by different communities of Assam. The part used in the extraction of dye, along with the vernacular name of the plant, is given in Table 1 & 2. From 13 different communities of Assam, 45 dye-yielding plants are recorded. Rutaceae, Rubiaceae, Moraceae, and Euphorbiaceae families were found to be dominant, with the Garo community utilizing eight different dye-yielding plant species, the highest diversity of usage among the 13 communities surveyed. These plants have been used by people of different communities to dye silk, yarns of wool, cotton, and garments.

DISCUSSION

Traditional costumes and colour combinations elucidate the identity of a particular community. Ethnic people extracted dye from different parts of plants to colour natural fibers like Eri silk yarn. Natural dye, like synthetic dye, can also be used to colour textiles at any stage, such as fiber, yarn or fabric. Mordants are used in the dyeing process to improve dye fastness. They have an affinity for both textile fibers and dyes. By using different metallic mordants variation in color can be achieved with the same dyestuff. Along with its eco-friendly nature, natural dyes are also soothing to eyes in harmony with nature. Beautiful colours on textiles, obtained with plant-based dyes, show significant variation among different plant sources and parts.

The present investigation recorded 45 dye-yielding plant species belonging to 30 families from different regions of Assam, and discusses the richness of the traditional knowledge of dyeing in 13 communities of Assam. Among them, the Garo community reported using eight plant species for dyeing. Sutradhar et al. (2015) recorded 39 species of dye-yielding plants belonging to 26 families from Tripura. Gaur (2007) reported 106 dye-yielding plant belonging to 63 families from Uttarakhand Himalaya. His extensive survey showed that the majority of dye resources belong to dicotyledons, with the exception of four monocots, three gymnosperms, and three lichens. Kar & Borthakur (2007) investigated and documented 47 species of dye-yielding plants prevalent among five communities of Assam, viz., Assamese, Bodo, Karbi, Missing, and Deori.

Table 1. List of dye-yielding plants traditionally used by 13 different communities of Assam.

	Scientific name	Family	Vernacular name	Colour of the dye
1	*Acanthus* sp.	Acanthaceae	Indigo grass / Neel gos	Dark Blue
2	*Aegle marmelos*	Rutaceae	Bel	Yellow
3	*Ageratum conyzoides*	Asteraceae	Gundhuabon	Soft green
4	*Allium cepa*	Liliaceae	Onion / Piyaj	Red
5	*Anthocephalus cadamba*	Rubiaceae	Pumgos (roghugos) / RaghuKadam	Yellow
6	*Areca catechu*	Arecaceae	Tamul	Dark brown
7	*Artocarpus integrifolia*	Moraceae	Jackfruit / Kathal	Yellow
8	*Artocarpus lacucha*	Moraceae	Bohot	Yellow
9	*Baccaurea ramiflora*	Phyllanthaceae	Leteku	Orange red
10	*Bixa orellana*	Bixaceae	Jorot / Annatto	Orange
11	*Calamus viminalis*	Arecaceae	Betguti	Yellow
12	*Ceriscoides campanulata*	Rubiaceae	Bihmona	Reddish-brown
13	*Citrus aurantiifolia*	Rutaceae	Kajinemu	Golden yellow
14	*Citrus reticulata*	Rutaceae	Orange / Komola	Yellow
15	*Corchorus capsularis*	Tiliaceae	Juteplant / Morapat	Light brown
16	*Curcuma longa*	Zingiberaceae	Kesahaldhi	Yellow
17	*Dillenia indica*	Dilleniaceae	Owtenga	Brown
18	*Diospyros melanoxylon*	Ebenaceae	Kendu	Brown
19	*Eclipta prostrata*	Asteraceae	Keheraj	Black
20	*Emblica officinalis*	Euphorbiaceae	Aamlokhi	Black
21	*Ficus bengalensis*	Moraceae	Aahot	Brown
22	*Garcinia xanthochymus*	Clusiaceae	Tepor-tenga	Yellow
23	*Hibiscus rosa-sinensis*	Malvaceae	JobaPhul	Purple
24	*Indigofera tinctoria*	Fabaceae	Sibu / Assam indigo	Blue
25	*Lawsonia inermis*	Lythraceae	Jetuka	Bluish- black
26	*Melastoma malabathricum*	Melestomataceae	FutuKola	Black
27	*Mangifera indica*	Anacardiaceae	Mango	Yellow
28	*Mesua ferrea*	Calophyllaceae	Nahar	Yellow
29	*Musa velutina*	Musaceae	Kolakhar	Reddish-brown
30	*Nyctanthes arbor-tristis*	Nyctanthaceae	Sewali	Orange
31	*Oryza sativa*	Poaceae	Dhankher	Yellow-brown
32	*Punica granatum*	Lythraceae	Dalim / Pomegranate	Yellow
33	*Rubia cordifolia*	Rubiaceae	Manjistha	Red
34	*Sapindus mukorossi*	Sapindaceae	Monichal	Light brown
35	*Spondias pinnata*	Anacardiaceae	Amora	Brown
36	*Syzygium cumini*	Myrtaceae	Jamun	Black
37	*Tagetes patula*	Asteraceae	Narzi / GendhaPhul	Yellow
38	*Tectona grandis*	Verbenaceae	Sagoon	Yellow
39	*Terminalia catappa*	Combretaceae	Silikha	Black
40	*Camellia sinensis* var. *assamica*	Theaceae	Tea	Pale green (Fresh leaves) Brown (Dried leaves)
41	*Trewia nudiflora*	Euphorbiaceae	Velou	Reddish-brown
42	*Ziziphus jujube*	Rhamnaceae	Bogori	Brown
43	*Argemone mexicana*	Papaveraceae	Siyalkata	Yellowish-green
44	*Impatiens roylei*	Balsaminaceae	Demderuka	Brown
45	*Basella rubra*	Basellaceae	Puroi	Maroon

Table 2. Dye-yielding plants used by different communities of Assam.

Community	Scientific name	Vernacular name	Parts used
Khamti	*Ceriscoides campanulata*	Bihmona	Whole plant
	Sapindus mukorossi	Monichal	Stem bark
	Artocarpus heterophyllus	Jackfruit	Stem bark and roots
	Garcinia cowa	Teportenga	Roots
Mising	*Terminalia chebula*	Silikha	Fruits
	Ziziphus jujuba	Bogori	Stem bark
	Camellia sinensis var. *assamica*	Tea	Leaf
	Syzygium cumini	Jamun	Stem bark
	Areca catechu	Tamul	Seed/ seed peel
	Calamus viminalis	Betguti	Seed/fruit
	Anthocephalus cadamba	Pumgos (roghugos) / RaghuKadam	Stem/bark
Deori	*Citrus aurantifolia*	Bortenga	Fruit skin
	Syzygium cumini	Jamun	Stem bark
	Artocarpus hetrophyllus	Jackfruit	Stem bark
Thengal-kachari	*Dillenia indica*	Owtenga	Stem bark
	Oryza sativa	Dhankher	Seed
Sonowalkachari	*Citrus aurantifolia*	Bortenga	Straw/ stem
	Musa velutina	Kolakhar	Dried stem
Tiwa	*Spondias pinnata*	Amora	Dried stem
	Aegle marmelos	Bel	Fruit
	Camellia sinensis var. *assamica*	Tea	Leaf
	Ficus benghalensis	Aahot	Bark
	Acanthus sp.	Niligos	Leaf
	Curcuma longa	Halodhi	Rhizome
	Basella rubra	Puroi	Seed
Karbi	*Hibiscus rosa sinensis*	JobaPhul	Flower
	Emblica officinalis	Aamlokhi	Bark
	Nyctanthes arbor-tristis	Sewali	Flower
	Diospyros melanoxylon	Kendu	Seed/ fruit
	Allium cepa	Onion	Rhizome
	Trewia nudiflora	Velou	Seed/ fruit
	Mesua ferrea	Nahar	Seed/ fruit
	Terminalia chebula	Silikha	Fruit
Bodo	*Tectona grandis*	Sagoon	Stem, bark, leaf
	Ageratum conyzoides	Gundhuabon	Flower
	Lawsonia inermis	Jetuka	Leaf
	Sapindus mukorossi	Monichal	Fruits
	Camellia sinensis var. *assamica*	Tea	Leaf
Garo	*Terminalia chebula*	Khilikha	Seed/fruit
	Eclipta alba	Kehraj	Black
	Baccaurea remiflora	Leteku	Leaf
	Rubia cordifolia	Manjistha	Whole plant
	Acanthus sp.	Indigo grass	Whole plant
	Artocarpus hetrophyllus	Jack fruits	Stem/bark/wood

Community	Scientific name	Vernacular name	Parts used
	Indigofera tinctoria	Indigo	Whole plant
	Curcuma longa	Halodhi	Rhizome
Rabha	*Punica granatum*	Dalim/Pomegranate	Fruit skin
	Tagetes patula	Narzi/GendhaPhul	Flower
	Artocarpus hetrophyllus	Jackfruit	Stem/ bark/ wood
	Terminalia chebula	Khilikha	Seed/ fruit
Motok	*Citrus aurantifolia*	Rababtenga	Fruit skin
	Oryza sativa	Dhankher	Poaceae
	Musa velutina	Vimkolorkoldil	Plant
	Terminalia chebula	Khilikha	Seed/ fruit
	Spondias pinnata	Amora	Fruit/ bark
	Mangifera indica	Mango	Bark
	Artocarpus lacucha	Bohot	Fruit
Moran	*Citrus reticulatus*	Orange	Fruit skin
	Corchorus capsularis	Morapat	Whole plant
Ahom	*Malestoma malabathricum*	FutuKola	Fruits/ flower
	Bixa orellana	Jorot/Annanto	Seed
	Argemone mexicana	Siyalkata	Seed
	Impatience roylei	Demderuka	Flower

From five districts of Arunachal Pradesh, Mahanta & Tiwari (2005) recorded 37 species of dye-yielding plants belonging to 26 families. Fabaceae was dominant, with six species, followed by Euphorbiaceae and Moraceae with four each, and Juglandaceae with two species, the remaining 21 families represented by one species each. Borgohain et. al. (2018) studied natural dyes and textiles as cultural markers among the Tai Phake of upper Assam. Colour combinations and costume variations differentiate age gradation among males and marital status among females. They also observed that colours such as black, violet, purple, and green are dominated by synthetic dye while yellow is extracted from the bark of *Garcinia xanthochymus*. They also noted that the culture is now confined to surviving aged women of the tribe. This study on natural dyes thus presents potential application and immense scope for small-scale industrial prospects.

CONCLUSION

The present study on natural dye-yielding plants of Assam revealed the rich traditional culture among the communities of Assam. This unique indigenous knowledge and practice on dye-yielding is declining day by day among the new generation because of the easy availability of cheap synthetic dyes and a modern attitude and lifestyle. It observes that the traditional practice of dye-making has survived only among a few elderly people, and there are few attempts to conserve and promote this beautiful treasure of traditional knowledge. The natural dyes obtained from plant sources are biodegradable, non-toxic and environmentally friendly. Dyes have multifarious applications, including an emerging branch of medicine, Chromotherapy, which relies heavily on natural dyes. Synthetic dyes contain chemicals that may cause sensitivities and potential health concerns. Dyes used in textiles, food, beverages, perfumes, lotions, and medicines must adhere to special safety measures like being nontoxic, less or non-allergenic, biodegradable, and eco-friendly. It is of the utmost necessity to document and conserve the valuable treasure of this traditional knowledge system, without which we will lose vital information on the utilisation of natural resources around us. Systematic and scientific approaches for the extraction, processing, and usage of natural dyes, along with their conservation strategy, will benefit the ethnic community of Assam, enhancing their economy and intensifying future bio-prospecting and eco-friendly products.

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OPEN ACCESS

REVIEW

Ichthyofaunal diversity and conservation status of Nagaland, India: a comprehensive review

Rejuba Pongen [1] & Pranay Punj Pankaj [2]

[1] Department of Zoology, Fazl Ali College, Mokokchung, Nagaland 798601, India.
[2] Department of Zoology, Nagaland University, Lumami, Nagaland 798627, India.
[1] r.pongen@gmail.com, [2] pranaypunj@gmail.com (corresponding author)

Abstract: Nagaland, located within the Indo-Burma biodiversity hotspot, is home to a rich diversity of freshwater fish species. However, the region's ichthyofaunal diversity and conservation status are inadequately documented, hindering effective conservation planning. This study aims to provide a comprehensive assessment of the ichthyofaunal diversity in Nagaland and evaluate the conservation status of these species. Systematic review of secondary sources, including research articles, technical reports, and taxonomic records, was conducted. Data were gathered through an extensive literature search across databases like Scopus, Web of Knowledge, and Google Scholar to capture studies on ichthyofaunal diversity and conservation in Nagaland. Keywords like "freshwater fish" and "conservation status" were used, ensuring thorough coverage. Fish species were classified by taxonomic standards, with conservation status based on the IUCN Red List. This study documented 202 fish species across 12 orders, 29 families and 91 genera. The Cyprinidae family was the most dominant, representing 79 species. Conservation status revealed that seven species are classified as 'Endangered' (EN), 15 as 'Near Threatened' (NT), and 17 as 'Vulnerable' (VU), while 6.93% of species remain 'Data Deficient' (DD). The primary threats to ichthyofaunal diversity in Nagaland include habitat degradation, over-exploitation, invasive species, and climate change. These findings underscore the urgent need for continuous biodiversity assessments and implementing sustainable management practices to preserve Nagaland's aquatic biodiversity.

Keywords: Assessment, biodiversity hotspot, climate change, Cyprinidae, endemism, freshwater fish, habitat degradation, IUCN Red List, ichthyofauna, Indo-Burma biodiversity hotspot, invasive species, overexploitation, species richness, taxonomic diversity, threat assessment.

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Author details: Dr. Pranay Punj Pankaj, associate professor of Zoology at Nagaland University, India. His research focuses on ichthyofaunal diversity, indigenous fisheries knowledge, and aquatic conservation. He has led multiple funded projects and published extensively, and actively mentors research scholars. Mr. Rejuba Pongen, assistant professor of Zoology at Fazl Ali College, Nagaland, India, with over 13 years of teaching experience. He holds an MSc from NEHU and is currently pursuing a PhD at Nagaland University, focusing on ichthyofaunal diversity and conservation in northeastern India.

Author contribution: RP conceptualized the study, conducted ichthyofaunal data collection, performed data analysis, and drafted the manuscript. PPP supervised the research, critically reviewed and edited the manuscript, and served as the corresponding author, ensuring scholarly rigor and coherence.

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INTRODUCTION

Freshwater ecosystems do not only support fish species but also many other aquatic species. Despite covering less than 1% of the Earth's surface, these habitats including rivers, lakes, and wetlands are home to over 40% of all fish species and approximately 10% of the world's documented species, including a quarter of all vertebrates (Strayer & Dudgeon 2010). The global fish fauna comprises around 17,948 marine species and 18,397 freshwater species (Fricke et al. 2022), with fish accounting for nearly half of all vertebrate species. However, human activities such as population growth and economic development have placed immense pressure on freshwater ecosystems. Habitat degradation, over-exploitation, the introduction of alien species, river flow alterations, and pollution pose significant risks to aquatic biodiversity, contributing to the high extinction rates observed in freshwater species (Dudgeon et al. 2006). This underscores the importance of monitoring and conserving ichthyofaunal diversity to ensure ecosystem stability and sustainability.

Nagaland, a small hilly state in northeastern India, is geographically positioned between 25.100°–27.067° N and 93.033°–95.017° E, encompassing an area of 16,579 km². Assam borders the state to the west, Myanmar to the east, Arunachal Pradesh and Assam to the north, and Manipur to the south. The eastern Himalayan region is recognized as one of the world's most biodiversity-rich regions (Biswas & Boruah 2000). With altitudes ranging 194–3,048 m and an average annual rainfall of 2,000–2,700 mm, Nagaland possesses rich inland water resources, including rheophilic rivers and streams. Three major drainage systems, the Barak, Brahmaputra, and Chindwin, divide the state's river systems, traversing 16 districts through 11 major and 10 minor rivers (Ao et al. 2008).

Ichthyofaunal diversity and river Systems

The major rivers of Nagaland include the Dhansiri, Dikhu, Doyang, Intangki, Meguiki, Milak, Tizit, Tizu, Tsurang, Shili and Zungki, while the minor rivers consist of Arachu, Chathe, Chokla, Dzulakie, Dzuna, Lanyi, Likhimro, Seidzu, Tepuiki, and Tesuru (Tables 1 & 2). Figure 1 illustrates the river network of Nagaland, providing a detailed representation of the state's hydrological features. These rivers form the backbone of the state's aquatic ecosystem, supporting a diverse range of fish species. However, comprehensive documentation of ichthyofaunal diversity across these different drainage systems remains incomplete.

Several scholars have documented the ichthyofaunal diversity of Nagaland. Ao et al. (2008) catalogued the fish species present in the state, identifying 149 distinct species. Goswami et al. (2012) enumerated 187 fish species from the state. Bendangkokba & Ahmed (2007) reported 66 fish species across 16 families and five orders from the Milak, Dikhu, and Tsurang rivers in Mokokchung district. Ezung et al. (2020) recently compiled a list of fish species from the state, identifying 197 species over 10 orders, 26 families, and 87 genera. Kechu & Pankaj (2025) documented high ichthyofaunal richness in the Dikhu River, Nagaland, characterized by the dominance of Cypriniformes and the presence of threatened and data-deficient species under increasing anthropogenic pressure. Similarly, Khesoh et al. (2025) demonstrated that the Tsurang and Milak rivers of Mokokchung District, Nagaland, despite being smaller tributaries, support substantial fish diversity, including species of conservation concern. Recent discoveries have significantly advanced our comprehension of the ichthyofaunal variety in Nagaland (Figure 2). Although there have been recent contributions to the state fish fauna, the species compositions in numerous water bodies remain undocumented and require further investigation. The inaccessibility of most rivers, situated in steep, mountainous regions characterized by dense forest cover, prevents the examination of many lotic systems in the state.

According to current study, Nagaland is home to 202 fish species. Despite significant increases in the documented number of fish species in the state, there is still a significant amount of work to fully explore and document the ichthyofaunal diversity in many of Nagaland's rivers, particularly in remote and challenging landscapes with dense forest vegetation. The exploration of these lotic systems is far from complete, and further research is necessary to discover and protect the species that inhabit these underexplored areas. The ichthyofaunal diversity in Nagaland is significant yet remains inadequately documented. Continued efforts in research and conservation are crucial for comprehensively understanding and safeguarding the diverse aquatic biodiversity of this region.

MATERIALS AND METHODS

Study Design and Objectives

The study aimed to review the ichthyofaunal diversity and assess the conservation status of freshwater fish species in Nagaland, India. By analyzing

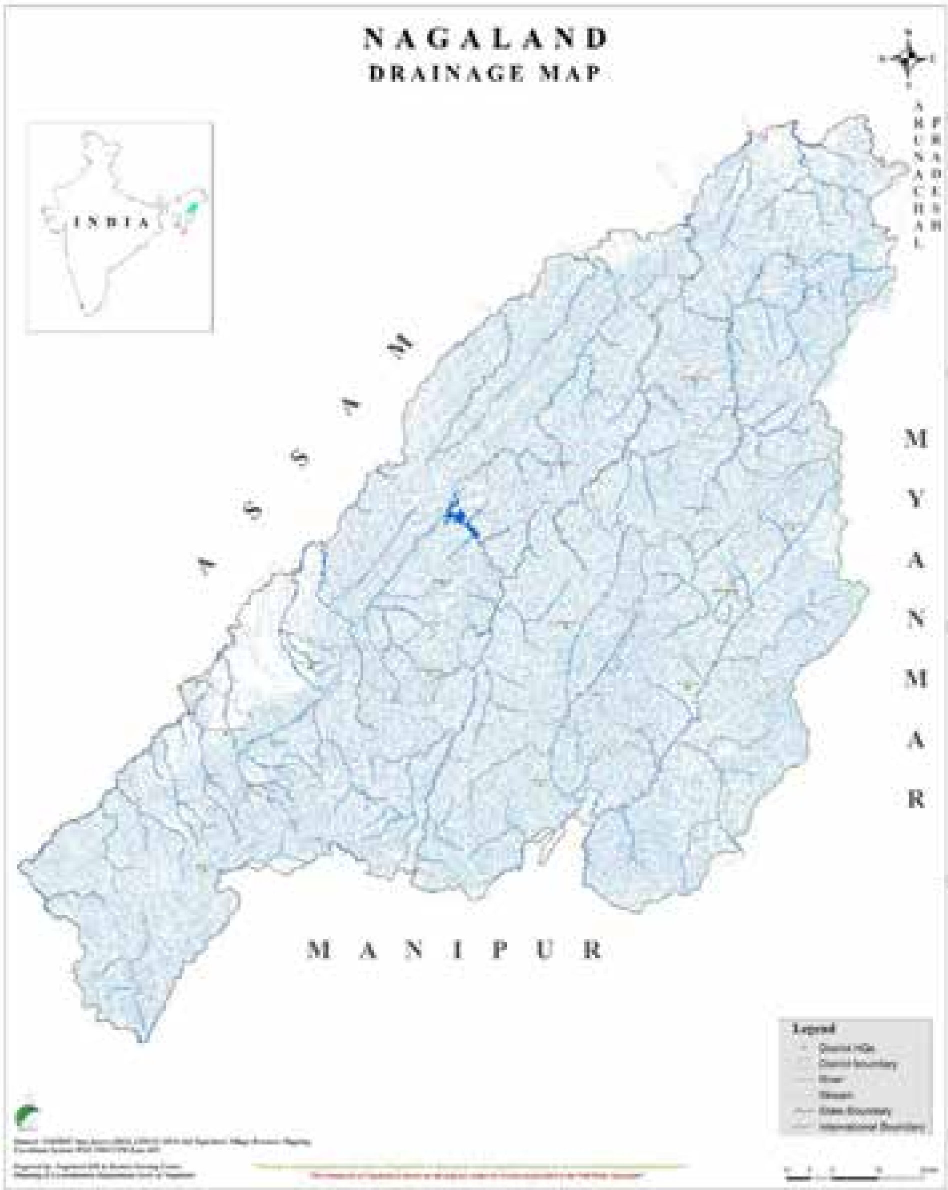

Figure 1. Nagaland State drainage map. (Source: Nagaland GIS & Remote Sensing Centre, accessed on 17.xi.2024)

secondary data on taxonomy, distribution, economic importance, habitat preferences, and conservation status, the goal was to provide a detailed understanding of the region's fish diversity and highlight the need for conservation efforts.

Data Sources and Literature Search

An extensive literature search was conducted using databases like Scopus, Web of Knowledge, Google Scholar, and other repositories to identify peer-reviewed articles, reports, and books on Nagaland's ichthyofaunal diversity and conservation status. Search terms included "ichthyofaunal diversity," "freshwater fish," "conservation status," and "Nagaland". Publications from all the available years were included. Manual searches of key references were also performed to ensure comprehensive coverage, providing a robust dataset for analysis and capturing studies that may have been overlooked.

Inclusion and Exclusion Criteria

The initial screening process involved reviewing the titles and abstracts of all retrieved articles to assess their relevance to the study objectives. Studies were included if they provided detailed information on the freshwater fish species of Nagaland, including aspects

Table 1. Major Rivers of Nagaland, India.

	Major rivers	District	River system
1	Dhansiri	Dimapur	Brahmaputra
2	Dikhu	Mokokchung	Brahmaputra
3	Doyang	Wokha	Brahmaputra
4	Intangki	Wokha	Brahmaputra
5	Milak	Mokokchung	Brahmaputra
6	Shili	Longleng	Brahmaputra
7	Tizit	Mon	Brahmaputra
8	Tsurang	Mokokchung	Brahmaputra
9	Meguiki	Peren	Barak
10	Tizu	Phek	Chindwin
11	Zungki	Kiphire	Chindwin

Table 2. Minor rivers of Nagaland, India.

	Minor rivers	District	River system
1	Chathe	Kohima	Brahmaputra
2	Dzuna	Kohima	Brahmaputra
3	Tepuiki	Kohima	Barak
4	Dzulakie	Kohima	Barak
5	Tesuru	Phek	Irrawaddy
6	Arachu	Phek	Irrawaddy
7	Lanyi	Phek	Irrawaddy
8	Likhimro	Kiphire	Irrawaddy
9	Seidzu	Phek	Irrawaddy
10	Chokla	Tuensang	Irrawaddy

such as taxonomy, distribution, economic importance, habitat, and conservation status. Articles that did not meet these criteria, such as those focused on marine species or unrelated geographical areas, were excluded from the analysis. Full-text reviews were conducted for studies that passed the initial screening to confirm their relevance and inclusion in the final dataset.

Data Extraction and Compilation

Data were meticulously extracted from the selected studies, focusing on several key parameters:

- **Taxonomy and Nomenclature:** The classification of fish species followed the taxonomy outlined by Nelson (2016). Each species' scientific name was cross-checked with Eschmeyer's Catalogue of fish, a globally recognized database for fish species, to ensure the accuracy and validity of the taxonomic information.

- **Economic Importance:** Information on the economic significance of each species, such as, their use in local fisheries, aquaculture, or as ornamental fish, was collected.

- **Fin Formula and Morphological Traits:** Details regarding the fin formula, a key aspect of fish morphology, were documented. This included the number and arrangement of fins, which is crucial for species identification and classification.

- **Habitat and Distribution:** Data on the natural habitats of the fish species, including the types of water bodies they inhabit (e.g., rivers, streams, lakes) and their geographical distribution within Nagaland, were compiled.

- **Food Habits:** The dietary preferences of the fish species were documented, providing insights into their ecological roles within freshwater ecosystems.

- **Conservation Status:** The conservation status of each species was assessed using the IUCN Red List categories and criteria (Allen et al. 2010). Species were categorized as 'Not Evaluated' (NE), 'Data Deficient' (DD), 'Least Concern' (LC), 'Near Threatened' (NT), 'Vulnerable' (VU), or 'Endangered' (EN) based on their risk of extinction.

Data Analysis

The extracted data were systematically organized and analyzed using descriptive methods. This involved calculating the frequency and distribution of species across different taxonomic groups, habitat types, and conservation statuses. The results were presented in tables and charts to provide a clear and comprehensive overview of the ichthyofaunal diversity in Nagaland.

RESULT AND DISCUSSION

The study identified 202 fish species across 12 orders, 29 families, and 87 genera in Nagaland, India. The family Cyprinidae exhibited the highest diversity with 79 species, followed by Sisoridae with 26 species, and Nemacheilidae with 16 species (Figure 4). Other families, including Bagridae and Channidae, also showed notable diversity with 12 and six species, respectively. This diversity underscores the ecological richness of Nagaland's freshwater systems.

A systematic list of fish species and their IUCN conservation status (Table 3) reveals that most are classified as 'Least Concern', with some listed as 'Vulnerable' or 'Endangered'. About 6.93% are 'Data Deficient', highlighting the need for further research (Figure 3). Threats to these species include habitat

Figure 2. Timeline of newly discovered fish species in Nagaland, India.

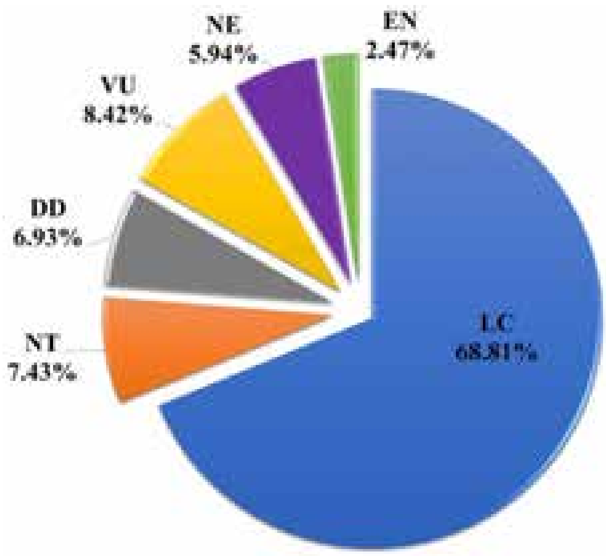

Figure 3. Pie charts showing the percentages of fish under different IUCN threat categories in Nagaland.

degradation, over-exploitation, and pollution. While many species are currently stable, the presence of 'Vulnerable' and 'Endangered' species indicates risks to their populations (Table 4).

Recent years have brought the discovery of new species such as *Garra chathensis* in the Chathe River, *Badis limaakumi* in the Milak River, and *Psilorhynchus kosygini* in the Tepuiki River. These findings reflect Nagaland's role in contributing to global ichthyofaunal knowledge and emphasize the need for continued research and conservation. The discovery of these new species also suggests the potential for additional undiscovered species in Nagaland's rivers, which are valuable for understanding evolutionary and biogeographic patterns.

Biogeographically, Nagaland's ichthyofauna shares patterns with neighbouring Himalayan and Brahmaputra regions, particularly the dominance of Cyprinidae. Species unique to Nagaland suggest localized speciation, likely driven by its complex topography and microhabitats. Species distributions across the Brahmaputra, Barak, and Irrawaddy drainage systems reflect Nagaland's role as a biogeographic crossroads, shaped by historical river capture and geological events.

CONCLUSION

In conclusion, Nagaland's freshwater ecosystems, rich in biodiversity, play a critical role in global ichthyofaunal diversity. Despite covering a limited geographic area, the state supports 202 fish species across various families, with notable diversity within the Cyprinidae family. The state's unique river systems and mountainous topography, which create diverse aquatic habitats, facilitate this high species richness. However, increasing human activities, including habitat destruction, overexploitation, and pollution, pose serious threats to these ecosystems. As a result, many species face extinction risks, with several categorized as 'Vulnerable' or 'Endangered', while others remain 'Data Deficient', indicating a pressing need for further research.

However, the ichthyofauna in this region faces pressing threats from habitat degradation, pollution, over-exploitation, and flow alterations due to human activity, leading to high extinction risks for vulnerable species. Although recent discoveries, such as *Garra chathensis*, *Badis limaakumi*, and *Psilorhynchus*

Table 3. Systematic list of fish species in Nagaland and their IUCN Red List conservation status.

	Scientific Name	Family	Fin formula	IUCN Red List status (2024)
1	*Ailia coila* (Hamilton, 1822)	Ailiidae	A58-75;PI14-16;Vi5	NT
2	*Clupisoma garua* (Hamilton, 1822)	Ailiidae	DI7;Aiii26-33;PI11;Vi5	LC
3	*Parambassis nama* Hamilton, 1822	Ambassidae	DVII+I15-17;AIII15-17;Pii11-12;VI5	LC
4	*Parambassis baculis* (Hamilton, 1822)	Ambassidae	DVI+I12-13;AIII12-13;Pi11-12;VI5	LC
5	*Parambassis ranga* Hamilton, 1822	Ambassidae	DVII+I11-14;AIII13-15;Pi11-12;VI5	LC
6	*Amblyceps apangi* Nath & Dey, 1989	Amblycipitidae	Dii5-6; Aii-iii7; PI16;VI5; C7+7	LC
7	*Amblyceps arunachalense* Nath & Dey, 1989	Amblycipitidae	DI7;AV8;PI7;VI5;C6+9	EN
8	*Amblyceps mangois* (Hamilton, 1822)	Amblycipitidae	DI5-6;Aii-iii6-8;PI7;Vi5-6	LC
9	*Anabas cobojius* (Hamilton, 1822)	Anabantidae	DXVI-XVIII9-10; AIX-XI9-11;Pi13-15;VI5	DD
10	*Anabas testudineus* (Bloch, 1792)	Anabantidae	DXVI-XVIII8-10;AVIII-XI9-11;Pi13-14;VI5	LC
11	*Anguilla bengalensis* Gray, 1831	Anguillidae	D250-305;A220-250;P18	NT
12	*Badis badis* (Hamilton, 1822)	Badidae	DXVI-XVIII 7-10;AIII 6-8;P12;VI5	LC
13	*Badis limaakumi* Praveenraj, 2023	Badidae	D17(8)9(10);A3(10)7(4);P13(5),14(1)V1,5(10)	NE
14	*Batasio batasio* (Hamilton, 1822)	Bagridae	DI7;Aiii-iv9-10;PI5-8;Vi5	LC
15	*Mystus armatus* Day, 1865	Bagridae	DI7;Aiii8;PI9;Vi5	LC
16	*Mystus bleekeri* Day, 1877	Bagridae	DI7-8;Aiii6-7;PI9-10;Vi5	LC
17	*Mystus cavasius* (Hamilton, 1822)	Bagridae	DI7;Aiv7-9;PI8;Vi5	LC
18	*Mystus tengara* (Hamilton, 1822)	Bagridae	DI7;Aii-iii9-10;PI8;Vi5	LC
19	*Mystus vittatus* (Bloch, 1794)	Bagridae	DI7;Aii-iii7-9;PI9;Vi5	LC
20	*Olyra burmanica* Day, 1872	Bagridae	Di7;Aiii13;PI4;Vi5	DD
21	*Olyra horae* Prashad & Mukerji, 1929	Bagridae	Di7;Aiii18;PI7;Vi5	DD
22	*Olyra kempi* Chaudhuri, 1912	Bagridae	Di6-7;A iii15-20;PI4-6;Vi5	LC
23	*Olyra longicaudata* McClelland, 1842	Bagridae	Di6-7;Aiii15-20;PI4-6;Vi5	LC
24	*Sperata aor* (Hamilton, 1822)	Bagridae	DI7;A iii-iv 8-10;PI9-10;Vi5;C17	LC
25	*Sperata seenghala* (Sykes, 1839)	Bagridae	DI7; Aiii8-9;PI9;Vi5;C19-21	LC
26	*Balitora brucei* Gray, 1830	Balitoridae	Diii8;Aiii5;Pix-x10-12;Vii9-10	NT
27	*Balitora burmanica* Hora, 1932	Balitoridae	Diii8;Aiii5;Pviii-x10-12;Vii9	LC
28	*Homalopteroides rupicola* (Prashad & Mukerji, 1929)	Balitoridae	Dii7;Aii5;Pv11;Vii6	LC
29	*Strongylura strongylura* (van Hasselt, 1823)	Belonidae	D12-15;A15-18;P10-12;V6	LC
30	*Xenentodon cancila* (Hamilton, 1822)	Belonidae	D15-18;A16-18;P11;V6	LC
31	*Botia almorhae* Gray, 1831	Botiidae	Diii9-10;Aii5-6;P14;Vi7	LC
32	*Botia dario* (Hamilton, 1822)	Botiidae	Dii8;Aii5;P15;Vi7	LC
33	*Botia histrionica* (Blyth, 1860)	Botiidae	Diii9;Aii6;Pii12;Vi7	LC
34	*Botia rostrata* (Günther, 1868)	Botiidae	Diii8;Aii5;Pi10;Vi6	VU
35	*Channa barca* (Hamilton, 1822)	Channidae	D47-52;A34-36;P16;V6	DD
36	*Channa gachua* (Hamilton, 1822)	Channidae	D32-37;A20-23;P14-15;V6	LC
37	*Channa marulius* (Hamilton, 1822)	Channidae	D45-55;A28-36;P16-18;V6	LC
38	*Channa punctata* (Bloch, 1793)	Channidae	D28-33;A20-23;P15-18;V6	LC
39	*Channa stewartii* (Playfair, 1867)	Channidae	D39-40;A27;P17;V6	LC
40	*Channa striata* (Bloch, 1793)	Channidae	D37-46;A23-29;P15-17;V6	LC
41	*Oreochromis mossambicus* (Peters, 1852)	Cichlidae	DXV-XVI10-12;AIII10-11;P14-15;VI5	VU
42	*Oreochromis niloticus* (Linnaeus, 1758)	Cichlidae	D 15-19/11-15; A 3/8-11;P14;V 1/5; C16-22.	LC
43	*Clarias gariepinus* Burchell, 1822	Clariidae	D70-76; A45-58;PI8-11;Vi5	LC

	Scientific Name	Family	Fin formula	IUCN Red List status (2024)
44	*Clarias magur* (Hamilton, 1822)	Clariidae	----------------------------	EN
45	*Canthophrys gongota* (Hamilton, 1822)	Cobitidae	Dii9-10;Aii5-6;P14:Vi7	LC
46	*Lepidocephalichthys annandalei* Chaudhuri, 1912	Cobitidae	Di-ii6-7;Aii5;Pi6-7;Vi6	LC
47	*Lepidocephalichthys berdmorei* (Blyth, 1860)	Cobitidae	Dii-iii6;Aii5-6;Pi7-9;Vi6-7	LC
48	*Lepidocephalichthys guntea* (Hamilton, 1822)	Cobitidae	Dii-iii6-7;Aii-iii5;Pi6-7;Vi6-7	LC
49	*Lepidocephalichthys irrorata* Hora, 1921	Cobitidae	Dii-iii6-7;Aii-iii5;Pi6-7;Vi6	LC
50	*Pangio pangia* (Hamilton, 1822)	Cobitidae	Dii6;Aii5-6;Pi9-10;Vi5-6	LC
51	*Amblypharyngodon mola* (Hamilton, 1822)	Cyprinidae	D8;P15; V8;A6-7;C19	LC
52	*Bangana dero* (Hamilton, 1822)	Cyprinidae	Dii-iii9-12; Pi16-17; V i7; Aii-iii5	LC
53	*Opsarius barila* (Hamilton, 1822)	Cyprinidae	Dii7; Pi 12;Vi 8; A iii10-11	LC
54	*Opsarius vagra* (Hamilton, 1822)	Cyprinidae	Dii-iii7;P i14-15;Vi7;Aii12;C19	LC
55	*Opsarius morar* (Hamilton, 1822)	Cyprinidae	Dii-iii7-9; P 14-15; V 8; A ii 8-10	LC
56	*Chagunius chagunio* (Hamilton, 1822)	Cyprinidae	Dv8;Pi15;Vi 8; Aiii5;C19	LC
57	*Chagunius nicholsi* Myers, 1924	Cyprinidae	Dv8;Pi14;Vii8;Aiii5	LC
58	*Chela cachius* (Hamilton, 1822)	Cyprinidae	Dii7;Pi8;Vi5-6;Aii-iii19-23	LC
59	*Cirrhinus mrigala* (Hamilton, 1822)	Cyprinidae	Diii-iv12-13;Pi17;Vi8;Aiii5	LC
60	*Cirrhinus reba* (Hamilton, 1822)	Cyprinidae	Dii-iii8;Pi15;Vi8:Aiii5	LC
61	*Tariqilabeo burmanicus* (Hora, 1936)	Cyprinidae	Div10-11;Pi14;Vi7;Aiii5	LC
62	*Tariqilabeo latius* (Hamilton, 1822)	Cyprinidae	Div8;Pi13;Vi8;Aii5	LC
63	*Ctenopharyngodon idella* Valenciennes, 1844	Cyprinidae	Diii7;Pi17;Vi8;Aiii7-8	LC
64	*Semiplotus semiplotus* (McClelland, 1839)	Cyprinidae	Diii24-25;Pi15;Vi9;Aii7	VU
65	*Cyprinus carpio* Linnaeus, 1758	Cyprinidae	Diii-iv18-20;Pi-15;Vi8;Aiii5	VU
66	*Danio dangila* (Hamilton, 1822)	Cyprinidae	Dii9-11;Pi11-12;Vi7:Aii-iii12-15	LC
67	*Danio rerio* (Hamilton, 1822)	Cyprinidae	Dii7;Pi12;Vii 9;Aii 5;C19	LC
68	*Devario acuticephala* Hora, 1921	Cyprinidae	Dii6-7;Pi10-11;Vi6;Aii9-10	LC
69	*Devario aequipinnatus* (McClelland, 1839)	Cyprinidae	Dii-iii9-12;Pi11-12;Vi6:Aii-iii14-16	LC
70	*Devario devario* (Hamilton, 1822)	Cyprinidae	Dii7-8;Pii12; Vi9;Aii-iii 13-14;C21	LC
71	*Devario naganensis* (Chaudhuri, 1912)	Cyprinidae	Dii-iii8-9;Pi11-12;Vi6;Aii12-13	VU
72	*Esomus danrica* (Hamilton, 1822)	Cyprinidae	Dii6;Pi14-15;Vi6-7;Aiii5	LC
73	*Garra annandalei* Hora, 1921	Cyprinidae	Diii7-8;Pi12-14;Vi7;Aii5	LC
74	*Garra birostris* Nebeshwar & Vishwanath, 2013	Cyprinidae	Dii8½;Pi12-14;Vi8;Aii5½	NE
75	*Garra chathensis* Ezung, Shangningam & Pankaj, 2020	Cyprinidae	Diii8½;Pi13-14;Vi7½;Aiii5½	LC
76	*Garra gotyla* (Gray, 1830)	Cyprinidae	Diii7-8;Pi14;Vi8;Aii5	LC
77	*Garra gravelyi* Annandale, 1919	Cyprinidae	Dii7;Pi13;Vi8;Aii5	NT
78	*Garra kempi* Hora, 1921	Cyprinidae	Dii8;Pi12;Vi7:Aii5	LC
79	*Garra lamta* (Hamilton, 1822)	Cyprinidae	Diii7-8;Pi12;Vi7-8;Aii5	LC
80	*Garra langlungensis* Ezung, Shangningam & Pankaj, 2021	Cyprinidae	Dii8½;Pi11-12;Vi7½;Aii5½	NE
81	*Garra lissorhynchus* (McClelland, 1842)	Cyprinidae	Dii6-7;Pi14-15;Vi7-8,Ai5	LC
82	*Garra naganensis* Hora, 1921	Cyprinidae	Diii6; Pi12;Vii8;A ii6;C19	LC
83	*Garra nasuta* (McClelland, 1838)	Cyprinidae	Dii8-9;Pi14;Vi7;Ai-ii5	LC
84	*Garra notata* (Blyth, 1860)	Cyprinidae	Dii7;Pi13-14;Vi8;Aii5	LC
85	*Garra rupecula* (McClelland, 1839)	Cyprinidae	Dii6-7; Aii5; Pi14-15;Vi8;	NT
86	*Garra lungongza* Ngangbam & Lithoingambi, 2023	Cyprinidae	Dii7½; Pi13; Pi13;Aii5½	NE
87	*Garra zubzaensis* Tenali, Shangningam, Bhattacharjee, Patel & Kosygin, 2024	Cyprinidae	Dii,8.5; Pi,14;Vi,8; Aii 5.5;C9+8	NE

	Scientific Name	Family	Fin formula	IUCN Red List status (2024)
88	*Gymnostomus ariza* (Hamilton, 1807)	Cyprinidae	Dii9;Pi17;Vi8;Aii-iii5	LC
89	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	Cyprinidae	Diii7;Pi17;Vi7;Aii-iii12-14	NT
90	*Hypophthalmichthys nobilis* Richardson, 1845	Cyprinidae	Diii7;Pi19;Vi7;Aiii11	DD
91	*Labeo angra* (Hamilton, 1822)	Cyprinidae	Dii-iii10;Pi15;Vi8;Aii5	LC
92	*Labeo bata* (Hamilton, 1822)	Cyprinidae	Dii-iv9-10;Pi15-17;Vi8;Aii-iii5	LC
93	*Labeo boga* (Hamilton, 1822)	Cyprinidae	Dii-iii9-10;Pi15;Vi8;ii5	LC
94	*Labeo calbasu* (Hamilton, 1822)	Cyprinidae	Diii-iv13-16;Pi16-18;Vi8;Aii-iii5	LC
95	*Labeo catla* (Hamilton, 1822)	Cyprinidae	Diii15; Pi16;V i8;A ii5;C19	LC
96	*Labeo dyocheilus* (McClelland, 1839)	Cyprinidae	Dii-iii10-11;Pi16;Vi8;Aii5	LC
97	*Labeo fimbriatus* (Bloch, 1795)	Cyprinidae	Diii-iv15-18;Pi15;Vi8;Aii-iii5	LC
98	*Labeo gonius* (Hamilton, 1822)	Cyprinidae	Dii-iii13-16;Pi16;Vi8;Aii5-6	LC
99	*Labeo pangusia* (Hamilton, 1822)	Cyprinidae	Dii-iii10-11;Pi14-15;Vi8;Aii5	NT
100	*Labeo rohita* (Hamilton, 1822)	Cyprinidae	Diii-iv12-14;Pi16-18;Vi8;Aii-iii5	LC
101	*Laubuka laubuca* (Hamilton, 1822)	Cyprinidae	Dii8-10;Pi8-11;Vi6;Aii17-22	LC
102	*Neolissochilus hexagonolepis* (McClelland, 1839)	Cyprinidae	Div9;Pi16;Vi8;Aiii5	NT
103	*Neolissochilus hexastichus* (McClelland, 1839)	Cyprinidae	Div9;Pi16;Vi8;A iii5;C19	NT
104	*Opsarius barna* (Hamilton, 1822)	Cyprinidae	Diii6; Pii12;VI9;Aiii11-12;C18	LC
105	*Opsarius barnoides* (Vinciguerra, 1890)	Cyprinidae	Dii-iii7-8;Pi13;Vi8;Aii-iii10-11	LC
106	*Opsarius bendelisis* (Hamilton, 1807)	Cyprinidae	Diii8;Pi14;Vii9;Aii 8;C19	LC
107	*Opsarius dogarsinghi* (Hora, 1921)	Cyprinidae	Dii7; Pi12;Vi8; Aiii9	VU
108	*Opsarius shacra* (Hamilton, 1822)	Cyprinidae	Dii7;Pi14;Vi8;Aii-iii8	LC
109	*Opsarius tileo* (Hamilton, 1822)	Cyprinidae	Dii7;Pi13;Vi8;Aiii10	LC
110	*Oreichthys elianae* Praveenraj & Vijayakrishnan, 2026	Cyprinidae	Dii,8½;Pi,13;Vi,9;Aii,5½; C19(1+9+8+1)	NE
111	*Osteobrama cotio* (Hamilton, 1822)	Cyprinidae	Diii-iv8;Pi12-14;Vi8;Aiii33-38	LC
112	*Pethia conchonius* (Hamilton, 1822)	Cyprinidae	Diii7-8; Aii-iii5;Pi18;Vi8	LC
113	*Pethia dikhuensis* Praveenraj, Limaakum, Knight, Moulitharan & Imchen, 2022	Cyprinidae	Div8;Aiii5(13);Pi12;Vi7-8	NE
114	*Pethia shalynius* (Yazdani & Talukdar, 1975)	Cyprinidae	Diii7;Aii5;Pi12-13;Vi7	VU
115	*Pethia ticto* (Hamilton, 1822)	Cyprinidae	Diii-iv8;Aii-iii5;Pi12-14;Vi8	LC
116	*Puntius chola* (Hamilton, 1822)	Cyprinidae	Diii8;Pi14;Vi8;Aii5	LC
117	*Puntius sophore* (Hamilton, 1822)	Cyprinidae	Diii-iv8-9;Aiii5;Pi14-16;Vi8	LC
118	*Puntius terio* (Hamilton, 1822)	Cyprinidae	Diii8;Aii5;Pi14;Vi8	LC
119	*Raiamas bola* (Hamilton, 1822)	Cyprinidae	Diii7-8;Aiii10; Pi12; Vi8	LC
120	*Raiamas guttatus* Day, 1870	Cyprinidae	Dii7;Aiii9-10;Pi14;Vi8	LC
121	*Rasbora daniconius* (Hamilton, 1822)	Cyprinidae	Dii7;Aii5;Pi14;Vi8	LC
122	*Rasbora rasbora* (Hamilton, 1822)	Cyprinidae	Dii7;Aii-iii5;Pi14;Vi8	LC
123	*Salmostoma acinaces* (Valenciennes, 1844)	Cyprinidae	Diii7;Aii-iii14-17;Pi14;Vi8	LC
124	*Salmostoma bacaila* (Hamilton, 1822)	Cyprinidae	Dii-iii7;Aiii10-13;Pi11-12;Vi8	LC
125	*Schizothorax richardsonii* (Gray, 1832)	Cyprinidae	Diii8;Aiii5;Pi15-16;Vi9	VU
126	*Poropuntius clavatus* (McClelland, 1845)	Cyprinidae	Div8;Aiii5;Pi14;Vi8	NT
127	*Systomus sarana* (Hamilton, 1822)	Cyprinidae	Diii-iv8;Aiii5;Pi14-16;Vi8	LC
128	*Tor putitora* (Hamilton, 1822)	Cyprinidae	D iii8-9;Pi18;Vi8;Aii5;C19	EN
129	*Tor tor* (Hamilton, 1822)	Cyprinidae	Div8;Aiii5;Pi14-17;Vi8	DD
130	*Gudusia chapra* (Hamilton, 1822)	Dorosomatidae	Div11-13;A(ii)iii19-22;Pi12-13;Vi7	LC
131	*Glossogobius giuris* (Hamilton, 1822)	Gobiidae	DVI+I8-9;AI7-8;Pi16-21	LC

	Scientific Name	Family	Fin formula	IUCN Red List status (2024)
132	*Heteropneustes fossilis* (Bloch, 1794)	Heteropneustidae	D6-7;A60-70;PI7;Vi5	LC
133	*Macrognathus aral* (Bloch & Schneider, 1801)	Mastacembelidae	DXVI-XXIII 44-45;AIII44-52;P19-24;C15	LC
134	*Macrognathus pancalus* (Hamilton, 1822)	Mastacembelidae	DXXIV-XXVI30-42;AIII31-46;P17-19;C12	LC
135	*Mastacembelus armatus* (Lacepède, 1800)	Mastacembelidae	DXXXII-XL;64-92;AIII64-90;P21-27;C14-17	DD
136	*Rhinomugil corsula* (Hamilton, 1822)	Mugilidae	D_1IV,D_2I8;AIII9;P16;VI5	LC
137	*Nandus nandus* (Hamilton, 1822)	Nandidae	DXII-XIV11-13;AIII7-9;P15;VI5	LC
138	*Paracanthocobitis botia* (Hamilton, 1822)	Nemacheilidae	Diii9-11;Aiii5;Pi11;Vi7	LC
139	*Neonoemacheilus assamensis* (Menon, 1987)	Nemacheilidae	Diii8;Aii5;Pi10;Vi7	NT
140	*Paracanthocobitis zonalternans* (Blyth, 1860)	Nemacheilidae	Diii10;Aiii5-6;Pi11;Vi7	LC
141	*Schistura beavani* (Günther, 1868)	Nemacheilidae	Diii9-11;Aiii5;Pi11;Vi7	LC
142	*Schistura kangjupkhulensis* (Hora, 1921)	Nemacheilidae	Dii7;Aii5;Pi8;Vi6	EN
143	*Rhyacoschistura manipurensis* (Chaudhuri, 1912)	Nemacheilidae	Di7;Aii5;Pi11;Vi7	NT
144	*Schistura multifasciata* (Day, 1878)	Nemacheilidae	Dii8;Aii5;Pi10-11;Vi7-8	LC
145	*Schistura nagaensis* (Menon, 1987)	Nemacheilidae	Dii8;Aii5;Pi8;Vi6	VU
146	*Mustura prashadi* (Hora, 1921)	Nemacheilidae	Dii8;Aii5;Pi10;Vi7	VU
147	*Schistura reticulofasciata* (Singh & Bănărescu, 1982)	Nemacheilidae	Diii8;Aii-iii5;Pi9;Vi6-7	VU
148	*Acantopsis savona* (Hamilton, 1822)	Nemacheilidae	Diii9;Aii5;Pi9:Vi6	LC
149	*Schistura scaturigina* McClelland, 1839	Nemacheilidae	Diii8;Ai5;Pi9;Vi7	LC
150	*Mustura sijuensis* (Menon, 1987)	Nemacheilidae	Dii8;Aii5;Pi10;Vi7	EN
151	*Schistura sikmaiensis* (Hora, 1921)	Nemacheilidae	Dii8;Aii5;Pi10-11;Vi7	LC
152	*Schistura singhi* (Menon, 1987)	Nemacheilidae	Diii7;Aii5;Pi8;Vi6	VU
153	*Schistura tirapensis* Kottelat, 1990	Nemacheilidae	Dii8;Aii5;Pi10;Vi7	LC
154	*Schistura vinciguerrae* (Hora, 1935)	Nemacheilidae	Diii8;Aii5;Pi11;Vi6	LC
155	*Chitala chitala* (Hamilton, 1822)	Notopteridae	D9-10;A+C110-135;V6	NT
156	*Notopterus notopterus* (Pallas, 1769)	Notopteridae	D7-9;A+C100-110;V5-6	LC
157	*Trichogaster chuna* (Hamilton, 1822)	Osphronemidae	DXVII-XVIII6-9;AXVIII-XXII11-13;P9	LC
158	*Trichogaster fasciata* (Bloch & Schneider, 1801)	Osphronemidae	DXV-XVII9-14;AXV-XVIII14-19;P9-10	LC
159	*Trichogaster lalius* (Hamilton, 1822)	Osphronemidae	DXV-XVII7-10;AXVII-XVIII13-17;P10	LC
160	*Osphronemus goramy* Lacepède, 1801	Osphronemidae	DXI-XIII11-12;AIX-XII19-21;Pi11;VI5	LC
161	*Psilorhynchus balitora* (Hamilton, 1822)	Psilorhynchidae	Diii8;Aii5;Pv-viii7-9;Vii7	LC
162	*Psilorhynchus homaloptera* Hora & Mukerji, 1935	Psilorhynchidae	Dii7;Aii5;Pvii-viii9;Vii7	LC
163	*Psilorhynchus sucatio* (Hamilton, 1822)	Psilorhynchidae	Dii7;Aii5;Piv8-9;Vii7-8	LC
164	*Psilorhynchus kosygini* Shangningam, 2024	Psilorhynchidae	Dii.8,Aii.6,Pviii(7)7(i)8(3),Vii.7	NE
165	*Eutropiichthys murius* (Hamilton, 1822)	Schilbeidae	DI7;Aiii35-40;PI10-11;Vi5	LC
166	*Eutropiichthys vacha* (Hamilton, 1822)	Schilbeidae	DI7;Aiii-iv41-52;PI13-16;Vi5	LC
167	*Johnius coitor* (Hamilton, 1822)	Scianenidae	DX+I26-29;AII7;Pi15-16;VI5	LC
168	*Ompok bimaculatus* (Bloch, 1794)	Siluridae	D4;Aii-iii57-58;PI12-14;Vi7-8	NT
169	*Ompok pabda* (Hamilton, 1822)	Siluridae	D4-5;Aii48-54;PI11-13;Vi6-7	NT
170	*Pterocryptis berdmorei* (Blyth, 1860)	Siluridae	D4;Aii60-62;PI11;Vi9	LC
171	*Pterocryptis gangelica* Peters, 1861	Siluridae	D2;Aii72;PI11;Vi8	DD
172	*Pterocryptis indicus* Datta, Barman & Jayaram, 1987	Siluridae	Di;Aiii85;Pi11;Vi7	DD
173	*Wallago attu* (Bloch & Schneider, 1801)	Siluridae	D5;Aiii74-93;PI13-15;Vi7-9	VU
174	*Conta conta* (Hamilton, 1822)	Sisoridae	DI5-6;Aii-iii7;PI6;Vi5	DD
175	*Erethistes hara* (Hamilton, 1822)	Sisoridae	DI6-7;Aiv7-8;PI7;Vi5	LC
176	*Erethistes horai* (Misra, 1976)	Sisoridae	DI6;Aiii7;PI6;Vi5	LC

	Scientific Name	Family	Fin formula	IUCN Red List status (2024)
177	*Erethistes jerdoni* (Day, 1870)	Sisoridae	DI5;Aiv-v5-7;PI4-5;Vi5	LC
178	*Erethistes pusillus* Müller & Troschel, 1849	Sisoridae	DI6;Aiii8;PI5-6;Vi5	LC
179	*Pseudolaguvia vespa* Praveenraj, Vijayakrishna, Lima & Gurumayum, 2021	Sisoridae	D 5, i (1), 6, i*(2) or 6 (7);P 7*(2) or 8 (8);Vi,4,i(2) or i,5, i* (8);A iv, 5, i* (5), iv, 6, i (4) or iv,or iv,7, i(1);C i,14,i(10)	NE
180	*Bagarius bagarius* (Sykes, 1839)	Sisoridae	Di7;Aiii9-12;Pi11-14;Vi5	VU
181	*Exostoma berdmorei* (Blyth, 1860)	Sisoridae	Di6;Ai5;Pi10;Vi5	DD
182	*Exostoma labiatum* (McClelland, 1842)	Sisoridae	Di6;Ai5;Pi11-12;Vi5	LC
183	*Exostoma stuarti* (Hora, 1923)	Sisoridae	Di6;Ai5;Pi10;Vi5	DD
184	*Exostoma vinciguerrae* Regan, 1905	Sisoridae	Di6;Ai5;Pi10;Vi5	DD
185	*Exostoma sentiyonoae* Shangningam & Limatemjen, 2024	Sisoridae	Di6(7); Ai5(7);Pi10(7);Vi5(7);Ci,6,7,i (3) or i,7,8,i(4)	NE
186	*Gagata cenia* (Hamilton, 1822)	Sisoridae	Di6:Aii-iii10-14;Pi7-9;Vi5	LC
187	*Glyptosternon maculatum* Regan, 1905	Sisoridae	Di6;Ai5;Pi12;Vi5	LC
188	*Glyptothorax cavia* (Hamilton, 1822)	Sisoridae	Di6;Aii9-10;PI9;Vi5	LC
189	*Glyptothorax saisii* Jenkins, 1910	Sisoridae	Di6;Aiv8;Pi10;Vi5	VU
190	*Glyptothorax sentimereni* Praveenraj & Vijayakrishnan 2026	Sisoridae	DI,6*(3);Aiv,8*(2) or iv,9(1);Pi,10*i(3);Vi,5(3); Ci,7,8,i*	NE
191	*Glyptothorax indicus* Talwar, 1991	Sisoridae	DI5-6;Aii8-9;PI8-9;Vi5	LC
192	*Glyptothorax manipurensis* (Menon, 1955)	Sisoridae	DI6;Aii9;PI9;Vi5	VU
193	*Glyptothorax platypogonides* (Bleeker, 1855)	Sisoridae	Di6-7;Aiii-iv9;Pi8-9;Vi5	LC
194	*Glyptothorax sinensis* Regan, 1908	Sisoridae	Di6;Aii9;Pi9;Vi5	DD
195	*Glyptothorax telchitta* (Hamilton, 1822)	Sisoridae	DI6-7;Aii9-10;PI7-9;Vi5	LC
196	*Glyptothorax trilineatus* (Blyth, 1860)	Sisoridae	DI6-7;Ai9-10;PI10-11;Vi5	LC
197	*Myersglanis jayarami* Vishwanath & Kosygin, 1999	Sisoridae	D;A5;P10;C15-16	VU
198	*Nangra nangra* (Hamilton, 1822)	Sisoridae	DI9-10;Aiii10;PI9;Vi5	LC
199	*Pseudecheneis nagalandensis* Shangningam & Kosygin, 2020	Sisoridae	Di,6(8);Aiii,8(8);Pi,14(8);Vi,5(8);Ci,7,8i(8)	NE
200	*Sisor rabdophorus* (Hamilton, 1822)	Sisoridae	DI6;Aii4;PI8;Vi7	LC
201	*Monopterus albus* Zuiew, 1793	Synbranchidae	--------	LC
202	*Monopterus cuchia* (Hamilton, 1822)	Synbranchidae	-------	LC

D—Dorsal fin | D1—First dorsal fin | D2—Second dorsal fin | A—Anal fin | P—Pectoral fin | V—Pelvic fin | LC—Least Concern | DD—Data Deficient | NT—Near Threatened | VU—Vulnerable | EN—Endangered | NE—Not Evaluated.

kosygini, have enhanced the documentation of local biodiversity, further research is necessary, especially in remote areas. Continued efforts to study, monitor, and conserve Nagaland's fish diversity are essential for maintaining ecosystem stability, protecting species from extinction, and contributing valuable knowledge to global freshwater biodiversity conservation initiatives.

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Table 4. Threatened fish species under the IUCN Red List in Nagaland.

Scientific name	IUCN Red List category	Threats	Criteria IUCN (ver 3.1)	Conservation actions needed
Amblyceps arunachalense Nath & Dey, 1989	EN	1. Mining & quarrying 2. Fishing & harvesting aquatic resources	B1ab(iii)	1. Land/water protection 2. Land/water management
Schistura kangjupkhulensis (Hora, 1921)	EN	1. Destructive fishing methods 2. Human intrusions & disturbance	A3c+4ac; B2ab(iii,iv,v)	1. Land/water protection 2. Land/water management 3. Education & awareness 4. Law & policy
Mustura sijuensis (Menon, 1987)	EN	1. Mining & quarrying 2. Logging & wood harvesting	B1ab(iii)	1. Land/water protection 2. Land/water management 3. Species management 4. Education & awareness 5. Law & policy
Clarias magur (Hamilton, 1822)	EN	1. Domestic & urban waste water 2. Agricultural & forestry effluents 3. Fishing & harvesting aquatic resources 4. Invasive non-native	A3cde+4acde	1. Land/water protection 2. Land/water management 3. Species management 4. Education & awareness 5. Law & policy 6. Livelihood, economic & other incentives
Tor putitora (Hamilton, 1822)	EN	1. Housing & urban areas 2. Mining & quarrying 3. Fishing & harvesting aquatic resources 4. Recreational activities 5. Dams & water management/use 6. Domestic & urban waste water 7. Agricultural & forestry effluents 8. Habitat shifting & alteration 9. Droughts 10. Storms & flooding	A2abcd	1. Species management 2. Education & awareness 3. Law & policy
Schistura nagaensis (Menon, 1987)	VU	1. Annual & perennial non-timber crops. 2. Agricultural & forestry effluents	B1ab(iii).	1. Site/area protection 2. Site/area management 3. Habitat & natural process restoration
Mustura prashadi (Hora, 1921)	VU	1. Housing & urban areas 2. Domestic & urban waste water 3. Agricultural & forestry effluents	B1ab(iii)	1. Site/area protection 2. Resource & habitat protection 3. Site/area management 4. Habitat & natural process restoration 5. Awareness & communications
Schistura reticulofasciata (Singh & Bănărescu, 1982)	VU	1. Logging & wood harvesting 2. Other ecosystem modifications	B1ab(iii); D2.	1. Site/area protection 2. Resource & habitat protection 3. Site/area management 4. Habitat & natural process restoration 5. Species management 6. Species recovery 7. Ex-situ conservation 8. Awareness & communications 9. Legislation 10. Policies and regulations
Schistura singhi (Menon, 1987)	VU	1. Annual & perennial non-timber crops 2. Dams & water management/use	B1ab(iii); D2	More research is needed on distribution, life history, population, trends, habitat, and impacts of threat.
Oreochromis mossambicus (Peters, 1852)	VU	1. Invasive non-native/alien species/ diseases	A4ae	1. Site/area protection 2. Invasive/problematic species control 3. Awareness & communications Policies and regulations
Botia rostrata (Günther, 1868)	VU	1. Housing & urban areas 2. Mining & quarrying 3. Fishing & harvesting aquatic resources	A2cd	Impact of threats on the species distribution and population requires detailed studies.
Cyprinion semiplotum (McClelland, 1839)	VU	1. Fishing & harvesting aquatic resources 2. Other ecosystem modifications	A2acde+3cde	1. Resource & habitat protection 2. Harvest management 3. Legislation at International level 4. Livelihood, economic & other incentives (Substitution)
Cyprinus carpio Linnaeus, 1758	VU	1. Transportation & service corridors (Shipping lanes) 2. Dams & water management/use 3. Introduced genetic material	A2ce	1. Site/area management 2. Invasive/problematic species control 3. Habitat & natural process restoration
Devario naganensis (Chaudhuri, 1912)	VU	1. Dams & water management/use	B1ab(iii)	More research is needed on distribution, life history, population, trends, habitat, and impacts of threat.

Scientific name	IUCN Red List category	Threats	Criteria IUCN (ver 3.1)	Conservation actions needed
Opsarius dogarsinghi (Hora, 1921)	VU	1. Human intrusions & disturbance	B1ab(iii)	Resource & habitat protection
Pethia shalynius (Yazdani & Talukdar, 1975)	VU	1. Mining & quarrying	B1ab(iii)	More research is required on distribution, biology, population, habitat, trends and threats to the species
Schizothorax richardsonii (Gray, 1832)	VU	1. Tourism & recreation areas 2. Fishing & harvesting aquatic resources 3. Dams & water management/use 4. Invasive non-native/alien species/ diseases 5. Other threat	A2acd+3cde+ 4acde	1. Site/area protection 2. Resource & habitat protection 3. Site/area management 4. Invasive/problematics species control 5. Species recovery 6. Species re-introduction 7. Ex-situ conservation 8. Formal education 9. Awareness & communications 10. Policies and regulations
Wallago attu (Bloch & Schneider, 1801)	VU	1. Fishing & harvesting aquatic resources 2. Recreational activities 3. Domestic & urban waste water 4. Agricultural & forestry effluents 5. Droughts 6. Storms & flooding	A2d	1. Resource & habitat protection 2. Harvest management
Bagarius bagarius (Hamilton, 1822)	VU	1. Fishing & harvesting aquatic resources 2. Dams & water management/use	A2d	More information about the population size and trend, as well as the effect of fishing and other anthropogenic activities on the global population, is needed.
Glyptothorax saisii (Jenkins, 1910)	VU	1. Mining & quarrying 2. Logging & wood harvesting	B1ab(iii)+ 2ab(iii); D2	Data on the species' population status, distribution, and associated threats is needed
Glyptothorax manipurensis Menon, 1955	VU	1. Dams & water management/use	B2ac(ii)	1. The potential threats to this species require more thorough and immediate study.
Myersglanis jayarami Vishwanath & Kosygin, 1999	VU	1. Annual & perennial non-timber crops 2. Fishing & harvesting aquatic resources	B1ab(iii)	1. Further investigation into the distribution and biology of this species is necessary due to the lack of adequate information currently available.
Anguilla bengalensis (Gray, 1831)	NT	1. Housing & urban areas 2. Commercial & industrial areas 3. Oil & gas drilling 4. Mining & quarrying 5. Renewable energy 6. Fishing & harvesting aquatic resources 7. Dams & water management/use 8. Invasive non-native 9. Domestic & urban waste water 10. Industrial & military effluents 11. Agricultural & forestry effluents	A2cd	1. Species management 2. Education & awareness
Balitora brucei Gray, 1830	NT	1. Mining & quarrying 2. Agricultural & forestry effluents	------	1. Site/area protection 2. Resource & habitat protection 3. Site/area management 4. Ex-situ conservation
Neonoemacheilus assamensis (Menon, 1987)	NT	1. Fishing & harvesting aquatic resources	------	1. Site/area protection
Garra gravelyi (Annandale, 1919)	NT	1. Human intrusions & disturbance 2. Domestic & urban waste water	------	1. Resource & habitat protection
Garra rupecula (McClelland, 1839)	NT	1. Mining & quarrying 2. Logging & wood harvesting 3. Dams & water management/use	------	1. Resource & habitat protection 2. Awareness & communications
Hypophthalmichthys molitrix (Valenciennes, 1844)	NT	1. Fishing & harvesting aquatic resources 2. Dams & water management/use 3. Domestic & urban waste water 4. Industrial & military effluents 5. Agricultural & forestry effluents	------	1. Wild population should be monitored.
Labeo pangusia (Hamilton, 1822)	NT	1. Fishing & harvesting aquatic resources	------	1. Awareness & communications

Scientific name	IUCN Red List category	Threats	Criteria IUCN (ver 3.1)	Conservation actions needed
Neolissochilus hexagonolepis (McClelland, 1839)	NT	1. Commercial & industrial areas 2. Tourism & recreation areas 3. Annual & perennial non-timber crops 4. Wood & pulp plantations 5. Mining & quarrying 6. Roads & railroads 7. Logging & wood harvesting 8. Dams & water management/use 9. Domestic & urban waste water 10. Industrial & military effluents	------	1. Site/area protection 2. Resource & habitat protection 3. Site/area management 4. Habitat & natural process restoration 5. Harvest management 6. Awareness & communications 7. Legislation at National Level 8. Compliance and enforcement
Neolissochilus hexastichus (McClelland, 1839)	NT	1. Mining & quarrying 2. Logging & wood harvesting 3. Fishing & harvesting aquatic resources 4. Dams & water management/use	------	1. Research 2. Biology of the fish
Systomus clavatus (McClelland, 1845)	NT	1. Mining & quarrying 2. Fishing & harvesting aquatic resources 3. Dams & water management/use	------	1. Site/area protection
Chitala chitala (Hamilton, 1822)	NT	1. Fishing & harvesting aquatic resources 2. Other ecosystem modifications	------	1. Site/area protection 2. Resource & habitat protection
Ailia coila (Hamilton, 1822)	NT	1. Fishing & harvesting aquatic resources	------	1. Pollution and habitat destruction's impact on population declines needs more research.
Ompok bimaculatus (Bloch, 1794)	NT	1. Fishing & harvesting aquatic resources	------	1. Harvest management 2. Awareness & communications
Ompok pabda (Hamilton, 1822)	NT	1. Fishing & harvesting aquatic resources	------	1. Pollution and habitat destruction's impact on population declines needs more research.
Rhyacoschistura manipurensis (Chaudhuri, 1912)	NT	1. Dynamite and other destructive fishing 2. Human interference and poisoning	------	1. Site/area protection

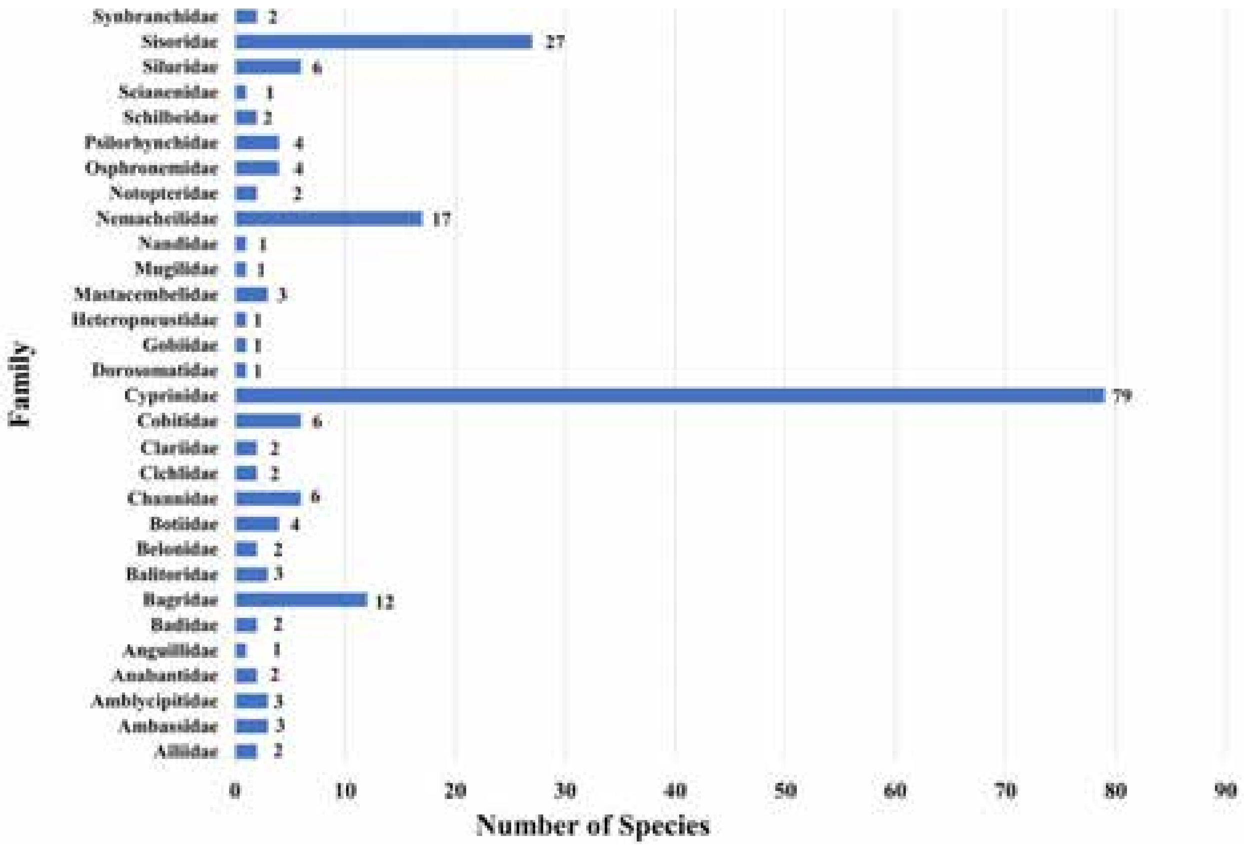

Figure 4. Species count across different fish families in Nagaland.

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SHORT COMMUNICATION

Preliminary observations on the breeding ecology and potential threats to Bonelli's Eagle *Aquila fasciata* in Sithagiri Malai, Tamil Nadu, India

S. Naveenkumar [1], H. Byju [2] & H. Maitreyi [3]

[1] 439, 6th Street, K.K. Pudur, Coimbatore, Tamil Nadu 641038, India.
[2,3] Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai, Tamil Nadu 608502, India.
[1] naturenks@gmail.com, [2] byjuhi@gmail.com (corresponding author), [3] maithgd@gmail.com

Abstract: Bonelli's Eagle ([illegible]; meaning hare hunter) *Aquila fasciata* is a top predator experiencing population declines across its range. This study presents preliminary findings from a periodic survey (April 2024–May 2025) in Sithagiri Malai, a rocky outcrop in Tamil Nadu, India. We document the presence of breeding territory, potential prey species, and discuss imminent threats, particularly from windmills, emphasising the ecological value of rocky outcrops for the species in this landscape.

Keywords: Accipitridae, Accipitriformes, bioindicators, power line collisions, raptors, rock outcrop, wind turbines.

Raptors are indicators of environmental health and are keystone species (Kitowski et al. 2017), vital for maintaining ecosystem balance. As apex predators, they help regulate prey populations, preventing overgrazing, and agricultural damage (Donázar et al. 2016). Globally, 18% of raptors are threatened with extinction and 52% exhibit declining populations (McClure et al. 2018), making demographic studies crucial for their conservation (Byju et al. 2023).

The Bonelli's Eagle *Aquila fasciata* is an uncommon resident throughout the Indian subcontinent from plains to 2,600 m (Ali & Ripley 1987; Rasmussen & Anderton 2012). It is a cliff-nesting raptor with fragmented distribution across the Palearctic, Indo-Malayan, and marginally Afrotropical regions (Di Vittorio et al. 2017; Birdlife International 2020). Breeding period varied in the western range (January–July); Indo-Malayan region (November–September) (Ferguson-Lees & Christie 2001), and Indian region (December–May) (Ali & Ripley 1987; Ontiveros 1999; Rasmussen & Anderton 2012). Bonelli's Eagle is a long-lived, territorial, and monogamous species. The nest is a massive platform built on cliffs or on tall trees and reused in successive years (Hernández-Matías et al. 2011). Rocky outcrops provide critical nesting habitat for this species, offering inaccessible cliff faces that protect nests from mammalian predators (Fitzsimons & Michael 2017).

The population is declining drastically throughout its range owing to over-use of pesticides, habitat degradation, loss of prey species, collision with power lines, and persecution by hunters & pigeon fanciers (Ferguson-Lees & Christie 2001; Bharos & Pare 2023). This study reports initial observations on Bonelli's Eagle breeding in Sithagiri Malai, focusing on its potential threats. This study emphasizes the conservation significance of this rocky hillock as a potential breeding area for birds, despite growing anthropogenic pressures, including rock mining in the vicinity.

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Observations

Breeding was recorded in Sithagiri Malai, Kuppanavalasu, Tamil Nadu (approx. 10.45^0 N, 77.72^0 E), a rocky outcrop with elevations ranging from 287–376 m (Image 1). This hill supports moderate dry-deciduous scrub vegetation. Sithagiri Malai comprises at least three sacred temples, one of which is a cave temple that hosts a bat population. Natural water holes locally called 'Paali' and 'Sonai' are present here; the former has served as a water source for people and cattle, and the latter is used as a sacred water to treat illness until the mid-20th Century. The area is surrounded by grasslands either with bio-fences or fenced with granite poles, agricultural lands, and villages. The region receives the north-east monsoon from October–December, and summers last from March–June with occasional summer showers. Geographically, it lies ~100 km east of the Palakkad Gap, leading to strong westerly winds during the south-west monsoon season (June–September).

Field visits were carried out from April 2024 to May 2025, at fortnightly intervals, every month. The bird's behaviour was recorded from 0700–0900 h and 1600–1800 h. Observation was carried out at a distance of at least 250 m to avoid disturbance through a Nikon Aculon binocular (8 × 42). Photographic documentation was done using a Nikon P950 camera.

With information from local villagers, the activity of Bonelli's Eagle was followed. We confirmed the first breeding record of this species from the area, and the breeding season is from December–March (Bharos & Pare 2023). A detailed chronological follow-up of some field observations of nesting details is given separately in Table 1. Sithagiri Malai breeding territory is consistent with the species' preference for rocky, arid to semi-moist habitats (Ferguson-Lees & Christie 2001). A nest, composed of sticks and approximately 1.5 m in

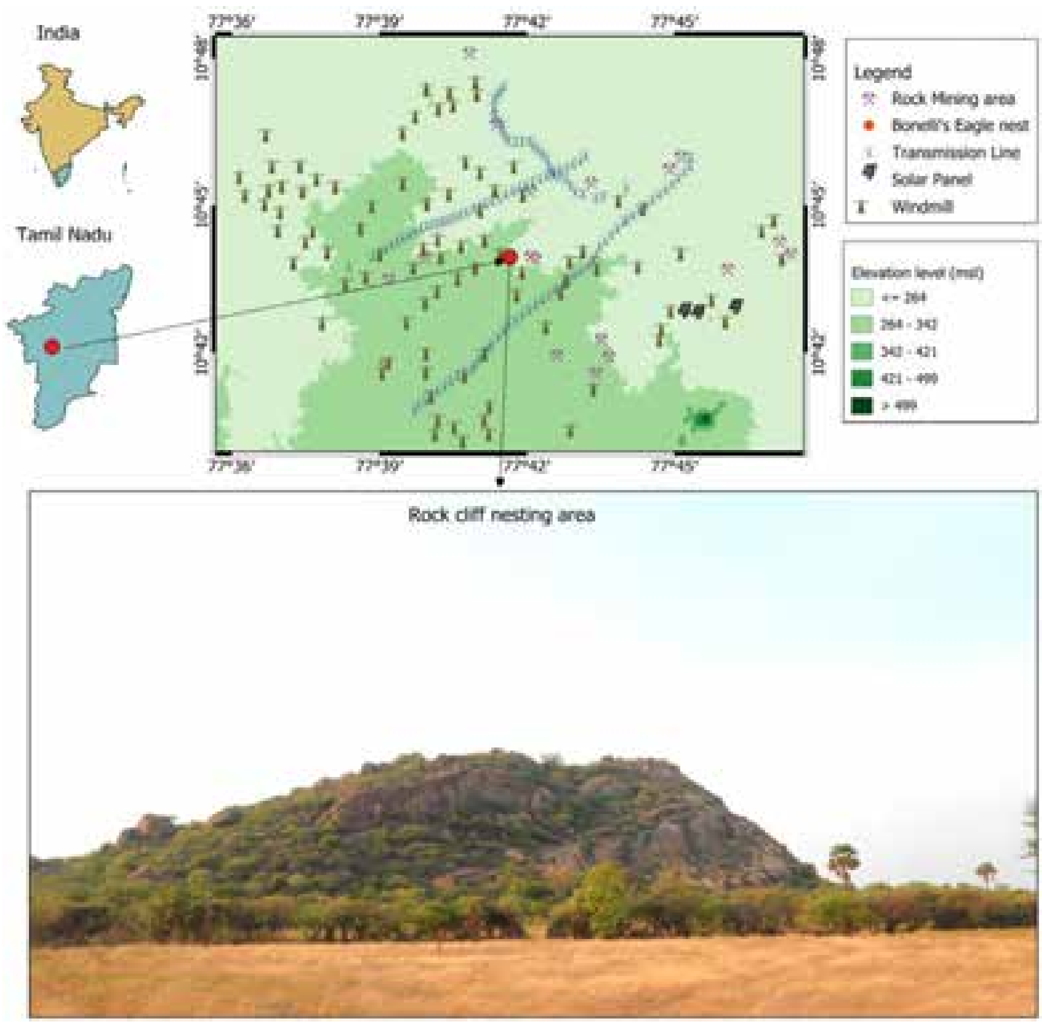

Image 1. Map showing the nesting area of Bonelli's Eagle surrounded by windmills, electric lines, solar panels, and mining areas.

Table 1. Summary of observations on the nesting Bonelli's Eagle.

Date of observation	Time of observation	Activities and behaviour
09.iv.2024	0700–0900 h	Two adult birds were taking advantage of the thermal current upwind and actively scanning for prey. Then the female bird perched on the rocks looking for food.
18.viii.2024	0700–0900 h	Observed both male and female roosting on a single tree. Remnants of an old nest are observed on the rock cliff.
29.xii.2024	0700–0900 h	One adult was observed roosting in a tree and grooming.
16.i.2025	0700–0900 h	Nest looks in good shape with a reinforced base on an inaccessible cliff face. Approximately 1.5 m in diameter.
22.ii.2025	0700–0900 h	The male was perched on the rock in the vicinity of the nest. The female was seen inside the nest; chicks or eggs were not visible.
27.iii.2025	1600–1800 h	Two fledglings were seen inside the nest with dropped wings. A male was seen guarding the nest from the rock situated above it.
28.iii.2025	0700–0900 h	The female was feeding two chicks inside the nest. Prey was recorded from the bottom of the cliff.
26.iv.2025	0700–0900, 1600–1800 h	Initially, the fledglings, which have become juveniles, were seen with adults in flight. Then, one juvenile was seen roosting in a tree. The juveniles were seen soaring very close to the adults. On the ground, the juveniles were still dependent on the adult for food.
15.v.2025	0700–0900 h	Two of the juveniles were flying together and engaged in aerial combat a couple of times. One was trying to catch an Asian Palm Swift. At previous night, the nearest temple had crackers for the festival.

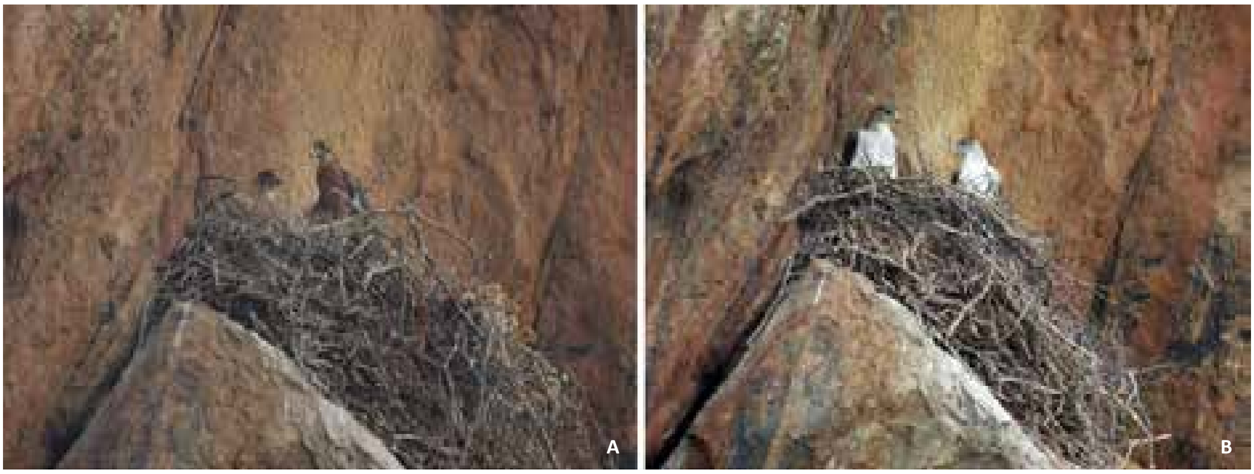

Image 2. Nest of Bonelli's Eagle on the rock cliff: A—juveniles | B—adults. © S. Naveen Kumar.

diameter, was located on a remote cliff ledge (Image 2). The surrounding landscape, including grasslands and agricultural fields, likely serves as foraging areas, as eagles often hunt several kilometers from the nest.

Adult male is dark brown above with a capped head and a white patch on the back. The tail is grey, obscurely barred, with a broad sub-terminal band; white below with thin streaks, broader on breast/flanks, bars on belly/crissum. During flight, below the white body, a black band on the linings; obscure dark trailing edges to greyish remiges; a subterminal band on paler tail. Above white on back; grey tail, dark band. Adult female—flight below smaller; quills more clearly barred; belly/thighs/crissum more boldly marked (Ferguson-Lees & Christie 2001).

From both our field observations and local villagers' accounts, the potential prey species identified included Indian Hare *Lepus nigricollis*, Bonnet Macaque *Macaca radiata*, Grey Francolin *Ortygornis pondicerianus*, Rock Bush Quail *Perdicula argoondah*, and domestic poultry. The presence of the Grey Slender Loris *Loris lydekkerianus* and Bengal Monitor Lizard *Varanus bengalensis* suggests a diverse prey base (Image 3). Potential predators of the eagle chicks include Indian Golden Jackal *Canis aureus*, Jungle Cat *Felis Chaus*, and Rock Eagle-Owl *Bubo bengalensis*, the latter being a known predator of Bonelli's Eagle chicks in other regions (Image 4).

Potential Conservation Threats

The primary threats identified are linked to energy infrastructure and habitat modification.

Bonelli's Eagle nesting area is in proximity to windmills, and the birds are often observed flying around

Image 3. A few prey species observed near the Bonelli's Eagle nest: A—Bonnet Macaque | B—Indian Hare | C—Grey Slender Loris. © S. Naveen Kumar.

Image 4. A few predators observed around the Bonelli's Eagle nest: A—Indian Golden Jackal | B—Rock Eagle-owl. © S. Naveen Kumar.

it for foraging. The region's high wind potential, ideal for energy development, poses collision risks for raptors like Bonelli's Eagle, which engage in kiting and stooping while hunting (Smallwood & Thelander 2008; Skarabal et al. 2025), limiting maneuverability, and increasing collision risk (De Lucas et al. 2008), as they might lose track of their wind turbine position (Krijgsveld et al. 2009). While the present study focuses on nesting ecology rather than mortality assessment, the proximity of active wind turbines to known nesting and flight corridors warrants caution. Incorporating bird flight height data and seasonal activity patterns could help avert future bird and bat collision risk assessments, which would be essential for accurately quantifying turbine-related threats to Bonelli's Eagle populations in the Dindigul landscape. In the Western Ghats (Karnataka and Maharashtra), most victims of this collision were land birds such as Bonelli's Eagle, Changeable Hawk Eagle *Nisaetus cirrhatus*, and Black Kite *Milvus migrans* (Kumar et al. 2019, 2022).

Electrocution on poorly designed power pylons and collision with power lines are leading causes of mortality for Bonelli's Eagles globally (Hernández-Matías et al. 2015). Even though we did not observe any electrocution of the species, the existing and expanding network of electric pylons in the landscape poses a potential risk, as electrocution of raptors is increasingly reported (Manigandan et al. 2022). The conversion of traditional bio-fences to impermeable granite stone walls reduces microhabitats for prey species. The sacred and cultural significance of Sithagiri Malai (e.g., cave temples, water holes) may offer some protection, but rising anthropogenic pressure remains a concern. The emerging threat to this rocky outcrop is the potential impact of climate change, as species inhabiting mountain regions are predicted to be adversely affected by rising temperatures and reductions in bioavailable water (Fitzsimons & Michael 2017). Cattle grazing and firewood collection are not observed, but bird poaching is still reported by locals, along with honey gathering. Presently, there is no mining, but we observed that the sounds created by nearby rock mines created panic for peafowls. This is not impacting the nesting of eagles, at present. The bio-fence of the grassland patch, which is being converted to a metal fence with granite stone, is reducing hiding spots for several reptile, mammal, and bird species. Currently, no conservation outreach, either by villagers or NGOs, is active. Hence, immediate conservation measures are warranted.

Conclusion

Sithagiri Malai provides a critical breeding habitat for the Bonelli's Eagle in Tamil Nadu. The confirmed nesting site and diverse prey base highlight this rocky outcrop ecosystem's high conservation value.

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SHORT COMMUNICATION

A nesting attempt by Greater Flamingo *Phoenicopterus roseus* in an inland wetland in Kachchh District, Gujarat, India

Gaurav Sirola [1], Harindra Baraiya [2], Rajdeep Mitra [3], Anju Baroth [4] & R. Suresh Kumar [5]

[1–5] Department of Endangered Species Management, Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India.
[1] gauravsirolaofficial@gmail.com (corresponding author), [2] hareendra3994@gmail.com, [3] rajdeep221240@gmail.com,
[4] barothanju@gmail.com, [5] suresh.wii@gmail.com

Abstract: India is home to the two flamingo species – Greater Flamingo *Phoenicopterus roseus* and Lesser Flamingo *Phoeniconaias minor*. Saline mudflats (Rann) of the Kachchh landscape in western India support the largest breeding sites of flamingos in Asia. In 2019, we conducted a wetland survey across Kachchh between January and December 2019 and recorded nesting of Greater Flamingos in Ratnal, a freshwater irrigation tank. Around 400 Greater and 700 Lesser Flamingos were observed foraging at this site on 25 July 2019. We recorded a total of 35 mud mounds, the morphometrics of 10 intact mounds were taken, and the mean height was 26.4 (± 2.38) cm, and the circumference was 28.4 (±1.36) cm. These measurements closely matched the published dimensions of Greater Flamingo nests, indicating the species likely constructed them. The courtship displays of both species were observed during the study period; however, no eggs were laid. Further, the nests were abandoned following heavy rainfall in August 2019. We monitored the wetland for the next three years, 2020–2023, but no further nesting attempt was recorded. This observation likely represents a false nesting attempt by Greater Flamingo and highlights potential flexibility in nest-site selection, underscoring the importance of systematic monitoring of freshwater wetlands, and they may serve as both breeding and non-breeding habitats.

Keywords: Breeding sites, foraging, freshwater irrigation tank, nest-site selection, Phoenicopteriformes, Phoenicopteridae, wetland survey.

The Greater Flamingo *Phoenicopterus roseus* and Lesser Flamingo *Phoeniconaias minor* are the two most widely distributed flamingo species across Asia, Africa, and Europe (BirdLife International 2025). In India, Greater Flamingo is widely distributed across the country, with the exception of the northeastern Indian states, and occurs in a diverse range of wetland habitats, such as inland freshwater bodies, reservoirs, salt pans, coastal wetlands, lagoons, and intertidal zones (Tere 2005; Salvador et al. 2022). In contrast, Lesser Flamingo has a more restricted distribution, particularly in mudflats near coastal areas (Tere 2005). The wetlands of Kachchh District serve as significant sites for both breeding and non-breeding populations of flamingos. The Greater Rann and Little Rann of Kachchh, collectively spanning over 20,000 km^2, are vast seasonal salt marshes that get inundated during the monsoon season, creating ideal conditions for flamingo nesting. The Greater Rann of Kachchh houses one of Asia's largest breeding colonies of Greater Flamingos at the site famously known as 'Flamingo City'. The Little Rann of Kachchh largely supports a breeding population of Lesser Flamingos, especially in shallow saline mudflats and salt pans (Ali 1945; Mundkur et al. 1989; Singh et al. 1999; Tere 2005; Vyas 2015; Rathwa 2022). Both species are recorded breeding successfully at the Great Rann of Kachchh, near Kuda (Parasharya et al. 2010; Sirola &

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Kumar 2023; Tere et al. 2025). The nesting of flamingos is highly erratic, influenced by a complex interplay of hydrological conditions, habitat availability, and anthropogenic disturbances (Johnson & Cézilly 2007; Krienitz 2018). Irregular nesting and low reproductive success due to human disturbances pose a threat to the population of both species of flamingos (BirdLife International 2025). In India, flamingos have been listed as a Schedule II species under the Wildlife Protection Act 1972. In recent years, the Greater Flamingos have been recorded breeding successfully at the Gulf of Khambhat, outside their regular breeding sites in the Rann of Kachchh (Parasharya & Gadhvi 2020). Both species are also recorded making nesting attempts at several non-traditional sites across India, suggesting a potential shift and expansion in their nesting sites (Andharia & Andharia 2024). These observations indicate the importance of regular and systematic monitoring of flamingos' habitats (Byju et al. 2025) to assess habitat quality and guide targeted conservation interventions.

We conducted pilot surveys across 91 wetlands of Kachchh District from January to March 2019 to record the presence of flamingos as part of a study to assess the impacts of energy infrastructure on large bird species (Image 1). Based on the pilot surveys, the Ratnal wetland (23.19° N, 69.91° E) was selected for monthly monitoring to understand the seasonal fluctuations in the population of flamingos. Ratnal is a 19 ha freshwater irrigation tank built to collect rainwater and irrigate agricultural fields in the surrounding areas. We report

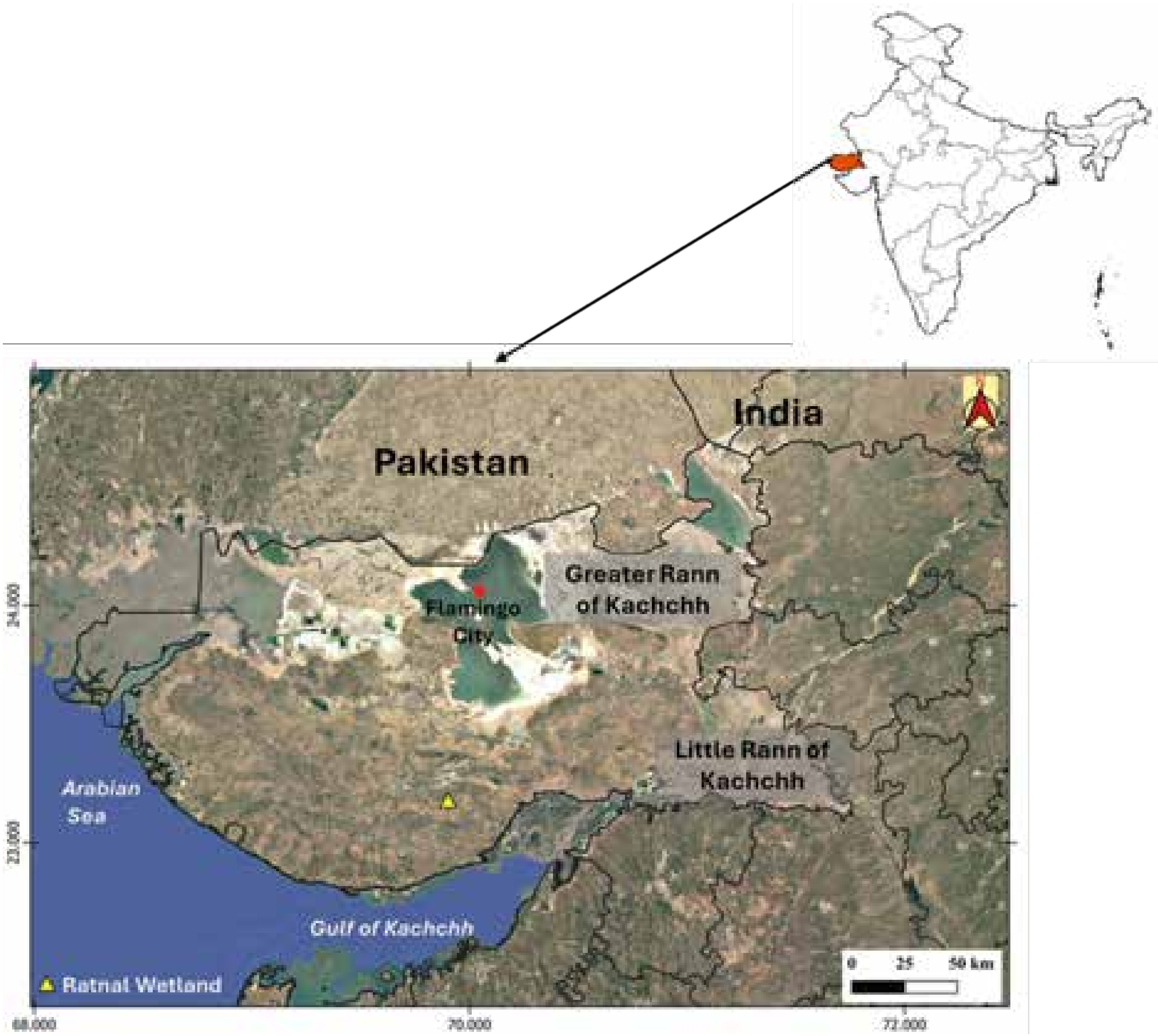

Image 1. Location of Ratnal wetland in western India.

an instance of Greater Flamingo attempting to nest in the Ratnal freshwater wetland.

Observations

We recorded Lesser Flamingos (~700) and Greater Flamingos (~400) at the Ratnal wetland on 25 July 2019. Both species were foraging actively. We documented 35 cylindrical, empty, unattended mud mounds of flamingos on the eastern side of the wetland (Image 3). These structures were not observed in our previous field visits in June 2019, indicating their construction in the interim period. Among the total, eight mounds were smaller and malformed, likely representing incomplete nest structures. Thereafter, the site was monitored continuously over three consecutive days from a fixed position from the bank of the wetland, using a spotting scope to minimize disturbance to the birds. Both the flamingo species were observed engaging in courtship displays (Image 2); however, none approached or occupied the nests, suggesting their abandonment prior to egg-laying. All nests were located on an island with an area of 645 m^2 and surrounded by knee-deep water on the northern side and shallow water on the southern fringes (Image 3). The nesting area was estimated by recording the boundary of the wetland through GPS tracking along its perimeter. The recorded track was then imported into QGIS software, where it was converted into a polygon using the "Path to polygon" tools. This polygon was subsequently used to calculate the total nesting area. The nest monitoring was retrospectively conducted in accordance with the guidelines proposed in Barve et al. (2020). The nests were not physically examined by the authors until the flamingos left the site. With the onset of monsoon in August, the area experienced heavy rainfall and subsequently, all flamingos left the wetland on 14 August 2019, likely moving toward the Rann of Kachchh. The morphometric data of 10 fully intact nests with the

Image 2. a—Greater Flamingos performing Wing Salute and Alert posture | b—Lesser Flamingos displaying at Ratnal wetland in July 2019. © Harindra Baraiya.

least visible damage due to rainfall were collected on 20 August 2019. The mean top diameter of the nests was 28.4 ± 1.36 cm, and the mean height was 26.4 ± 2.38 cm. These measurements were compared with published nest morphometry data for flamingos (Table 1). Although there is some overlap in nest dimensions between Lesser and Greater Flamingos, the observed values in the present study more closely align with those reported for Greater Flamingos, particularly in terms of the larger top diameter.

Table 1. Comparison of nest morphometrics with available published literature.

Source	Species	Average Height (cm)	Top Diameter (cm)
Makwana 2022	Lesser Flamingo	~16	~21
Tere 2005	Lesser Flamingo	11.7–17.9	21.5–27.4
Vyas 2015	Lesser Flamingo	29.5–30.8	25.4–26.5
Salvador et al. 2024	Greater Flamingo	7.6–40	25–37
Tere 2005	Greater Flamingo	11.3–33.2	11.7–17.7
Current Study*	Greater Flamingo	26.4	28.4

*Measurements were taken post rainfall; actual height may be higher and diameter lower.

Follow-up visits (once a month) in the breeding season (July–December) of 2020 and 2021 (February–March, July–October) were made, but no nest-building activity was recorded. Continuous monthly monitoring could not be maintained throughout 2020 and 2021 due to COVID-19 restrictions and was resumed in 2022 and 2023. On 04 July 2022, Greater Flamingos were once

Image 3. Several nest mounds were observed near the eastern edge of the Ratnal wetland, July 2019. © Harindra Baraiya.

Image 4. Greater Flamingos observed performing a wing salute, a type of courtship display at Ratnal wetland, July 2022. © Gaurav Sirola.

Figure 1. Details of flamingo recorded at Ratnal during monthly surveys.

again observed performing courtship displays (Image 4), but no nest-building activity was observed during weekly visits conducted through the remainder of the season in 2022 and 2023.

Discussion

This is the first instance of a Greater Flamingo attempting to nest in a freshwater inland wetland in Gujarat's Kachchh District close to the "Flamingo City". Thakker (1983) recorded 70–80 nests of flamingos along with juveniles at Thol Bird Sanctuary near Ahmedabad, Gujarat; however, no confirmed successful breeding was documented at the site. Later, in 1993, at Shahwadi Wetland, Gujarat, Tatu (1997) observed 12 nests built by Greater Flamingos, which were later abandoned. Recently, Andharia & Andharia (2024) reported Lesser Flamingos nesting near Bhavnagar airport in Gujarat in 2021. They recorded 42 intact nests, however, the site was abandoned shortly after the nest-building phase.

In the present study, nest morphometrics were recorded after heavy rainfall, after the birds had vacated the site. Flamingo nests, being composed primarily of mud, are susceptible to erosion, compaction, and structural alteration following rainfall events (Johnson & Cézilly 2007). Greater Flamingo nests are generally larger and more robust, whereas Lesser Flamingo nests are typically smaller and less elevated (Johnson & Cézilly 2007). Hence, we assume rainfall and weathering may have reduced the original height of the nests and slightly increased the apparent top diameter due to structural flattening. Consequently, the original nest dimensions were likely somewhat taller and narrower than actually recorded. This limitation should be considered when comparing the present measurements with published data. Despite this potential bias, the overall morphometric characteristics remain more consistent with Greater Flamingo nests and exceed those typically described for Lesser Flamingo nests, thereby supporting species identification (Table 1).

Flamingos generally prefer remote, undisturbed wetlands for breeding (Krienitz 2018), and nesting attempts in urban or inland environments near human settlements are uncommon. Abandonment of nests is often observed in flamingos and is commonly attributed to human disturbances, flooding of nest sites or the presence of predators. Furthermore, Johnson & Cézilly (2007) have described a phenomenon termed 'false nesting attempts', in which flamingos gather at non-breeding sites, construct elaborate nests, but do not proceed to egg-laying. Whereas in a failed breeding attempt, eggs are laid and the nest is abandoned due to disturbance or drastic changes in water level. False nesting has been widely documented across the distribution range of the flamingos, though the underlying mechanisms remain unclear. Interestingly, in some cases, false nesting sites later transform into permanent breeding colonies (Johnson & Cézilly 2007). Ratnal Wetland is surrounded by dense thickets of *Suaeda* spp. and *Neltuma juliflora*, with minimal to no human or livestock disturbance. Additionally, water levels were sufficient, and the nesting island was surrounded by water on all sides. Therefore, nest abandonment at this site is unlikely to have been driven by disturbance. We conclude that the nesting event at Ratnal wetland may likely be a false nesting attempt and is documented for the first time in an inland freshwater wetland from Kachchh close to the traditional nesting site of flamingos in the Greater Rann of Kachchh.

Additionally, we recorded a huge flamingo population at Ratnal wetland just before their breeding season at regular nesting sites in Rann of Kachchh, and then declined rapidly, suggesting their pre-breeding congregation at this site. The largest gathering was observed in July 2019 (approximately 500 Greater and 700 Lesser Flamingos), with numbers decreasing in subsequent years, likely due to increased water depth exceeding 50 cm, which is unsuitable for flamingos. The seasonal fluctuation in the population of flamingos in Ratnal was recorded for three years (Figure 1). This trend was echoed in other inland wetlands studied during the same period. Crucially, all these wetlands lie outside the protected area network and face anthropogenic pressures, such as the establishment of powerlines, water pollution, and wetland reclamation. Collisions with powerlines pose a significant threat to flamingos, particularly when these lines pass through or near wetland habitats (Tere & Parasharya 2011). Thus, systematic ecological monitoring is imperative to identify sites with potential for future breeding colonies, to assess the quality of these habitats, and to propose ways to conserve them.

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SHORT COMMUNICATION

First time in 110 years: sighting of *Gynacantha khasiaca* Maclachlan, 1896 (Odonata: Aeshnidae) in Arunachal Pradesh, India

R. Mahesh [1], Rajesh Gopinath [2], Gaurav Joshi [3] & Roshan Upadhaya [4]

[1] Kattiparambu Madam, Thekumbhagam, Tripunithura, Ernakulam, Kerala 682301, India.
[2] OIKOS (Eco-Club), BMS Institute of Technology and Management, Bengaluru, Karnataka 560119, India.
[3] Parwati Niwas, Jagat Mangla Colony, Haldwani, District Nainital, Uttarakhand 263139, India.
[4] Police Department, Basar, Leparada, Arunachal Pradesh 791101, India.
[1] maheshgreen96@gmail.com (corresponding author), [2] dr.rajeshgopinathnair@gmail.com, [3] gauravjoshi.0416@gmail.com, [4] roshanupadhaya14@gmail.com

Abstract: This communication reports the first confirmed sighting of *Gynacantha khasiaca* Maclachlan, 1896 after 110 years at Namdapha National Park and Tiger Reserve for the state of Arunachal Pradesh, India. Also commonly called as Long-tailed Duskhawker, the identification was based on photographic evidence documented in the presence of forest personnel at Deban in the Tiger Reserve during October 2024, and adds to the region's biodiversity inventory. This finding emphasizes upon the importance of continuous monitoring and habitat preservation of in situ biodiversity conservation.

Keywords: Biodiversity, Duskhawker, Deban, eastern Himalaya, ecosystem, entomofauna, insect, Namdapha National Park, rediscovery.

Dragonflies and damselflies (Odonata) are crucial components of freshwater ecosystems, playing significant roles as predators and prey in aquatic food webs (Corbet 1999; Córdoba-Aguilar 2008; Gopinath 2022). The global diversity of Odonata comprises 6,442 species across 693 genera (Paulson et al. 2026), with India being a habitat for 504 species and 27 subspecies from 152 genera and 18 families. The total species count for Arunachal Pradesh is 110 (Mitra 2002). The genus *Gynacantha* Rambur, 1842, includes large-sized dragonflies with pale brown and green colouration and crepuscular behaviour (Fraser 1936). This genus comprises 92 species globally, with approximately 30 species recorded in southeastern Asia and 10 species documented in India (Khan 2015a; Kalkman et al. 2020).

Study area

Namdapha National Park and Tiger Reserve (Figure 1), located in the Changlang District of Arunachal Pradesh, covers approximately 1,985 km², making it one of the largest protected areas in the eastern Himalaya (Arunachal Online 2024). Situated at the confluence of the Patkai Ranges and Dapha Bum Ridge of the Mishmi Hills, it spans latitude 27.383°–27.650° N and longitude of 96.250°–96.966° E. While the dense forest does receive significant rainfall (average annual rainfall 2,500–3,500 mm), the hilly areas also have a profound mountain climate influence upon it (Arunachal Online 2024). It

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Competing interests: The authors declare no competing interests.

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also features a dynamic riverine ecosystem alongside the Noa-Dihing and Namdapha rivers (Sathyakumar et al. 2011).

With an elevation range of 200 m to over 4,571 m, Namdapha National Park and Tiger Reserve supports diverse habitats, including tropical rainforests (Image 1), subtropical forests, and alpine meadows. The dense tropical rainforests include vegetation such as *Dipterocarpus turbinatus, Dipterocarpus retusus, Shorea assamica, Shorea robusta, Castanopsis roxburghiana,* and bamboo groves. Namdapha National Park and Tiger Reserve is a crucial component of the Indo-Burma biodiversity hotspot and supports rare and endangered species such as Snow Leopard *Panthera uncia* (Schreber, 1775), Clouded Leopard *Neofelis nebulosa* (Griffith, 1821), and Asian Elephant *Elephas maximus* (Linnaeus, 1758).

Methods

The field survey was conducted over a span of eight days from 10–17 October 2024, with the investigation focusing on riverbanks, forest trails, narrow streams, and waterfall habitats. Random field sampling was undertaken daily from 0500–1900 h along these habitats. Species identification was based on photographic evidence captured using a Nikon D3300 DX-format DSLR

Image 1. Typical landscape of Namdapha National Park and Tiger Reserve in Arunachal Pradesh, India. © Rajesh Gopinath.

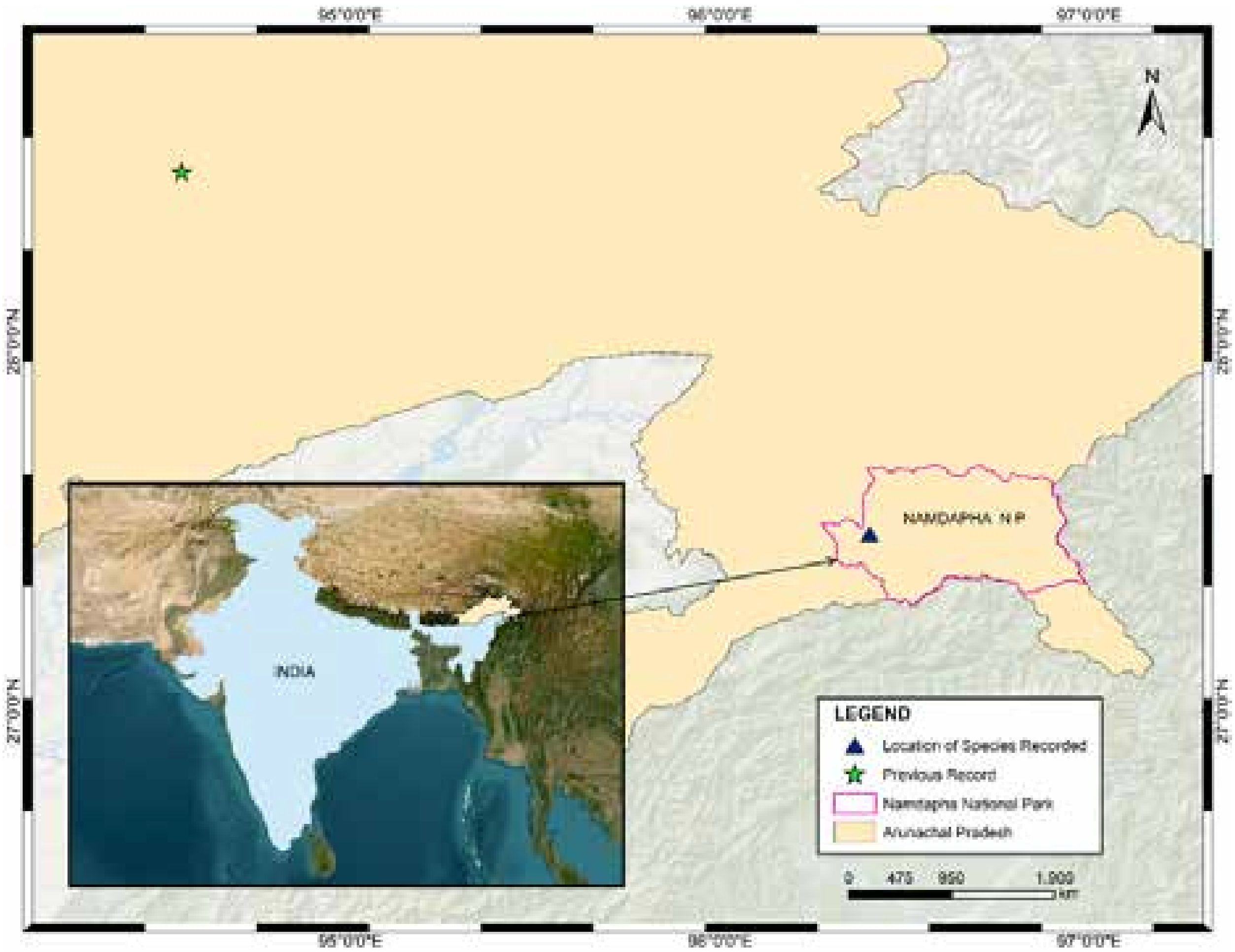

Figure 1. Location of Namdapha National Park and Tiger Reserve in Arunachal Pradesh, India.

with an 18–55 mm lens. The identification of species and confirmation was carried out in consultation with literature (Payra et al. 2017). No physical specimens were collected in strict adherence to forest norms in complete compliance with the Indian Wildlife Protection (Amendment) Act, 2022.

Observations and findings

Inclusive of the findings presented in this study, the field survey has resulted in several re-discoveries (Mahesh 2025; Upadhaya 2026). Totally 17 Odonata species were documented during 12 samplings. These include *Trithemis aurora* Burmeister, 1839, *Neurothemis fulvia* (Drury, 1773), *Orthetrum glaucum* (Brauer, 1865), *Echo margarita* Selys 1853, *Aristocypha spuria* Selys, 1879, and *Neurobasis chinensis* (Linnaeus, 1758). As a highlight among these observations, a single male specimen of *Gynacantha khasiaca* (Image 2, 3 & 4) was observed on 16 October 2024 around 08.00 h on a cloudy day along the Miao-Vijaynagar road (altitude of 600 m) within the Namdapha National Park and Tiger Reserve (Image 5). The male was initially observed rapidly patrolling along the road edge and hovering while defending its territory. It subsequently resumed pendent perching in the vertical hanging posture, within a shaded area surrounded by dense vegetation.

The systematic position of *Gynacantha khasiaca* Maclachlan, 1896 is represented below (Martin 1909).
Phylum: Arthropoda
Class: Insecta
Order: Odonata Fabricius, 1775
Suborder: Anisoptera Selys, 1854
Family: Aeshnidae Leach, 1815
Genus: *Gynacantha* Rambur, 1842
Species: *Gynacantha khasiaca* Maclachlan, 1896

The head was pale blue to olive-green eyes, olive-brown labrum and labium, and a light green frons with a distinct black 'T'-shaped marking. The thorax was bright green with two thick blackish-brown stripes on each side. The wings were hyaline with an amber tint at the base; pterostigma covers 4–5 cells. The forewing discoidal cells consisted of five cells, while hindwing discoidal cells ranged 4–6. The abdomen measured about 47–51 mm, with segments 8–10 being entirely black. The anal appendages were black; with inferior appendages about two-thirds the length of the superior appendages (Martin 1909).

Image 2. Lateral view of male Individual of *Gynacantha khasiaca.* © R. Mahesh.

Image 3. *Gynacantha khasiaca* (male) individual. © R. Mahesh.

Image 4. Dorsal view of *Gynacantha khasiaca* (male) individual, highlighting its terminal abdominal appendages. © Rajesh Gopinath.

Image 5. Location of Miao-Vijaynagar road within Namdapha National Park and Tiger Reserve (Source: Google Earth).

Discussion

Due to limited knowledge regarding distribution, seasonality, and habitat specificity, *G. khasiaca* is classified as 'Data Deficient' by the IUCN Red List of Threatened Species (Mitra et al. 2010). Outside India, it has been documented in Nepal (Vick 1989), Myanmar (Fraser 1936), and Bangladesh (Khan, 2015b). In India, as per the portal of indianodonata.org, *G. khasiaca* has been recorded from the states of Maharashtra in 2020, West Bengal during 2014 and 2015, and in Assam during

2019 (Sawant et al. 2026). As per research publications, *G. khasiaca* has been documented from the states of West Bengal (Payra et al. 2017; Mitra 2002), Uttarakhand (Prasad & Sinha 2010) and exclusively from northeastern states such as Meghalaya (McLachlan 1896; Fraser 1924; Kimmins 1969), Assam (Laidlaw 1923; Fraser 1936; Payra et al. 2017), and Arunachal Pradesh (Laidlaw 1914). Reports also indicate this species has also been documented in parts of Nagaland, but these records remain scarce and largely unverified.

As per the portal of indianodonata.org, it can be highlighted that the most recent sighting for entire India is from Majgaon, Sindhudurg in Maharashtra during July 2020 and when only north-eastern states are highlighted, the last confirmed sighting was way back in September 2019 from Orang National Park, Sonitpur in Assam (Sawant et al. 2026). When only research repositories are referred to, it was found that the last confirmed record in India was in 2017, at Purba Medinipur in West Bengal. If only northeastern states are considered, then the last confirmed record was in 2015 from Khalingduar Forest in Assam (Payra et al. 2017). These are located 1,710 km and 605 km away from the present site of discovery, respectively. Hence, in this context, the re-discovery of *Gynacantha khasiaca* in Namdapha National Park and Tiger Reserve (Arunachal Pradesh) is highly significant, considering that the species was last reported over a century ago from Arunachal Pradesh at Abor Hills (Laidlaw 1914). Abor Hills is also approximately about 600 km away from location of present discovery. Even, the nearest location from which a record of *Gynacantha khasiaca* has been observed to-date is about 400 km away at Deopahar, Golaghat Assam (Payra et al. 2017), hence extending its known range.

Earlier odonate surveys undertaken in Arunachal Pradesh by researchers (Ram & Prasad 1999; Mitra 2002) and the forest department (2018 & 2020 pers. comm.) have not recorded *G. khasiaca*. Conclusively, it can be hence stated that this sighting at Namdapha National Park and Tiger Reserve marks the first verifiable recent record of *G. khasiaca* from Arunachal Pradesh in a 100 year's timeline. The lack of confirmed records from similar habitats highlights its rarity and the possibility that *G. khasiaca* has a patchy or highly specialized distribution. It may also be attributed to limited surveys in the remote forested regions, habitat degradation, climate shift and low detection probability as a species (Theischinger et al. 2020; Aadarsa et al. 2021).

Biodiversity implications and conservation concerns

Gynacantha khasiaca has been documented from nine scattered localities across Assam and West Bengal, occurring at elevations ranging 7–377 m. Of these records, seven were from sites located near forested areas, essentially representing forest-edge habitats with human encroachment and settlements. The remaining two sightings were reported from dense forest habitats at Deo Pahar and the Murti River-bed. The species was mostly encountered during the day and crepuscular hours (1017–1850 h), and predominantly in lowland areas. The observations indicate that this species depends on structurally intact riparian microhabitats to maintain viable populations. Given the sparse records and fragmented distribution, additional studies are necessary to better understand its habitat specificity, breeding ecology, and seasonal activity patterns.

Conclusion

This study presents the first record of *Gynacantha khasiaca* after 110 years from the Indian state of Arunachal Pradesh, hinting at the scope for further inter-species and intra-species discoveries amidst the less explored ecologically rich Namdapha National Park and Tiger Reserve. Invariably, this communication also highlights conservation need of a potential biodiversity hotspot.

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NOTE

Small Wild Cats Special Series

Evidence of Rusty-spotted Cat *Prionailurus rubiginosus* (I. Geoffroy Saint-Hilaire, 1831) (Mammalia: Carnivora: Felidae) in National Chambal Sanctuary, Uttar Pradesh, India

Anshoo Nishad [1], Hiyashri Sarma [2], Rajib Saha [3], Vijay Pratap Singh [4], Maneesha Bhatt [5], Atit Rai [6], Qamar Qureshi [7] & Vishnupriya Kolipakam [8]

[1–8] Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India.
[1] anshoo@wii.gov.in, [2] hiyashri@wii.gov.in, [3] saha.rajib3472@gmail.com, [4] vjay@wii.gov.in, [5] maneesha@wii.gov.in, [6] raiatitk@gmail.com, [7] qureshi1510@gmail.com, [8] vishnupriya@wii.gov.in (corresponding author)

We report two roadkill incidents of the Rusty-spotted Cat *Prionailurus rubiginosus* in National Chambal Sanctuary, Etawah District, Uttar Pradesh. Both incidents were recorded on the road connecting Bharthana and Sindaus, which is a major district road with bituminous surface. The first carcass was spotted on 14 March 2025 at 0640 h at 26.572° N, 79.102° E. This location is approximately 2 km south of the Yamuna River and 3 km north of the Chambal River, and is bordered by crop fields, villages, and ravines (Figure 1). The carcass was a male cat measuring 78 cm in total length, including a 24 cm tail (Image 1). The second roadkill was found on 24 April 2025 at 0528 h along the same road, but closer to the Chambal River at 26.554° N, 79.096° E. Forested patches and ravines surround the road at this location (Figure 1). This individual was a female and measured 60.7 cm in total length, with an 18 cm long tail (Image 2). Both roadkill were recorded along the same stretch of road from Chakarnagar to the bridge over the Chambal River at Sahson.

Our records are the first documented occurrences of the Rusty-spotted Cat in southern Uttar Pradesh and also within the boundaries of the National Chambal Sanctuary. They add a new locality within the species' known range.

The Rusty-spotted Cat has previously been recorded in neighbouring regions of National Chambal Sanctuary, including Keoladeo National Park (Singh et al. 2017), Dholpur & Karauli Districts (Sharma & Dhakad 2020), Ranthambore Tiger Reserve (Jhala et al. 2020) in Rajasthan, and in Gwalior Forest Division in Madhya Pradesh (Pawar et al. 2024). Previous records in Uttar Pradesh are limited to the Terai region further north (Anwar et al. 2010, 2012; Jhala et al. 2020; Pawar et al. 2021).

Our records underscore the need for targeted surveys in these forested patches of the Chambal–Yamuna interfluve landscape. This region between both rivers consists of a network of rugged gullies and ravines, stretching for approximately 480 km in a 10-km wide belt for Chambal river (Haigh 1984; Joshi 2014) and The Yamuna River is bordered by ravines along roughly 250

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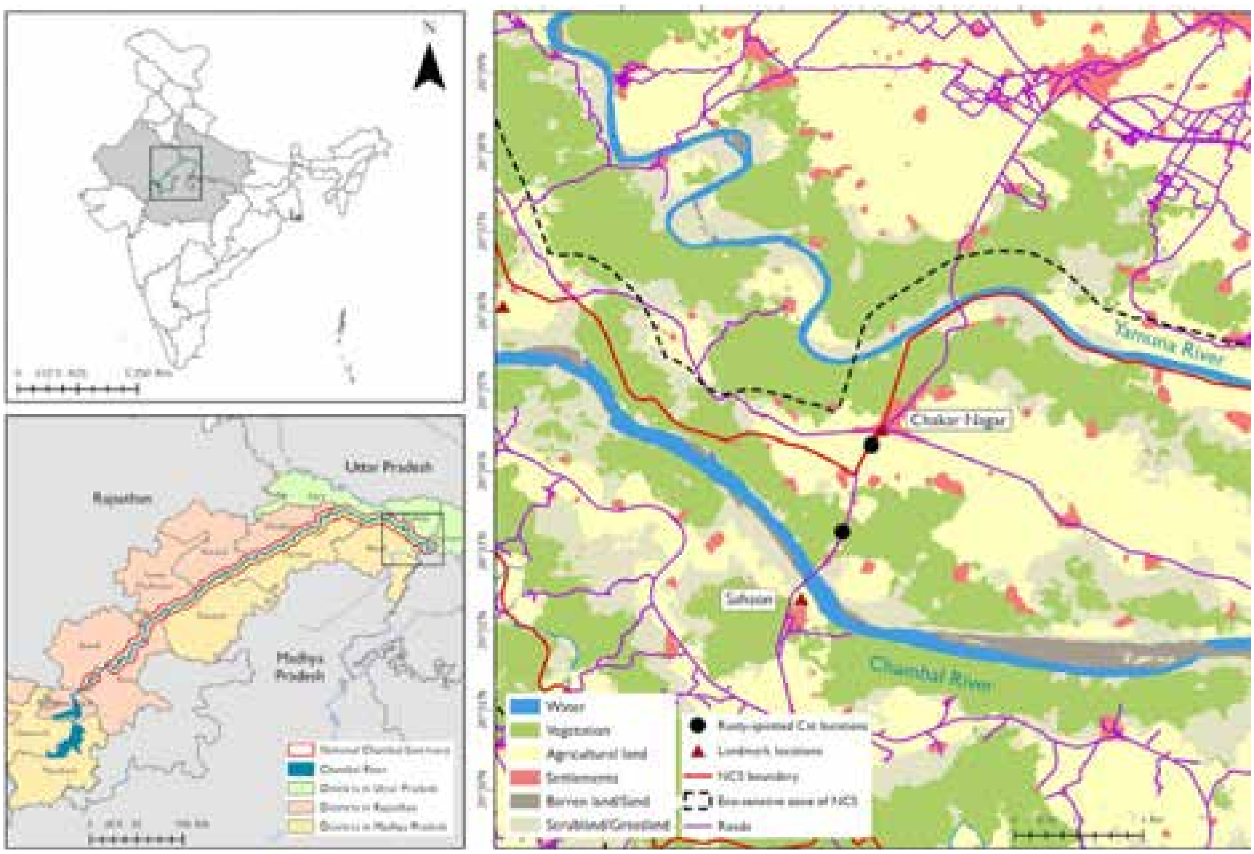

Figure 1. Locations of roadkill records of Rusty-spotted Cats in National Chambal Sanctuary, Etawah District, Uttar Pradesh.

km of its course (Chatterjee 2009), which are dominated by thorn forests (Champion & Seth 1968). Elsewhere in India, the Rusty-spotted Cat has been recorded in similar thorn and dry deciduous forests and rugged, hilly terrain (Vyas & Upadhyay 2014; Sharma & Dhakad 2020; Singh & Kariyappa 2020; Singh et al. 2026).

Multiple roadkill incidents indicate that vehicular traffic has been a significant threat to the Rusty-spotted Cat (Tehsin 1994; Digveerendrasingh 1995; Rao et al. 1999; Vyas & Upadhyay 2014; Nayak et al. 2017; Adhikari et al. 2019; Sharma & Dhakad 2020; Patel et al. 2024; Pawar et al. 2024; Vyas et al. 2025), which is a possible consequence of habitat fragmentation associated with developmental and agricultural activities. This threat reinforces the need for targeted mitigation measures to ensure the persistence of this small cat in human-modified landscapes.

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Image 1. Rusty-spotted Cat roadkill found on 14 March 2025. © Hiyashri Sarma.

Image 2. Rusty-spotted Cat roadkill found on 24 April 2025. © Rajib Saha.

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NOTE

First photographic record of Naumann's Thrush *Turdus naumanni* Temminck, 1820 from Assam, India

Pulakeswar Basumatary [1]

[1] Centre for the Environment, IIT Guwahati, Amingaon, Assam 781039, India.
[1] Balipara Tract & Frontier Foundation, Navin Enclave, Geeta nagar, Guwahati, Assam 781021, India.
pulakesw@iitg.ac.in

Naumann's Thrush *Turdus naumanni* Temminck, 1820, is a medium-sized (23–25 cm; 63–81 g) species belonging to the family Turdidae with a breeding range spanning central and eastern Siberia (Clement & Hathway 2000; Abhinav et al. 2022). Historically, considered conspecific with Dusky Thrush (*T. eunomus*), it was formally recognized as a distinct species (An et al. 2024), though confusion persists due to hybrid forms (Hatibaruah et al. 2019). The species winters across southeastern Russia, China, Korea, and Taiwan (Clement & Hathway 2000), with vagrants occasionally reaching western Europe and, more rarely, southern Asia.

Within India, *T. naumanni* remained largely unrecognized until its formal addition to the national checklist (Praveen et al. 2021). The most comprehensive assessment by Abhinav et al. (2022) documents only two confirmed records of pure species from India: an unconfirmed sight record from Ladakh (16 January 1982) and a photographed first-winter female from Shey, Ladakh (13 December 2021). In contrast, multiple hybrid individuals (*T. naumanni* × *T. eunomus*) have been documented across the subcontinent, with an apparent influx during the winter of 2018–2019 in northeastern India (Abhinav et al. 2022). Within Assam, prior records include a sight record from Manas National Park, Baksa District (6 January 2006), and an individual of hybrid or uncertain status from Digboi Oil Fields, Tinsukia District (17 December 2018) (Hatibaruah et al. 2019; Abhinav et al. 2022). The present record from Panbari Village, Dhemaji District (13 January 2026) thus constitutes the first photographically confirmed record of a pure individual from the state.

On 13 January 2026, at 0830 h, a single individual of the species was observed and photographed in grassland habitat mixed with rice paddy field at Panbari Village, Dhemaji District of Assam (27.540° N, 94.434° E; elevation ca. 105 m). The bird was encountered in open grassland interspersed with shrubs, actively foraging on the ground for invertebrates, a behaviour typical of wintering thrushes in this region. The bird was observed at the same spot for more than a month. Detailed photographs were taken to enable diagnostic assessment of plumage characters. These images (Image 1c–f) were subsequently submitted to eBird and Indian Biodiversity portal (https://indiabiodiversity.org/) and BirdCount India (https://birdcount.in/) and expert members confirmed the species as Naumann's Thrush, based on the following key diagnostic features:

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Image 1 . Naumann's Thrush *Turdus naumanni* recorded from Dhemaji District of Assam: a—Map showing the sighting location (red star) | b—Feeding habitat with green circle indicating the individual's position | c–f—Field photographs illustrating diagnostic morphology from multiple angles | c—Right lateral view |d—Left lateral view | e—Dorsal view | f—Frontal view, supporting species identification and absence of hybrid characters. © Pulakeswar Basumatary.

(1) rufous-orange wash extensively covering the breast, flanks, and undertail coverts; (2) pale supercilium extending from lore to nape; (3) brown-rufous (not black) streaking on the upper chest and malar region; (4) pale brown (not dark brown) upperparts with rufous tones on the rump and tail; (5) whitish central belly contrary to the extensive dark markings in Dusky Thrush or Naumann's × Dusky hybrids; and (6) absence of the pronounced golden-rufous wing panel diagnostic of hybrids (Clement & Hathway 2000; Hatibaruah et al.

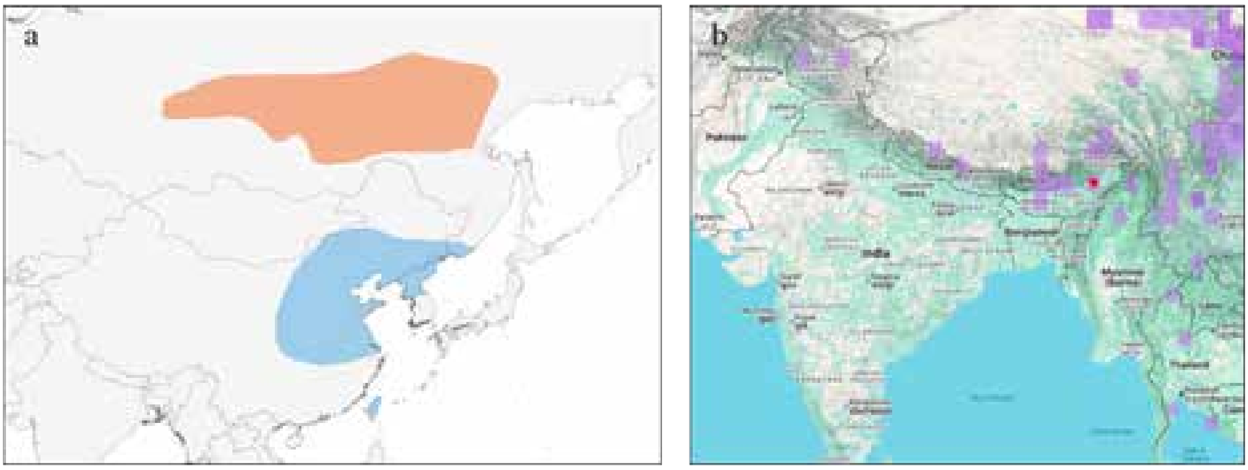

Image 2. Distribution map of the species according to a—the global breeding (orange) and nonbreeding (blue) range of *Turdus naumanni* as depicted in Birds of the World (Lynx Edicions & BirdLife International 2026) | b—eBird sighting records across India and Assam shown in purple. The present record location (Panbari Village, Dhemaji) is indicated with red star on the map.

2019; Abhinav et al. 2022). Based on the paler and less saturated rufous-orange colouration on the breast and flanks, visible pale fringes producing a slightly scalloped appearance on the breast feathers, and comparatively duller upperpart tones relative to males, the individual was identified as a female (Clement & Hathway 2000; Abhinav et al. 2022). Furthermore, the retained median coverts bearing pale buff-white tips contrasting with the replaced greater coverts, and the moderately worn primaries, indicate this to be a first-winter (first-year) individual, likely hatched in the preceding summer (Clement & Hathway 2000). Additionally, images were posted on the Facebook group 'Ask ID of Indian Birds', Assam Bird Monitoring Network (ABMN) and many Bird ID groups where it was identified as Naumann's Thrush with no feature of hybridization. Weather conditions at the time of observation were clear with moderate temperature (approximately 18–24 °C), following several days of cooler overnight temperatures (5–10 °C), a pattern typical of trigger conditions for vagrant arrivals in northeastern India.

Dhemaji District supports high avifaunal diversity, with more than 334 bird species recorded across the district according to eBird regional data (ebird 2026). The adjoining locations of the observation site also demonstrate substantial species richness, with approximately 155 bird species documented from the specific hotspot (ebird 2026). This record from Dhemaji represents noteworthy distribution data for several reasons. First, it constitutes the first confirmed photographed record of the species specifically from Dhemaji District. Second, it occurs at substantially lower elevation (ca. 105 m) compared to most previous Indian records, which are concentrated between 1,500 and 3,300 m elevation (Abhinav et al. 2022), suggesting ecological flexibility regarding wintering elevations. Third, the timing of this record in mid-January corresponds to the documented peak occurrence window for the species in northeastern India (December–February; Abhinav et al. 2022). The record thus aligns with the hypothesis that this Palearctic species has become increasingly regular in the region during winter months, particularly in years with severe continental weather patterns that may trigger irruptive movements southward (Abhinav et al. 2022).

Future monitoring of open grassland habitats and cultivated areas in the Brahmaputra Valley during winter months may reveal additional occurrences of this species and other rare Palearctic thrushes too, further refining understanding of vagrance patterns and range dynamics in the eastern Himalayan foothill's region. The present record underscores the importance of systematic documentation with photographic evidence for distinguishing between pure individuals and hybrid forms, a challenge particularly acute for species recently recognized in the region and still poorly understood in its distribution ecology in India (Image2).

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NOTE

New breeding record of Black-headed Ibis *Threskiornis melanocephalus* from Malappuram District, Kerala, India

K.K. Junaina [1] & **A.P. Rashiba** [2]

[1,2] Post Graduate & Research Department of Zoology, Farook College (Autonomous), Affiliated to University of Calicut, Kozhikode, Kerala 673632, India.

[1] kkjunaina@gmail.com (corresponding author), [2] rashiba@farookcollege.ac.in

The Black-headed Ibis *Threskiornis melanocephalus* is a medium-sized wader under the family Threskiornithidae of order Pelecaniformes (BirdLife International 2024). It inhabits freshwater marshes, lakes, rivers, flooded grasslands, paddy fields, tidal creeks, mudflats, mangroves, salt marshes, and lagoons (Sundar 2006; Sundar & Kittur 2013) and hunt in shallow water areas (Chaudhury & Koli 2018). Black-headed Ibis is also known as Black-necked Ibis, Indian White Ibis, Oriental White Ibis (BirdLife International 2024). The species exhibits an extensive biogeographic range across the Asian continent (Chaudhury & Koli 2018). The IUCN Red List assessments of 2004, 2006, 2008, 2012, and 2016 classified the species as 'Near Threatened'. There is a notable improvement in the global conservation status of Black-headed Ibis over recent years; it was upgraded to 'Least Concern' category in the 2024 assessment (BirdLife International 2024).

Breeding records of Black-headed Ibis from Kerala remain geographically sparse. Previously reported breeding records of Black-headed Ibis from the state include Panamaram Heronry in Wayanad (Balakrishnan & Thomas 2004), Kumarakom in Kottayam (Narayanan et al. 2006), Manthakad in Palakkad (Roshnath et al. 2017), Mavoor Wetlands in Kozhikode (Shifa 2021), and Thirunavaya Wetlands in Malappuram District (Chullakattil 2022). Successful captive breeding of the Black-headed Ibis at Thiruvananthapuram Zoo has been reported previously (Bindya et al. 2019). New breeding records are valuable for understanding local population trajectories and habitat use. In this study, we document a new breeding colony of Black-headed Ibis from Malappuram District, Kerala, and examine its relevance to regional population expansion.

An active breeding colony was observed on 04th November 2025 at Edavannappara (11.246^{0} N, 75.977^{0} E) in Malappuram District of Kerala, India (Figure 1 & Image 1). Three active nests with seven chicks were built on higher branches of a mature *Alstonia scholaris* tree. The nests were constructed of twigs and leaves of common plants, mainly *Alstonia scholaris,* which had plastic ropes integrated into its structure, which is an indication of anthropogenic contamination of the surrounding environment. In one nest, an adult was observed bringing new twigs with fresh leaves from *Alstonia Scholaris* and incorporating them into the existing structure. Observation was done using a binocular (SOLOGNAC 8x25) and photographs were taken using Nikon Z6II camera with Nikkor Z 180-600 mm lens. The nest height from the ground was calculated using a clinometer. The breeding period of Black-headed Ibis is generally associated with the monsoon season,

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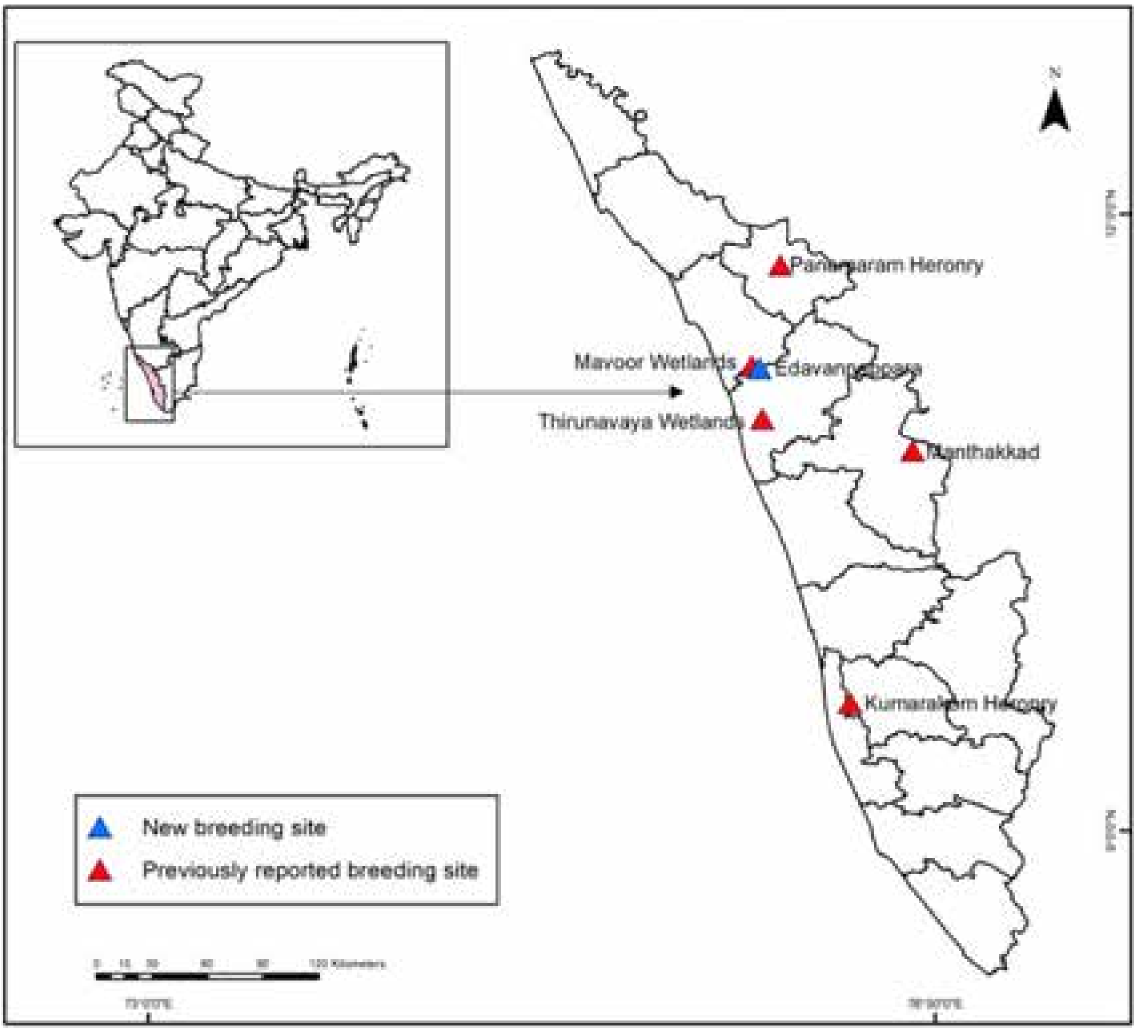

Figure 1. Breeding sites of Black-headed Ibis in Kerala (Created using ArcMap10.8).

although late breeders may extend the nesting period until April (Chullakattil 2022).

The tree is positioned along a busy roadside, subject to frequent human movement, vehicular traffic, infrastructure development, private construction, and daily disturbances such as light and noise pollution. The tree serves as breeding and roosting site for several birds such as Black-crowned Night Heron *Nycticorax nycticorax*, Eastern Cattle Egret *Bubulcus ibis*, Little Cormorant *Microcarbo niger*, Little Egret *Egretta garzetta*, and House Crow *Corvus splendens*. Surrounding landscapes comprised of shallow water pools, paddy fields, and agricultural lands. During the present study, the Black-headed Ibis was frequently observed visiting the nearby agricultural fields for feeding, indicating that these habitats provide suitable foraging grounds for the species (Image 2).

Previous studies have reported variation in nest height across Kerala. At Kumarakom wetlands, Kottayam District, the mean height of nesting trees was 2.59 ± 0.66 m (Narayanan et al. 2006), while nests in Panamaram, Wayanad District, were located at a mean height of 7 ± 0.45 m (Balakrishnan & Thomas 2004). In Palakkad District, the recorded nest height was around 5 m (Roshnath et al. 2017), while in Thiruvananthapuram Zoo it was 6 m (Bindya et al. 2019). The report from Kozhikode District did not document precise nest heights (Shifa 2021; Chullakattil 2022). Observations from Thirunavaya wetlands indicate an average nest height of 3.18 ± 0.49 m (Chullakattil 2022). The newly discovered nests were located on the branches of *Alstonia scholaris* around 14.4 m, significantly greater height than those reported in earlier studies. The species can successfully exploit agricultural lands (Sundar 2006), attributing to population increase in Kerala. Breeding colony indicate the presence of suitable habitat conditions such as

Image 1. Nests of Black-headed Ibis *Threskiornis melanocephalus*. © K.K. Junaina.

Image 2. Black-headed Ibis *Threskiornis melanocephalus* foraging in the nearby agroecosystem. © K.K. Junaina.

adequate food availability, secure nesting grounds, and surrounding wetland health.

With the continued degradation and loss of natural wetlands, agroecosystems are increasingly emerging as important alternative foraging and breeding habitats for wetland birds (Czech & Parsons 2002). The management of bird-preferred tree species, and conservation of habitats and existing trees in and around agricultural landscapes and adjacent wetlands, can enhance the availability of suitable roosting and nesting sites, thereby supporting population conservation (Byju et al. 2025). Moreover, long-term and systematic monitoring is essential to evaluate breeding success, colony persistence, and the sustained suitability of these modified habitats.

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NOTE

From the heart of Urpad: records of *Cyrtodactylus bapme* Kamei & Mahony, 2021 (Reptilia: Squamata: Gekkonidae) from Assam, India, with comments on the pre-cloacal region in males

Manmath Bharali [1], Pranjal Swargiary [2], Tejas Mariswamy [3], Madhurima Das [4], Jayaditya Purkayastha [5] & Sanath Chandra Bohra [6]

[1,2,5,6] Help Earth, 16, Raghunath Choudhury Path, Lachitnagar, Guwahati, Assam 781007, India.
[3] Goalpara Forest Division, Goalpara, Assam 783101, India.
[4] Department of Zoology, Assam Don Bosco University, Sonapur, Assam 782402, India.
[1] manmathbharali9@gmail.com, [2] pranjalswargiary296@gmail.com, [3] tejasm24@gmail.com, [4] madhuherp@gmail.com,
[5] mail.jayaditya@gmail.com, [6] sreptilian6@gmail.com (corresponding author)

The Asian gekkonid genus *Cyrtodactylus* is recognized as the third most speciose vertebrate genus worldwide, with *Cyrtodactylus khasiensis* (Jerdon, 1870) being the first species of the genus to be described from northeastern India. Owing to limited taxonomic investigations and morphological similarities among regional populations, the species was long presumed to have a wide distribution across the Indo-Burma region (Smith 1935; Li 2007). Subsequent studies (Li 2007; Mahony 2009; Agarwal et al. 2014) established a systematic framework based on samples from northeastern India and adjacent regions, highlighting the need for further taxonomic evaluation. As a result, the distribution of *C. khasiensis* is now restricted to the eastern Khasi Hills of Meghalaya, India (Agarwal et al. 2018a). Following this taxonomic reassessment, 31 new species of the genus have been described from various states of northeastern India within the last nine years (Agarwal et al. 2018a,b; Purkayastha et al. 2020, 2021, 2022; Mirza et al. 2022; Kamei & Mahony 2021; Bohra et al. 2022, 2026; Lalremsanga et al. 2022, 2023; Mahony & Kamei 2022; Boruah et al. 2024; Basfore et al. 2026; Bharali et al. 2026).

Cyrtodactylus bapme Kamei & Mahony, 2021, a member of the *khasiensis* group, was described from the eastern Garo Hills of Meghalaya, India, based on a type series comprising four female individuals. In the absence of males, the authors relied on pitted precloacal scales in females to distinguish and compare the new species with congeners, under the assumption that the number of pit-bearing scales corresponds approximately to the number of precloacal pores in males, which was the only feasible approach at the time. Herein, additional data on *C. bapme* is provided, including details of femoral pores in males based on recently collected specimens, and present the first record of the species from the state of Assam, India.

Four males (ADBUSB31; ADBUSB32; ADBUSB33; ADBUSB34) and two female specimens (ADBUSB35; ADBUSB36) were collected from the hills surrounding

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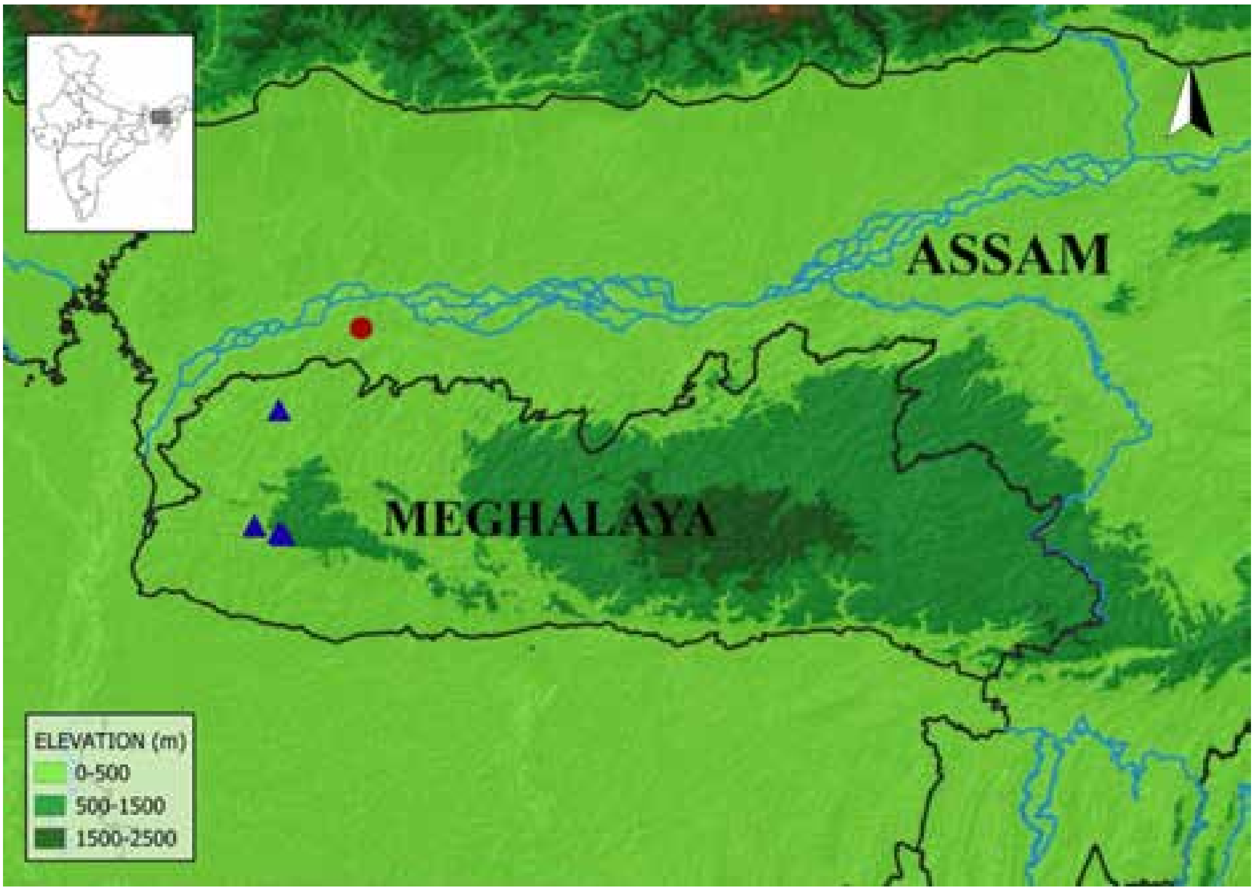

Image 1. Distribution records of *Cyrtodactylus bapme*: Blue triangles—locality records of the species from Meghalaya (Daribokgre Hamlet, East Garo hills) | Red dot—the new locality record of the species from Agia Village, Goalpara District, Assam.

Urpad Beel, Agia Village, Goalpara District, Assam, India (26.087° N, 90.569° E; Image 1), and have been deposited in the museum collection of Assam Don Bosco University (ADBU), Sonapur, Assam.

Morphological and molecular data were generated following Kamei & Mahony (2021). The specimens were compared morphologically with all known species of the *khasiensis* group using literature containing original descriptions and taxonomic revisions based on type specimens (e.g., Darevsky et al. 1998; Bauer 2003; Li 2007; Mahony 2009; Agarwal et al. 2018a,b; Purkayastha et al. 2020, 2021; Grismer et al. 2021; Mirza et al. 2021, 2022; Kamei & Mahony 2021; Bohra et al. 2022, 2026; Mahony & Kamei 2022; Lalremsanga et al. 2023; Boruah et al. 2024, Basfore et al. 2026; Bharali et al. 2026).

Molecular analysis revealed that the *Cyrtodactylus* specimens collected from Agia Village are conspecific with the type sequences of *C. bapme*, differing by an uncorrected p-distance of only 1.3–3.5% in the mitochondrial ND2 gene (Table 1). The Agia Village specimens of *C. bapme* were also recovered as the sister lineage to *C. karsticola* (type locality – South Garo Hills District, Meghalaya, India), from which they differ by an uncorrected p-distance of 6.7% in the mitochondrial ND2 gene (Table 1).

Based on literature and the present collections, *C. bapme* can be defined as a moderate-sized species, ranging in snout–vent length from 60.2–77.0 mm, with 8–12 supralabials and 8–11 infralabials. Dorsal tubercles are usually feebly keeled, bluntly conical, four to five times larger than the dorsal granular scales, and arranged in 20–24 longitudinal rows at midbody. There are 30–37 paravertebral tubercles between the level of the axilla and the groin, 46–51 paravertebral tubercles from the occiput to the mid-sacrum, and 30–39 mid-ventral scale rows between the indistinct ventrolateral folds. Males possess a continuous series of 12–17 precloacal pores (PcP) accompanied by one to seven pitted scales, either in a continuous or discontinuous series on either side of the pore-bearing scales. Females usually exhibit 10–13 pit-bearing precloacal scales in a continuous series, except for a single specimen (BNHS/Bombay Natural History Society 2754) lacking pits (Kamei & Mahony 2021). Subdigital lamellae range 12–19 under finger IV

Image 2. *Cyrtodactylus bapme* in life from Agia Village, Goalpara District, Assam. A & B—ADBUSB31, an adult male | C—ADBUSB32, an adult male | D—ADBUSB33, an adult male | E—ADBUSB34, an adult male | F—Uncollected gravid female. © Sanath Chandra Bohra.

and 15–22 under toe IV (both counts excluding non-lamellar scales between the proximal and apical lamellae series). The dorsal pattern consists of 7–10 paired dark brown transverse blotches on either side of the mid-vertebral region, arranged somewhat parallel to each other, leaving a thin mid-dorsal stripe. The tail exhibits a continuous series of alternating dark and light transverse bands, with subcaudal scales arranged in small granular series and lacking transverse enlargement.

Cyrtodactylus bapme differs from all the members of the *khasiensis* group in the morphology of the precloacal region, with males possessing 12–17 precloacal pores in a continuous series, versus 34–38 precloaco-femoral pores (PcFP) and no pits in *C. karsticola*; 7–8 PcP in *C. aaronbaueri*; 3–4 precloacal pores in *C. annapurnaensis*; 5–7 PcP in *C. bengkhuaiai*; 8 PcP in *C. brevidactylus*; 6–10 PcP in *C. cayuensis*; 7–8 PcP in *C. dianxiensis*; 26–39 PcFP in *C. guwahatiensis*; 7–8 PcP in *C. karanshahi*; 34–38 PcP in *C. karsticola*; 10–11 PcP in *C. kazirangaensis*; 6–7 PcP in *C. kiphire*; 3–5 PcP in *C. lungleiensis*; 5 PcP in *C. mandalayensis*; 7 PcP in *C. manipurensis*; 7–8 PcP in *C. martinstolii*; 10–11 PcP in *C. mombergi*; 8–10 PcP

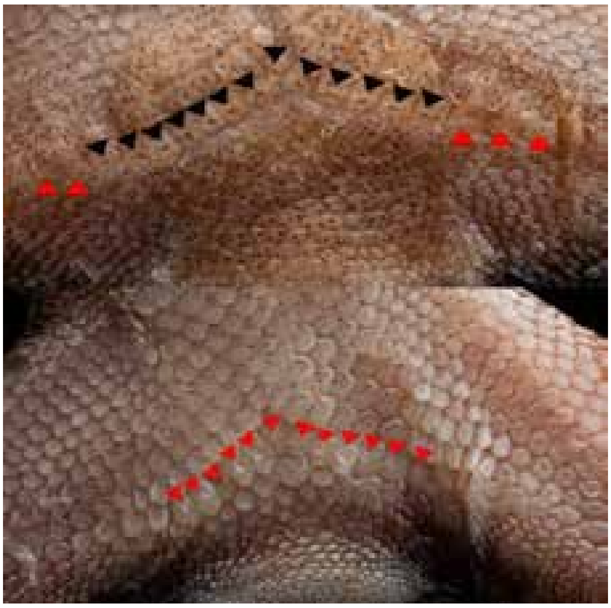

Image 3. Top—Arrangement of precloacal pores in a male (ADBUSB31) of *Cyrtodactylus bapme* (the black arrows indicate pre-cloacal pores whereas the red arrows indicate pitted scales) | Bottom—Arrangement of pre-cloacal pits in females of *C. bapme* (indicated by red arrows). © Sanath Chandra Bohra

in *C. montanus*; 7–9 PcP in *C. namdaphaensis*; 27 PcP in *C. ngengpuiensis*; 6 PcP in *C. ngopensis*; 7 PcP in *C. siahaensis*; 8–10 PcP in *C. siangensis*; 40 PcFP in *C. tamaiensis*; 29–37 PcFP in *C. tripuraensis*; 9–11 PcP in *C. vairengtensis*; 10 Pcp in *C. vanarakshaka*; 18–28 in *C. jayadityai*.

Regional congeners within the *khasiensis* group exhibiting PcP or PcFP counts that overlap with the range observed in males of *C. bapme* include *C. agarwali* (11–18); *C. aunglini* (12–13); *C. ayeyarwadyensis* (10–28); *C. chrysopylos* (8–13); *C. exercitus* (11–15); *C. gansi* (16–29); *C. jaintiaensis* (11–12); *C. khasiensis* (10–12); *C. namtiram* (12); *C. septentrionalis* (14); *C. urbanus* (9–12), *C. raimonaensis* (13).

Kamei & Mahony (2021), citing comparative literature, remarked that the number of pitted scales in females, when present, is either the same as or less (but never higher) than the number of precloacal pores in males of related species for which both sexes are known. Accordingly, they interpreted the 0–13 pitted scales observed in the all-female type series of *C. bapme* as indicative of the minimum number of precloacal pores that would be expected in males of that species. Although this inference is reasonable given the available material, the results demonstrate that such metrics are insufficient for species delimitation when only females are available. The males of *C. bapme* examined herein possess 12–17 precloacal pores, surpassing the 0–13 pitted scales reported in the type series and thereby illustrating that female-derived values may underestimate male pore ranges.

Table 1. Uncorrected pairwise (ND2) genetic divergence between the individuals of *Cyrtodactylus bapme*.

C. bapme (MW367437) [H] female					
C. bapme (MW367438) female	0.013				
C. bapme (MW367435) female	0.015	0.001			
C. bapme (ADBUSB31) * male	0.015	0.016	0.017		
C. bapme (ADBUSB32) * male	0.016	0.016	0.017	0.000	
C. bapme (MW367436) female	0.034	0.032	0.033	0.039	0.038

[H]—sequences generated from the holotype of Kamei & Mahony, (2021) | *—sequences generated in this study from Goalpara, Assam.

This species is presently known only from two states in northeastern India, namely Agia Village in Goalpara District, Assam (88–104 m), and multiple localities across a broad elevation range (90–1,015 m) in the East and West Garo Hills districts of Meghalaya (Image 1). In Meghalaya, it inhabits a variety of microhabitats, including rocks and trees within secondary as well as dense evergreen to semi-evergreen broad-leaved forests, often in association with streams, and is also found in betel vine jhum cultivations. It can be sympatrically found alongside *C. karsticola* and *C. agarwali* in South Garo Hills, Meghalaya, India. In Goalpara District, Assam, the species occurs in a disturbed yet relatively well-vegetated hill range at Agia Village, where the forest type is predominantly moist deciduous to semi-evergreen, intermixed with rubber tree plantations established by the local Garo community. Here, individuals were recorded in association with small to medium-sized rocks, loose soil patches, forest tracks, and minor hill streams. Gravid females and hatchlings were encountered between March and September. On 16 March 2024 at approximately 2045 h, a gravid female (uncollected) was observed preying upon a juvenile huntsman spider (*Heteropoda* cf. *venatoria*). Being strictly nocturnal, the species was most frequently observed to be active approximately two to three hours after dusk.

It is also noteworthy that several species from northeastern India, including *C. barailensis*, *C. myaleiktaung*, and *C. nagalandensis*, remain known only from female specimens, with male data still unavailable. In this context, the present documentation of males in

C. bapme provides important taxonomic insight, not only by confirming earlier suppositions regarding pore counts but also by addressing a knowledge gap that has similarly limited comparative diagnoses in several other recently described taxa from the region.

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