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P Kritika

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Cover: Parts of *Vachellia nilotica*, medium - watercolours. © P Kritika

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ARTICLE

The need for rigorous peer-review of Environmental Impact Assessments: a case from the Western Ghats, India

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Abstract: Environmental Impact Assessments (EIAs) are vital exercises for evaluating the effects of proposed activities on the environment and human well-being. In many countries, including India, they often suffer from incomplete biodiversity information and data manipulation. These issues are compounded by a lack of scientific rigour, independent review, and sufficient public participation—problems that are especially critical in biodiversity hotspots. This paper examines a 'Cumulative Impact Assessment' by the Wildlife Institute of India (WII) published in 2025, for the double-tracking of an existing railway line passing through Bhagwan Mahavir Wildlife Sanctuary and National Park in Goa, and Kali Tiger Reserve in Karnataka—both part of the Western Ghats, a global biodiversity hotspot. The WII EIA was compared with the Indian Institute of Science's (IISc) 'Biodiversity and Environmental Assessment' study that was previously prepared in 2017 for the same project. It was found that while the new EIA by WII addressed some of the gaps of the previous EIA, it failed to make a comprehensive assessment of projected biodiversity loss, leaving out some important taxonomic groups such as freshwater fish, insects, arachnids, and fungi, and failing to address its own study objectives, such as identifying critical wildlife habitats. It also neglected social impacts, despite widespread public opposition in Goa. The WII EIA fundamentally functions as an incomplete species inventory with mitigation measures, implying a conditional approval for the railway project. It does not assess loss in landscape-level connectivity, fragmentation of wildlife corridors, changes in human–wildlife interactions, and impacts on human health. This comprehensive review supports the call put forth by other scientists globally for the need for rigorous, independent peer reviews of EIAs, especially for projects with severe ecological and socio-economic consequences, planned in biodiverse and irreplaceable landscapes.

Keywords: Biodiversity assessments, biodiversity hotspot, forest governance, linear intrusions, mitigation measures, protected areas, railway, social impact assessments, tiger reserve, wildlife conservation.

Konkani (Devanagari script): प्रस्तावित आशिल्ल्या विकास कामांखातीर, पर्यावरण आनी मनीस कल्याणाचेर जावपी परिणामांचें मूल्यमापन करपाक अत्यंत महत्त्वाची प्रक्रिया आसा. भारता वांगडाच हेर कितल्याशाच देशांनी हीं मूल्यमापनां चडशा वेळार जैवविविधते विशयीच्या अर्धवट म्हायती, आनी आकडेमोडींन फेरफार जावप अशा समस्यांनी ग्रस्त आसता. ह्या समस्यां वांगडा वैज्ञानिक नदरेतल्या काटेकोरपणाचो अभाव, स्वतंत्र पुनरावलोकनाचो अभाव आनी लोकसहभागाचे अपुरेपण अश्या समस्यावांगडा जोडिल्ल्यो आसतात . चड करून ह्यो समस्या जैवविविधतेच्या नदरेतल्यान अती संवेदनशील भागानी चड गंभीर आसतात. ह्या शोधनिबंधांन 2025 वर्सा "वाइल्डलाइफ इन्स्टिट्यूट ऑफ इंडिया (WII)" हाणीं प्रकाशित केल्ल्या एका एकत्रित परिणाम मूल्यांकनाच्या (Cumulative Impact Assessment) अभ्यासाचें परीक्षण केल्ले आसा. हो अभ्यास गोयांतल्या "भगवान महावीर वन्यजीव अभयारण्य आनी राष्ट्रीय उद्यान" आनी कर्नाटकांतल्या " काळी व्याघ्र राखीव क्षेत्र " हांगाच्यांन वचपी विद्यमान रेल्वेमार्गाचें दुपदरीकरण (double tracking) करपाच्या प्रस्तावाक लागून तयार केल्लो. हे दोनूय वाठार जागतिक स्तराचो जैवविविधता हॉटस्पॉट आशिल्ल्या अस्तम घाटाचे वाठार आसात. WII च्या EIA ची तुलना ह्याच प्रकल्पाखातीर 2017 ह्या वर्सा "इंडियन इन्स्टिट्यूट ऑफ सायन्स (IISc)" हाणीं तयार केल्ल्या "जैवविविधता आनी पर्यावरणीय मूल्यांकन" (Biodiversity and Environmental Assessment) अभ्यासा वांगडा केल्ली. नव्या WII , EIA न आदल्या EIA तल्यो कांय उणिवो भरून काडपाचो यत्न केल्लो, पूण प्रस्तावित जैवविविधता नुकसानाचें सर्वसमावेशक मूल्यमापन करपांत ते अपुरे पडला. हाका लागून गोड्या उदकातले माशे, किडे, आठ पायांचे जीव(arachnids) आनी बुरशी (fungi) ह्यासारखे महत्त्वाचे घटक , गृहित धरुकना तशेच आपणाल्या अभ्यासा उद्देशांत समाविष्ट आशिल्ल्या महत्त्वाच्या वन्यजीव अधिवासांची वळख पटोवप हें उद्दिष्ट फळादीक जावंक ना. गोयांन रेल्वे प्रकल्पाविरोधांन व्यापक लोकविरोध आसूनलेगीत ह्या EIA न सामाजिक परिणामांचेर पूर्णपणान दुर्लक्ष केलां. WII चो EIA मुळसातत्यान नियंत्रीत करपाच्या उपायावांगडा (mitigation measures) , तयार केल्ली एक अपुरी प्रजाती सूची (species inventory) अशा रितीची भूमिका निभायता आनी अप्रत्यक्षपणान रेल्वे प्रकल्पाक अटींचेर आधारीत मान्यता सुचयता. तातून भूदृश्य पातळी वयल्या (landscape-level) जोडणीचो ऱ्हास, वन्यजीव मार्गांचें तुकडे करपाक (fragmentation), मनीस - वन्यजीव परस्पर संवादांतले बदल, आनी मनशाच्या भलायकीचेर परिणाम हांचें मूल्यमापन केल्लें ना. हें सर्वसमावेशक पुनरावलोकन जगभरांतल्या हेर वैज्ञानिकांनी माणिलल्या मागणीक पाठबळ दिता की, विशेष करून जैवविविधतेन समृद्ध आनी खाशेल्या प्रदेशांत प्रस्तावित, गंभीर पर्यावरणीय आनी सामाजिक-आर्थिक परिणाम घडोवपी प्रकल्पांच्या पर्यावरणीय परिणाम मूल्यांकनांचें कठोर, स्वतंत्र आनी समकक्ष तज्ज्ञांकडून (peer review) पुनरावलोकन जावप गरजेचें आसा.

INTRODUCTION

The global ecological crisis, marked by unprecedented biodiversity loss and accelerating climate change, has led to calls for a more urgent and reflective ecological praxis (Pettorelli et al. 2025). India is highly vulnerable to the impacts of climate change, particularly in its biodiversity-rich regions such as the Western Ghats (MoEFCC 2021; IPCC 2022). Increasing and maintaining canopy cover and safeguarding the network of Protected Areas (PAs) are recognised as key nature-based solutions for both climate mitigation and ecosystem resilience (Ravindranath & Sukumar 1998; Balaji et al. 2022). Within this context, Environmental Impact Assessments (EIA) have become a widely adopted tool for evaluating the potential impacts of infrastructure projects on the natural environment. The EIA is a procedural and scientific mechanism used to predict, assess, and mitigate the potential socio-environmental impacts of proposed development activities before they are implemented. However, despite its near-universal application, research has underscored significant limitations in its effectiveness and has called for reforms to make the process more rigorous and ecologically responsive (Laurance 2022).

Studies have shown that EIA processes frequently fall short across multiple dimensions, including their underlying scientific methodology and rigour (Hughes et al. 2024). In India, these limitations of biodiversity assessments, mitigation studies, and environmental impact studies are particularly stark. The country's environmental governance and auditing frameworks have undergone significant changes in recent years with a greater emphasis on 'ease of doing business', catalysing infrastructural and industrial expansion (Dharmadhikary 2023). As a consequence, the rate of granting forest clearances has significantly increased. Since 2014, fewer than 1% of forest clearance proposals have been rejected (Joshi 2020). The rate of granting wildlife clearances for projects such as mining within PAs and Eco-sensitive Zones by the Standing Committee of the National Board for Wildlife (SC NBWL) has shown a similar increase (Srivastava & Singh 2026). Menon & Kohli (2015) have argued that fast-tracking clearance processes in the name of industrialisation and urban development have fundamentally reshaped forest governance in India. However, this acceleration has faced resistance, particularly through an increase in the number of Public Interest Litigations (PILs), which, as Menon & Kohli (2015) observe, function as a crucial check on governance mechanisms (Dilay et al. 2019).

Multiple stakeholders take part in an EIA, including project developers, EIA consultants, regulatory government authorities, politicians, affected citizens, scientists, media, and civil society. Given the diversity of stakeholders, each with a different agenda, the EIA process may be subject to manipulation through falsifying or exaggerating data, withholding information, undervaluing or overvaluing impacts, intentionally presenting confusing information and by bribing developers or consultants (Enríquez-de-Salamanca 2018). Kopas et al. (2022) demonstrated how corrupt local-level political networks led to an increase in the approval of new environmental clearances, particularly in the coal sector. Although their analysis extends only until 2014, they anticipate a worsening trend under the current political climate. The impacts of linear infrastructure projects, for instance, extend to speculative property markets (Balakrishnan 2019) and abrupt disruptions to local livelihoods (Bathla 2024). These consequences underscore a broader failure to adequately account for the social dimensions of environmental decision-making (Dilay et al. 2019; Hegde et al. 2022).

In India, the Ministry of Environment, Forest and Climate Change (MoEFCC), established in 1985, has served as the primary regulatory body overseeing projects with potential environmental and forest-related impacts. The EIA Notification, initially introduced in 1994 under the Environment (Protection) Act, 1986 and subsequently revised in 2006, outlines the procedures for reporting, engaging consultants, and the appraisal of such projects (Lin & Zaidi 2025). The EIA has become a highly contested terrain. Repeated amendments to the notification have, over time, diluted environmental protection and shifted the balance towards commercial interests (Menon & Kohli 2009). Furthermore, compliance with EIA norms remains weak, with little follow-up data to assess effectiveness (Ghosh 2013). EIA procedures have been reduced to tokenistic exercises, serving more as procedural hurdles than substantive assessments aimed at environmental protection. These systemic deficiencies in EIA processes have contributed to the unchecked degradation of ecologically sensitive areas, the displacement of indigenous communities, and a lack of meaningful public participation in environmental decision-making (Balaton-Chrimes 2015).

In this study, the current ecological and environmental information associated with the double-tracking of an existing railway line through Bhagwan Mahavir Wildlife Sanctuary and National Park (BMWS & NP) in Goa and the adjacent Kali Tiger Reserve (KTR) in Karnataka were analysed. The project has been the focus of significant social contestation, with widespread concerns raised over its potential socio-ecological impacts (Singh 2022). Since the project involves the expansion of a railway line, it remains outside the purview of the EIA Notification, 2006 (MoEFCC 2025b). Hence, decision-making hinges on the wildlife clearance process, despite concerns of significant cumulative environmental impacts (Lin & Zaidi 2025).

Notably, the Goa State Board for Wildlife (SBWL) initially rejected the proposal in 2013, and the Hon'ble Supreme Court of India later revoked the wildlife clearance previously granted for the project within Goa's largest PA and the adjoining tiger reserve in Karnataka. Elaborating on this context, particularly in relation to the EIAs and associated studies, the following sections focus on identifying the gaps in expert appraisals, primarily related to biodiversity, within the current structural framework of the EIA. While, the EIA process itself is discussed, a detailed critique of the legal tenets of EIAs and systemic issues in implementation is beyond the scope of this paper.

STUDY SITE AND PROJECT BACKGROUND

The state of Goa has a well-documented precedent of citizen appraisals on issues of land dispossession and EIAs, with civil society employing various mechanisms to challenge procedural lapses (Nielsen 2017). In 2020, public concern escalated when the Standing Committee of the National Board for Wildlife (SC-NBWL) granted clearances to three large-scale linear infrastructure projects passing through BMWS & NP in Goa—part of the Western Ghats biodiversity hotspot and a UNESCO World Heritage Site. Punjabi et al. (2020) undertook a comprehensive peer-reviewed analysis of the initial impact assessments for each of these projects, highlighting their ecological implications. Among them, the railway double-tracking project emerged as a particularly contentious development, galvanising widespread public opposition across Goa.

The Hon'ble Supreme Court of India upheld the recommendations made by the Central Empowered Committee (CEC) regarding the railway doubling project segment passing through BMWS & NP in Goa and contiguous forests of KTR in Karnataka in its order dated 09 May 2022 (Supreme Court of India 2022). In its report, the CEC stated that it "does not find any justification for undertaking a project of this nature which will destroy the fragile ecosystem of the Western Ghats, which is an internationally recognised biodiversity hotspot and also one of the most important wildlife corridors of the country" (CEC 2021, page 59). The Committee noted that the project would only marginally enhance the capacity of a relatively inefficient railway section while causing irreversible ecological damage. Nevertheless, while the Hon'ble Supreme Court order cancelled the clearances, it allowed the project proponent, Rail Vikas Nigam Limited (RVNL), to reapply for wildlife clearances. Meanwhile, the forest clearances issued for the railway track inside the PAs were held in abeyance through an order by the MoEFCC. Since then, the government of Goa on behalf of the South Western Railway and the RVNL, has made several attempts to get the abeyance order vacated. The last of these attempts was deferred by the Regional Empowered Committee (REC) in its meeting dated 26 March 2026 (REC 2026). The detailed project timeline, from 2013 to March 2026, is presented in Figure 1.

The doubling of the Tinaighat–Kulem railway line forms part of a broader 342 km expansion project aimed at enhancing rail connectivity between the industrial regions of Hospet–Tinaighat in Karnataka and the port of Vasco da Gama in Goa. This existing line is the Hospet-Tinaighat-Vasco line. Of this, approximately 26 km of track falls within the BMWS & NP. The alignment traverses ecologically sensitive areas, including semi-evergreen forests in KTR—and the section from the Goa–Karnataka border to Kulem, which lies within BMWS & NP. According to the project proposal, the total number of trees to be felled in this stretch is 19,182 (MoEFCC 2025a).

The study area includes two PAs: BMWS & NP in Goa, and KTR in Karnataka (Figure 2). These PAs lie within the northern Western Ghats, a UNESCO World Heritage Site and global biodiversity hotspot, renowned for high levels of species endemism and ecological significance (Myers et al. 2000). The Western Ghats play a vital role in climate regulation through carbon capture and storage (Lo Seen et al. 2010; Ramachandra & Bharath 2020). These forests also offer crucial hydrological services like water provisioning and fisheries (Krishnaswamy et al. 2009; Pownkumar et al. 2022). BMWS & NP—Goa's largest and oldest PA—spans 240 km², with 133 km² designated as a Wildlife Sanctuary and 107 km² as a National Park. KTR, formerly the Dandeli–Anshi Tiger Reserve, comprises the Dandeli Wildlife Sanctuary and Anshi National Park, encompassing a total area of 1,346 km². Both BMWS & NP and KTR are governed under the Wild Life (Protection) Act, 1972 (WPA), which prohibits diversion of land within national parks and sanctuaries for non-forest purposes without stringent scrutiny and high-level clearances.

The All-India Tiger Estimation reports affirm the ecological value of both BMWS & NP and KTR, identifying them as critical tiger habitats and ecological corridors connecting tiger populations across Karnataka and Goa (Qureshi et al. 2023). Additionally, KTR serves as a refuge for the bulk of the elephant population of northern Karnataka (Menon et al. 2017).

METHODS

The team comprises researchers from both the natural sciences and the social sciences including entomology, ornithology, ichthyology, herpetology, mammalogy, and human geography, and practitioners from conservation and implementation research, and embedded citizen-led efforts.

The technical report prepared by the Wildlife Institute of India (WII) was submitted under the collective title Cumulative Environmental Impact Assessment on Wildlife Habitat and Ecological Values Due to Proposed Doubling of Railway Track from Tinaighat to Kulem in Northern Western Ghats. The reports were published in two parts; an assessment of biodiversity (WII 2025a), and mitigation measures (WII 2025b). This was commissioned in response to the Hon'ble Supreme Court order (I.A. No. 61370 of 2021 in Writ Petition (Civil) No. 202 of 1995), which revoked the wildlife clearance granted earlier by the SC NBW (Supreme Court of India 2022). Our present study focuses on Part I of the cumulative EIA (i.e., WII 2025a), and will henceforth refer to this document simply as EIA. The previous biodiversity assessment conducted by the Indian Institute of Science (IISc), was peer-reviewed by Punjabi et al. (2020). We draw on their assessment to reference relevant limitations across studies. In this document, we adopt the shorthand of EIA to mean WII (2025a) and IISc EIA to distinguish between the two. It must be noted, that while we refer to the WII report as an 'Environmental Impact Assessment', it is to retain consistency with the title and the normative expectations about such an exercise. However, purely in legal terms, the report serves essentially as a biodiversity assessment and is not linked with an environmental clearance process under the EIA Notification, 2006 (MoEFCC 2025b).

In the following sections, we present general conceptual concerns observed with the surveys across taxa in the WII EIA, followed by specific notes on each

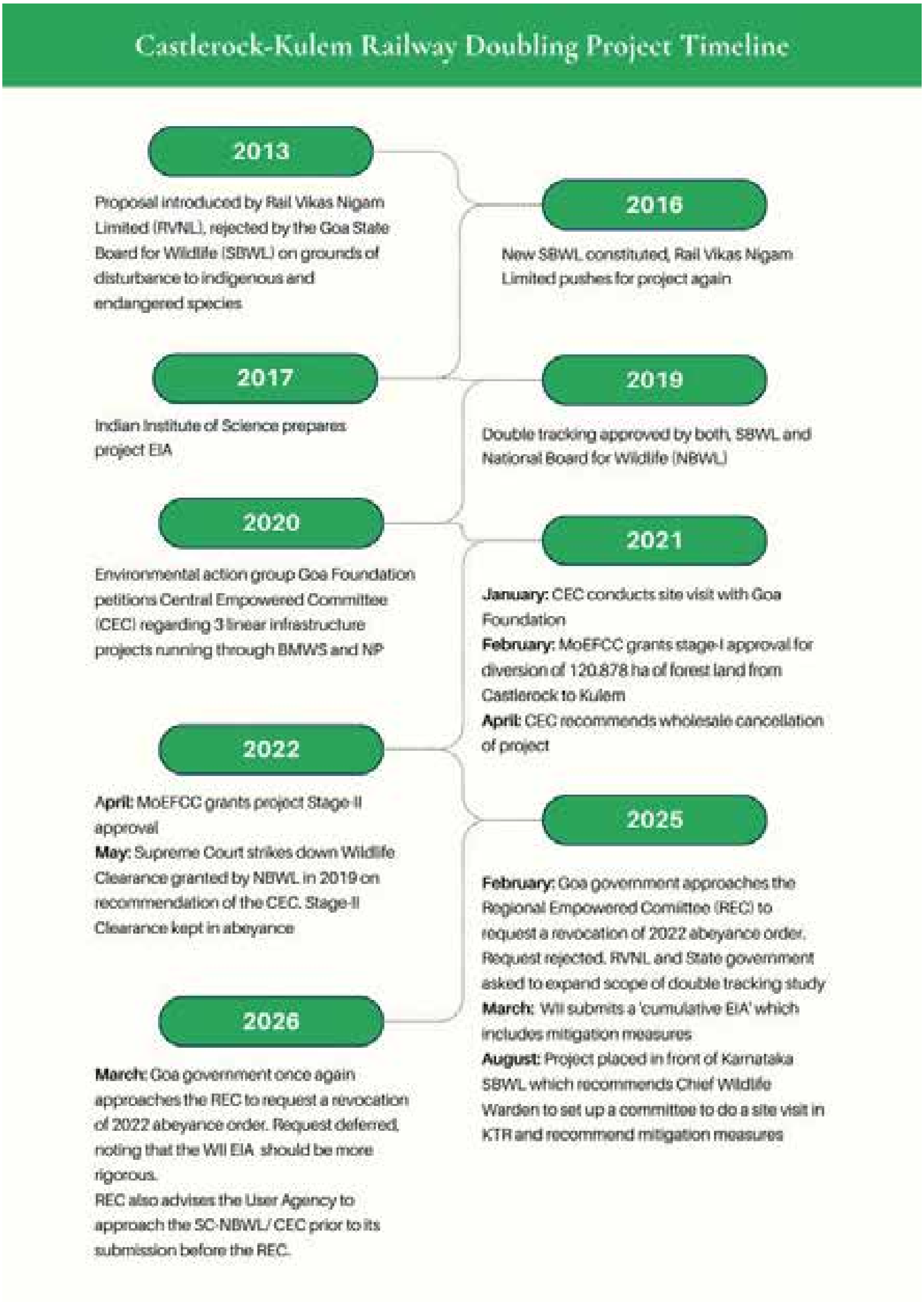

Figure 1. Timeline of the railway double-tracking project through Bhagwan Mahavir Wildlife Sanctuary and National Park in Goa (BMWS & NP) and Kali Tiger Reserve (KTR) in Karnataka.

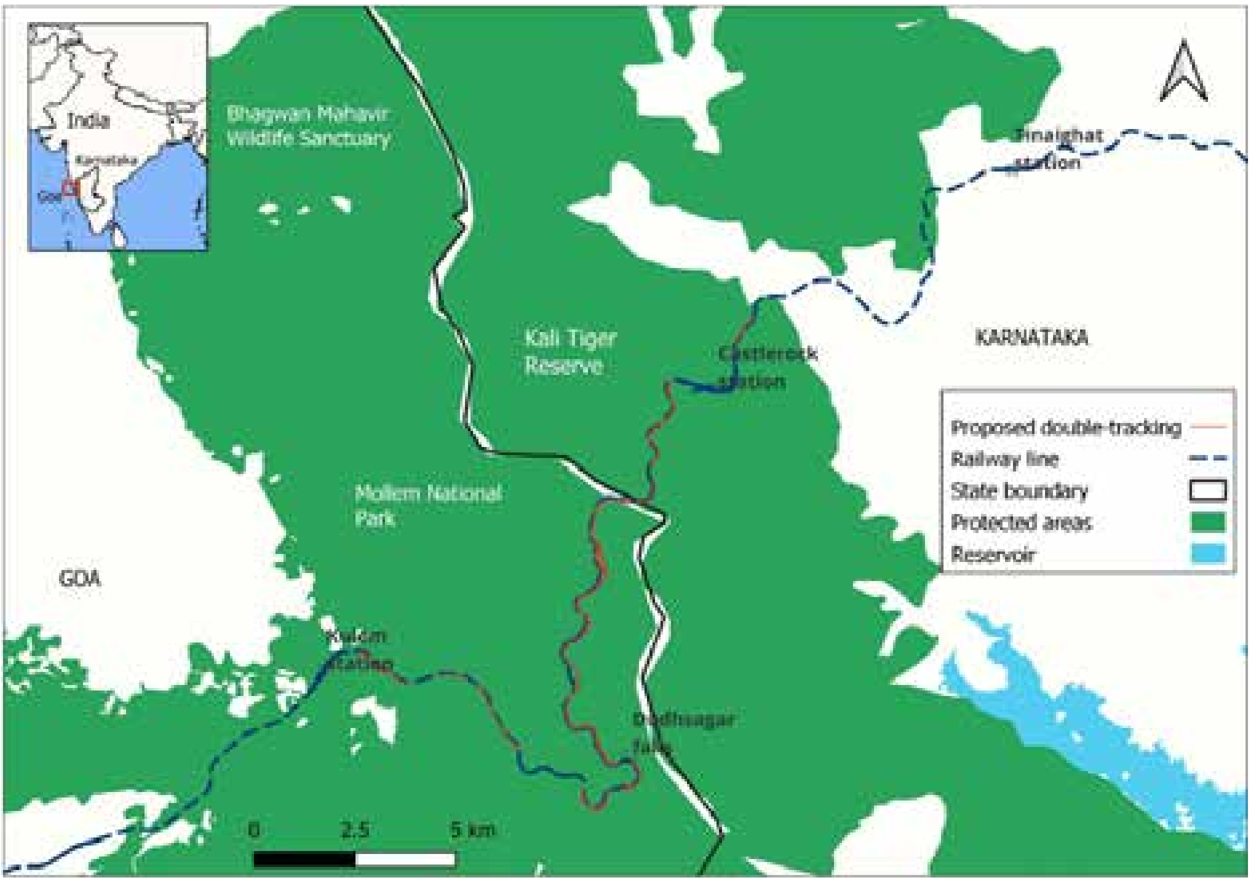

Figure 2. The extent of the proposed railway double-tracking through Bhagwan Mahavir Wildlife Sanctuary and National Park (formerly known as Mollem National Park) and Kali Tiger Reserve (formerly known as Anshi Dandeli Tiger Reserve). Project related information has been obtained from the project proponent's application uploaded to the Parivesh website (MoEFCC 2025a).

taxon in question, particularly threatened or poorly known species deemed to be important for an EIA of this nature. This is followed by a section reviewing social impacts. Finally, a table summarizing the salient observations in the WII EIA vis-à-vis the IISc EIA, along with additional missing information is revealed by its our own literature review.

To expand on the study by Punjabi et al (2020), a list of newly described species from the landscape between 2021 and 2025 is provided. The continued emergence of new scientific findings across taxa highlights the urgent need to undertake comprehensive, systematic studies across the region to better understand the full extent of its biological diversity and the ecological roles these species play in this critical landscape. Furthermore, we gathered records of large mammal rail kills along the existing Hospet-Tinaighat-Vasco railway line using online English news reports from 2015 to 2025.

RESULTS

The review of the WII EIA (WII 2025a) for the proposed railway expansion through BMWS & NP and KTR reveals significant deficiencies in baseline ecological data and methodological rigour.

The EIA begins by stating its project objectives aligned with the Terms of Reference (ToR) issued by project proponents (WII 2025a, page 10), yet it fails to articulate all ecological impacts and their magnitude. Objective 14 states that an "Environmental Management and Monitoring Plan" will be created to monitor the project during its construction and operation phase. Further, Objective 15 mentions that a "Biodiversity Impact Action Plan" will be created for both the PAs (WII 2025a, page 11). This appears to imply the pre-approval of the railway double-tracking project even before the biodiversity assessments were conducted. This raises critical questions about the integrity and independence of this EIA.

Biodiversity documentation is incomplete and taxonomically biased. While partial lists are provided for mammals and birds, several ecologically important, protected and endemic species across plants, fungi, insects, arachnids, fish and herpetofauna from the region are minimally represented, raising concerns about the EIA's reliability as a foundation for impact prediction or mitigation planning. Crucially, the report fails to contextualize the landscape's ecological functions, including its role as a tiger corridor, and omits discussions of habitat connectivity and ecosystem services.

General conceptual gaps

- The EIA focuses solely on species richness, often limited to checklists. It overlooks deeper dimensions of biodiversity, particularly phylogenetic and functional diversity, which are critical to understanding ecosystem integrity and resilience (Flynn et al. 2011). While we acknowledge that such studies might need longer duration and may not fit within the purview of an EIA, there is no mention even of the essential aspects of ecosystem persistence. The species reported in the study site have high phylogenetic and functional diversity, performing a range of ecological roles such as pollination, seed dispersal, or decomposition (Wordley et al. 2017; Bose et al. 2019; Naniwadekar et al. 2025). The proposed project would impact the phylogenetic and functional diversity of multiple taxa in the study site, besides introducing barriers in the movement of wide-ranging species (Jayadevan et al. 2020). The absence of such considerations renders the EIA ecologically inadequate.
- The EIA lacks rigorous inquiry into certain conceptual frameworks that are integral to conservation. While the impacts of linear infrastructure are noted (e.g., mortality, desiccation), there is no mention of edge and barrier effects, functional connectivity, or seasonal movement and metapopulation collapse due to linear intrusions (Laurance et al. 2009; Cumming & Tavares 2022). Forman & Alexander (1998) provide foundational concepts of roads as genetic barriers, while Cushman (2006) focuses specifically on amphibians, synthesizing evidence for population isolation and reduced connectivity due to habitat fragmentation caused by human-made linear features.

Gaps in taxon-specific surveys

Plants and Fungi

- The EIA study employs a biased sampling regime to enumerate vascular plants. Although they use the point-centred quarter (PCQ) method that mandates random selection of points to ensure no sampling bias (Mitchell 2010), the study fails to make an unbiased selection. The report itself states that "the locations of PCQ were chosen neither randomly nor in a systematic fashion", due to accessibility issues. Instead, the points should have been selected randomly (Mitchell 2010), and the ones that were logistically difficult to access could have been replaced with other points to ensure that the vegetation is sampled appropriately.
- Grasses, orchids and ferns need to be sampled more extensively in the zone of influence, a fact acknowledged in the study (WII 2025a, page 35).
- Even without a comprehensive assessment of plant diversity, the study still finds 26 threatened species as per the International Union for Conservation of Nature (IUCN) Red List along with 135 endemic and geographically restricted species (including 61 species endemic to the Western Ghats), and 18 records new to the state of Goa (WII 2025a, page 36). Given this, the study itself states that "no mitigation measure will help in reducing the negative impact of the proposed railway line on the native vegetation" (WII 2025a, page 42).
- The study finds that invasive species, particularly *Chromolaena odorata*, are most prevalent along the railway line, and concludes that these species will invade further and replace native vegetation during the construction of the new railway line (WII 2025a, page 39).
- The study failed to record any fungal diversity and no impact assessment was done for this taxon. While the report provides detailed assessments of vegetation, it does not address fungal diversity—including mushrooms and symbiotic fungi such as arbuscular mycorrhizal fungi and ectomycorrhizal fungi—which are integral to ecosystem functioning in the Western Ghats (Sridhar & Karun 2019). This omission highlights a broader knowledge gap in biodiversity assessments that often overlook fungi despite their crucial roles in nutrient cycling, soil stability, and plant health (Amaral-Silva et al. 2025).

Insects and Arachnids

- The EIA does not include any assessment of insect and arachnid diversity in the study area. Several key arthropod groups such as lepidopterans, odonates, hymenopterans, and arachnids have been left out of the study despite their ecological importance and potential sensitivity to habitat alteration. Insects play an important role in EIAs due to their diversity, sensitivity to environmental changes and essential functions in ecosystems (Rosenberg et al. 1986). Insects are major contributors to biodiversity; their exclusion can lead to underestimation of biodiversity loss, and lack of insect data can result in ineffective or misdirected mitigation measures (Crenna et al. 2017; Topping et al. 2020).

- The EIA omits the presence of legally protected butterflies in the landscape (such as Malabar Tree Nymph *Idea malabarica*) as per the WPA, 1972 (MoEFCC 2022). Punjabi et al (2020) documented the presence of 218 butterfly species from BMWS & NP.

- The odonate fauna (dragonflies and damselflies) of Goa is comparatively well documented, with 87 species recorded (Rangnekar et al. 2010). Notably, Goan Shadow Dancer *Idionyx gomantakensis* is a newly described, regionally endemic dragonfly recorded from Kulem, adjacent to the existing railway track (Subramanian et al. 2013). Punjabi et al (2020) documented 80 species of odonates from BMWS & NP. Among these, the dragonflies *Heliogomphus promelas* and *Megalogomphus hannyngtoni* are listed as 'Near Threatened' in the IUCN Red List (Kakkasery 2011; Subramanian 2011a), while the damselfly *Protosticta sanguinostigma* is listed as 'Vulnerable' (Subramanian 2011b).

- The compilation of new species discoveries in the last five years shows an addition of 14 arthropod species comprising nine species of wasps, two species of beetles, one species of gall midge, one species of crab and one species of katydid to the species list of BMWS & NP and KTR further underscoring the ecological significance of these PAs (Appendix I).

- Train-related noise and vibrations can disrupt insect communication, behaviour, and physiology. The EIA does attempt to assess the effects of train noise pollution (WII 2025a, pages 89–94) and train vibrations on insects (WII 2025a, page 99), but these conclusions are not substantiated, due to a lack of suitable baseline data on the diversity of this taxon in the study area.

Fish

- The EIA review has overlooked the impact of the railway alignment on the region's freshwater fish fauna, a critical component of aquatic biodiversity. The Western Ghats' freshwater fish are one of the richest in terms of their sheer biodiversity and endemism compared to any other region in India (Daniels 2002). A recent study documented 325 freshwater fish species in the Western Ghats (including 223 endemics) (Shukla et al. 2026). Since this study subject is not extensively studied yet, it is likely that many species remain undocumented to this date (Dahanukar et al. 2004; Raghavan et al. 2014). Several perennial streams intersect the proposed railway track. Even minor alterations to stream habitats can have adverse effects on habitat-specialist, threatened, and endemic fish species (Punjabi et al. 2020).

- Unregulated deposition of debris and sediments during construction could damage spawning grounds of migratory and resident cyprinid fishes such as stream loaches (e.g., *Schistura* spp.), carps, minnows, and catfishes (Atkore 2017).

- The Dudhsagar River serves as a headwater habitat for cyprinid species such as the Deccan Mahseer (*Tor khudree*) and Nash's Barb (*Osteochilichthys nashii*) (Image 1), both of which utilize this habitat for spawning and feeding during multiple seasonal migrations. Sensitive taxa such as *Bhavania australis* and *Balitora mysorensis* that prefer high-velocity riffle habitats are particularly vulnerable to tunnel construction and other habitat modifications (Atkore 2017).

Amphibians and Reptiles (Herpetofauna)

- The EIA recognises several key threats to herpetofauna due to the railway doubling. Nevertheless, studies indicate that infrastructure-related stress is often underestimated due to sampling biases and inadequate baseline data (Forman & Alexander 1998). Similarly, the collection of roadkill data can be influenced by infrastructure and landscape characteristics, potentially underrepresenting actual mortality rates (Sushanth et al. 2025). Further, amphibian sampling has been shown to exhibit significant geographic and temporal biases in tropical habitats such as the Amazon, often due to infrastructure and accessibility constraints (Penhacek et al. 2025). The EIA does not explicitly acknowledge or account for sampling biases and the limitations in detectability, spatial bias, and baseline data adequacy in tropical herpetofauna surveys.

- According to the EIA, a total of 62 species of herpetofauna (reptiles and amphibians) are recorded along the rail track in BMWS & NP and KTR, comprising 28 amphibians and 34 reptiles (WII 2025a, page 172). The Second Global Amphibian Assessment (GAA2) notes that the Western Ghats of India harbour 232 amphibian species, with 69% of these species endemic (Luedtke et al. 2023). This highlights that the EIA records represent a fraction of the region's amphibian diversity, underscoring the need for more comprehensive surveys.

- The EIA briefly mentions the infectious disease Chytridiomycosis and its impact on more than 500 species (WII 2025a, page 45). However, its impacts are not further explored in the study, despite evidence indicating that habitat loss can exacerbate disease vulnerability among amphibians due to increased stress and isolation (Scheele et al. 2019).

- A number of important taxa within this group are missing from the results. Sampling was restricted to the July–August months, thus ignoring the post-monsoon emergence and breeding of key stream-dwelling amphibians (*Micrixalus* spp., *Nyctibatrachus* spp., *Raorchestes* spp.) that are active later in the monsoon or post-monsoon period (Biju et al. 2014; Mudke et al. 2020). Some of these species including *Micrixalus* spp. are highly stream-dependent and threatened, and their absence from the displacement dataset (WII 2025a, page 48) likely skews the interpretation of barrier effects.
- A recent study on *Ophiophagus kaalinga* (Western Ghats King Cobra) in Goa highlights how railways and trains may act as unintended conduits for snake movement drawing individuals into areas that are ecologically unsuitable, thereby increasing conflict and mortality risk. This information underscores the need for landscape-level movement analysis in impact assessments of rail infrastructure (Parmar et al. 2025).
- Further, the EIA sampled "frogs of selected genera (*Indosylvirana*, *Hydrophylax*, *Rhacophorus*, *Minervarya*)" as model amphibians to understand amphibian movement and its disruption due to the railway expansion, excluding several other genera that exhibit distinct ecologies and evolutionary histories and stand to lose from an incomplete EIA (Cushman 2006).
- Among freshwater turtles, the report has mentioned only the Indian Black Pond Turtle *Melanochelys trijuga* included amongst the other reptiles (WII 2025a, pages 50 and 172). There has been no assessment of the project impact on turtles.
- In the rail kill survey (WII 2025a, pages 133–139) carried out between July to October 2023, the EIA mentions a "6 fold increase in amphibian mortality and a 2 fold increase in reptile mortality". Since the survey was conducted in a single season, the list is likely to be incomplete.
- Several herpetofaunal species such as *Draco dussumieri*, *Lycodon* cf. *travancoricus* *Micrixalus uttaraghati*, *Sphaerotheca* sp., *Uperodon mormorata*, *Rhabdops olivaceus*, and *Boiga thackerayi*, among others, depend on specific habitats and move across habitats using the forest floor, subcanopy and streams for survival and breeding. The EIA does not reflect refugia dependence of any of the herpetofauna species and does not present a quantitative analysis of microhabitat variable (leaf litter depth, canopy cover, sub-canopy moisture, and stream parameters) use across seasons (Spranger et al. 2024). The failure to measure refugia use and mortality across seasons presents a limited picture of the overall impacts of railway doubling on endemic herpetofauna.
- The EIA relies heavily on generic mitigation measures, such as fencing, culverts, amphibian underpasses and canopy bridges. However, studies often show poor effectiveness of such interventions, especially in complex tropical forest ecosystems, with diverse herpetofauna assemblages and high microhabitat specificity (Beebee 2013; van der Ree et al. 2015).

Birds

- Bird surveys were conducted using point count methods along the pre-existing railway track between Kulem and Tinaighat (WII 2025a, page 61). However, this methodology is insufficient to assess the impact of additional forest loss associated with the double-tracking project. Although surveys were conducted during the winter migration months and represented an improvement from the IISc EIA, the total survey effort and duration remain unreported. Each point location is reported with one value of abundance (count), with no further details as to how this number was obtained. This suggests each point may have been sampled only once across two years, with data pooled, reducing temporal resolution and leading to methodological ambiguity. Radius of the point counts is unspecified, raising concerns about variation in species detectability (Raman 2003). The distance data collected using range finders has not been incorporated in the analysis, with no explanation given. Other covariate data (forest type, terrain, canopy cover, temperature, humidity) were reportedly collected but have not been reported. These shortfalls and inconsistencies have made interpreting the data and the results a rather futile effort.
- The bird surveys also fail to fulfil Objective 10 (WII 2025a, page 11), which recognizes the need to identify critical habitats along the railway track. Further, no attempt has been made to document nesting and roosting sites.
- Legal conservation status under the WPA, 1972 is not reported. Of the 125 valid species observed (out of 135 reported), 18 (14.4%) fall under Schedule I and 105 (84%) under Schedule II of the WPA.
- Many of the reported species have geographic distributions that differ considerably from the region in question, as detailed in the following examples. Six individuals of Fork-tailed Drongo *Dicrurus adsimilis* were reported (WII 2025a, page 65); this is an Afro-tropical species. Three individuals of Greater Flameback *Chrysocolaptes lucidus* were recorded (WII 2025a, page 67); *C. lucidus* is however endemic to the Philippines

(Winkler & Christie 2020), and for the Western Ghats, the correct taxa would be *Chrysocolaptes socialis* Malabar Flameback, as per the updated Clements/eBird taxonomy (del Hoyo et al. 2023). Four individuals of Long-tailed Minivet *Pericrocotus ethologus* were reported (WII 2025a, page 65); this species has no known distribution south of Madhya Pradesh (Taylor 2020). Indian Yellow Tit *Machlolophus aplonotus* was assigned *Periparus ater* (WII 2025a, page 64), which refers to the Himalayan Coal Tit (Gosler & Clement 2023), not a species known from Goa. Square-tailed Bulbul *Hypsipetes ganeesa* was listed as *Hypsipetes leucocephalus* (WII 2025a, page 67), a name assigned to the Himalayan Black Bulbul (Fishpool & Tobias 2020; Jha 2024). Green Warbler *Phylloscopus nitidus* and Greenish Warbler *Phylloscopus trochiloides* were both listed with high counts (279 and 393 individuals, respectively) but assigned the same scientific name, *Phylloscopus nitidus* (WII 2025a, page 66), indicating misidentification or reporting error (Clement 2020; Clement & Sharpe 2020).

- Notably absent were common species such as the Malabar Barbet *Psilopogon malabaricus* and Jungle Babbler *Turdoides striata*. Reports of 49 individuals of Coppersmith Barbet *Psilopogon haemacephalus* and seven individuals of Yellow-billed Babbler *Turdoides affinis* suggests possible misidentification between morphologically or acoustically similar species.
- Five species were each recorded twice under different common names but with the same scientific name, possibly due to inconsistent checklist usage (e.g., Grimmett vs. Clements/eBird) or failure to synchronize taxonomy across years.

Mammals

- The mammal survey reported in the EIA was conducted using a single method, that is, camera trapping adjacent to the proposed railway alignment. As a result, the inventory is likely to be incomplete. Only 23 mammalian species were recorded, which does not reflect the full mammalian diversity expected in BMWS & NP and KTR, both located within a globally recognised biodiversity hotspot (Myers et al. 2000).
- The exclusive reliance on camera traps likely means that a number of nocturnal, arboreal, fossorial, and small-bodied species are likely underrepresented or entirely missed. Notably absent are the 'Near Threatened' Grey Slender Loris *Loris lydekkerianus*, canopy-dwelling rodents, and bats, despite one of the stated objectives of the EIA being to assess the distribution and abundance of arboreal mammals (Objective 3; WII 2025a, page 10). In contrast, Punjabi et al. (2020) compiled a list of 81 mammalian species from BMWS & NP alone, including the 'Endangered' Indian Pangolin *Manis crassicaudata* and two 'Vulnerable' species of otters, the Small-clawed Otter *Aonyx cinereus* and the Smooth-coated Otter *Lutrogale perspicillata*.
- Interestingly, despite methodological limitations, the species richness observed through camera traps is relatively high, with most records originating from the Kulem-Sonalium and Castlerock-Tinaighat stretches (WII 2025a, page 78). Many of the detected species are listed under Schedule I of the WPA, 1972. The EIA documents two IUCN Endangered species—the Bengal Tiger *Panthera tigris tigris* and the Dhole *Cuon alpinus*—as well as three 'Vulnerable' species: Leopard *Panthera pardus fusca*, Gaur *Bos gaurus*, Sloth Bear *Melursus ursinus*, and Bonnet Macaque *Macaca radiata*. Tiger cubs and Sloth Bear cubs were captured in multiple locations, underscoring the significance of the area as a breeding habitat. A total of eight independent photographic captures of tigers were reported, highlighting the ecological value of this region for large carnivores.
- An additional claim in the EIA mentions the camera-trapping of the Nilgai *Boselaphus tragocamelus* on two occasions (Table 7.2; WII 2025a, Page 78). No photographic evidence is provided. If verified, this would represent a novel mammalian record for the state of Goa and warrants further scrutiny. The only other Nilgai record reported from the Western Ghats is from the Muthodi range in Bhadra Tiger Reserve (Bhardwaj 2018). The EIA states that the Ruddy Mongoose is endemic but does not specify the area to which it is endemic to, that is, the Indian sub-continent. It also omits the Western Ghats endemic status of the Brown Palm Civet (Mudappa et al. 2024), despite including a photo of it (WII 2025a, Page 87), but not mentioning the species in the results (WII 2025a, Page 77).
- The 2022 National Tiger Conservation Authority (NTCA) report has stated that KTR is the only tiger reserve in the Western Ghats that showed an increase in tiger numbers even though there was a significant decrease in tiger occupancy in the border regions of Karnataka and Goa (Mollem-Mhadei-Anshi Dandeli complex). This statistic helps reiterate the ecological and conservation importance of KTR (Qureshi et al. 2023). The impact of doubling a track that already divides KTR, essentially fragmenting the reserve, will have a negative impact on the growing tiger population, preventing dispersal and isolating the populations. Maintaining connectivity between Karnataka and Goa is vital for tiger dispersal, territorial fidelity, and population stability. Dispersal,

driven by territory establishment, competition, and habitat conditions, especially among males, follows contiguous forest, higher elevations, and rugged ridges (Joshi et al. 2013; Krishnamurthy et al. 2016; Singh et al. 2021). The Karnataka–Goa belt thus serves as a natural corridor enabling routine gene flow, rather than one-off stress-induced movement. As dispersal is hindered by human settlements and roads, KTR's role as a source population must be maintained (Joshi et al. 2013; Sharma et al. 2013).

- The EIA fails to fully develop or integrate an argument for the role of KTR in supporting Elephant connectivity, despite Objective 9 (WII 2025a, page 11) explicitly stating this as one of the goals of the assessment. The Dandeli Elephant Reserve was notified by the Karnataka Forest Department in 2014. The reserve covers some parts of KTR and includes the Tinaighat area (WII 2023). Objective 9 of the EIA refers to the need for evaluating land cover change and assessing connectivity for movement of tigers and elephants under pre- and post-construction scenarios (WII 2025a, page 11). However, no data or modelling to support this objective are presented.
- The EIA's rail kill survey acknowledges that the fauna mortality rates caused by railway collisions are an underrepresentation of the true mortality rates in the landscape (WII 2025a, page 138). Through a collation of news reports on rail kill records from the existing Hospet-Tinaighat-Vasco railway line, we gathered six news articles in the last 10 years (Appendix II). Amongst these, the highest number of rail kills was of the Gaur (Image 2). This underscores the failure of any mitigation measures on existing railway lines passing through BMWS & NP and KTR and the broader central Western Ghats landscape.
- Critical components such as animal behavioural responses to railway infrastructure, effectiveness of existing mitigation structures (e.g., underpasses) and landscape-level connectivity analysis (e.g., continuity with larger tiger corridors) are either not addressed or only superficially mentioned. Consequently, the compatibility of the railway doubling project with long-term wildlife conservation remains insufficiently examined.

Social impact

The new EIA by WII does not include a social impact evaluation of the railway double-tracking project. The ToR issued by the project proponents makes no mention of a social impact assessment. This points to the limitation of not just the technical report submitted by WII but also a larger policy gap in which large-scale linear projects, such as the railways, are not mandated to conduct public consultations, as per the EIA Notification, 2006. In the following section, we demonstrate why public consultations are necessary in evaluating infrastructure projects, especially in the context of the expansion of the railway line.

- Public participation is a crucial element of evaluating environmental and ecological impact (O'Faircheallaigh 2010). It plays an important role in a democratic process (Thayyil 2014). In Goa, public consultation and impact assessment are particularly important. Civil society has been actively involved in tracking environmentally damaging projects, which are often related to the contentious tourism industry (Routledge 2001; Nielsen 2017; da Silva et al. 2020). While the initial EIA by IISc did present a social impact study in 2017, Punjabi et al. (2020) already noted the shortcomings of the so-called socio-economic assessment, including survey sample size, location, timeline, and bias in the content of the survey focusing on transport. However, no such assessments seem to exist for the 2025 EIA.
- The CEC highlighted the problems of the topographical difficulties regarding this route, such as the steep inclination (1:37 gradient), potential impact on biodiversity of levelling more land for this purpose and finally the flaws in the economic argument that does not justify the impacts on an eco-sensitive zone (CEC 2021, pages 52-55). The fact that the line was being used to transport coal beginning at Mormugao Port Trust in Goa, deposited into Karnataka, and returning empty, did not justify an economic argument for the erosion of the forest area (CEC 2021, page 56). In this regard, the proposal for double tracking does not take into consideration existing mandates against coal handling in the state (see, for details, D'Mello 2015). Correia (2018) links the double tracking to other such infrastructure projects as part of the controversial Sagarmala project, asserting a need for a cumulative impact assessment of all related projects.
- Coal handling and transportation, as well as increased railway activity, are likely to exacerbate detrimental effects on the population's health and well-being directly through coal dust particles in the air (Sharma & Patil 2016) and as it seeps into farmlands (Li et al. 2018). This has long-term implications for the population residing close to the tracks, as proven in other parts of India (Mishra & Das 2017). A comprehensive assessment of the human populations living in the vicinity of the proposed railway expansion

Table 1. A comparison between the old EIA report prepared by IISc titled 'Biodiversity and Environmental assessment of proposed doubling of railway track between Kulem and Castlerock in Goa-Karnataka' (2017) with the new EIA by WII titled 'Cumulative Environment Impact Assessment on wildlife habitat and ecological values due to proposed doubling of railway track from Tinaighat to Kulem in the northern Western Ghats. Part I: Assessment of Wildlife habitat and ecological values around railway track' (2025).

Study subject	Biodiversity assessment by IISc (2020)	Cumulative EIA by WII (2025)	Scientific sources
Plants and fungi	255 species of flowering plants (Page 64).	416 species of plants including 409 species of flowering plants (Page 36).	722 species of flowering plants in BMWS & NP (Datar & Lakshminarasimhan, 2013).
Plants and fungi	Neither EIA has assessed the diversity and abundance of fungi in the study area and the impact of the project on fungi.		148 species of ectomycorrhizal fungi reported from the Western Ghats itself (Sridhar & Karun 2019).
Insects and arachnids	Butterflies, dragonflies and damselflies are studied, but moths excluded (Pages 87, 101). No study on other insect groups and arachnids.	No study of insects and arachnids.	At least 418 species of moths reported from the northern Western Ghats (Shubhalaxmi et al. 2011). An initial survey revealed 6 scorpion species, 1 species each of whip scorpions and whip spiders and 16 species of spiders in BMWS & NP (Bastawade & Borkar 2008). The first definitive record of the Whip Scorpion (*Labochirus tauricornis*) for Goa was reported near BMWS & NP (Borkar 2018).
Fish	23 fish species. No assessment of project impact on the fish community (Page 116).	No study of freshwater fish.	A study of the Mhadei sub-basin (which includes BMWS & NP) reveals 49 fish species with 18 endemic species from the Western Ghats (Atkore 2017). Alterations in the stream environment such as changes in water quality or flow by anthropogenic pressures have negative impacts on fish guild composition (Atkore 2017; Atkore et al. 2020; Bhavan et al. 2025).
Amphibians and Reptiles	Survey carried out during the inactive season of reptiles i.e., winter due to which the impact on reptiles could not be assessed properly (Page 139).	Sampling restricted to two brief seasonal periods (dry: February–April; wet: July–August, 2023), taxonomically narrow, and did not include broader ecological or pathogen risk evaluations.	52 reptiles and 36 amphibians, collectively, 88 species have been recorded in BMWS & NP (Punjabi et al. 2020).
Birds	Two-day bird surveys conducted in September 2014 and May 2015 which enumerates only 35 bird species.	Surveys done in December to January of 2022–23 and 2023–24. Exact number of survey dates not reported. Each survey point was visited only once. A total of 135 species reported, of which 125 are valid entries.	A comprehensive checklist reveals 236 species of birds recorded in BMWS & NP (Rahmani et al. 2016).
Birds	Migratory birds are underrepresented in the survey as it was not conducted during the migratory season. (October to March)	Surveys were conducted during two months of the winter migratory season (October–March). Some winter migrants such as Blyth's Reed Warbler, Grey Wagtail, *Phylloscopus* Warblers recorded. No survey during summer and monsoon migration seasons.	A total of 57 migratory species from the different migration seasons are recorded from the BMWS & NP Important Bird Area (IBA) on eBird (eBird 2024; State of India's Birds 2024).
Mammal	23 mammal species were documented (Page 153). The EIA fails to explicitly mention the presence of the tiger in the study area. The study was affected by species misidentification; it recorded the Large Indian Civet *Viverra zibetha* in the Western Ghats, a species found in northeastern India.	23 mammal species were documented (Page 75). Tigers with cubs were photographed in 5 locations along the railway line. The study records the presence of a Nilgai in the Western Ghats (Page 78), a species that avoids dense forests and prefers dry areas.	Punjabi et al. (2020) compiled a list of 81 mammalian species from BMWS & NP.
Social impacts	The EIA carried out a social impact survey with 60 families in four villages. There is no mention of how selection of the villages and those interviewed were done. Questions were leading, focusing on transportation needs in the region. Panchayat concerns were noted by Punjabi et al. (2020) as not incorporated and did not include consultation with the wider public.	No social impact was considered.	A submission to the CEC (D'Silva et al. 2021) highlights a number of villages and structures of socioeconomic and cultural importance along the proposed railway line in Goa. The impact far exceeds that considered by the WII study. The people of the region have actively resisted coal handling in the area (Correia 2018).
Public health	The potential health effects of air pollution caused by coal transportation on residents of villages in the study area were not considered.		Air pollution can impact respiratory functioning (Sharma & Patil 2016) and also contaminate farmlands and water through particles that may be distributed (Li et al. 2018).
Traditional ecological knowledge	The study lists out medicinal plants and minor forest produce (Page 170) but fails to assess the impacts of the project on these species and broader impacts on human-nature relationships. In the 'public consultation' meeting conducted by the IISc team for the old EIA, members of the Kulem Gram Panchayat raised concerns about the threat to medicinal plants as a result of double-tracking (Page 191).	There has been no consideration of the use of medicinal plants by people within the region or other such traditional ecological knowledge nor have there been efforts to collect data on the same and incorporate it within the biodiversity assessments.	Sawant & Rodrigues (2015) documented traditional knowledge of 50 medicinal plant species from 20 families and 46 genera in Goa alone.

Image 1. Some species representing the taxa that were not studied in Wildlife Institute of India's EIA in Bhagwan Mahavir Wildlife Sanctuary and National Park and Kali Tiger Reserve (from left to right): Nash's Barb *Osteochilichthys nashii* and Deccan Mahseer *Tor khudree* (© Vidyadhar Atkore) and bioluminescent fungi, Painted Bats *Kerivoula picta*, Asiatic Long-tailed Climbing Mouse *Vandeleuria oleracea*, a Scorpion *Hottentotta* sp. and Autumn Leaf Butterfly *Doleschallia bisaltide* (© Omkar Dharwadkar).

area is essential. This should provide a thorough understanding of the communities, including their socio-economic conditions, existing infrastructural assets, and the potential socio-economic, cultural, and infrastructural impacts (both positive and negative) of the development. Additionally, the assessment should detail the nature of public consultations conducted and outline the recommendations derived from those engagements.

- Impact on infrastructure, including heritage homes and other spaces of social, cultural and economic importance across the entire railway expansion project has not been considered at all. A submission to the CEC (D'Silva et al. 2021) highlighted that the existing railway line from Vasco to Castlerock in Goa passes through 36 villages and will impact a minimum of 132 structures of socioeconomic and cultural importance. The study used a zone of influence of 200 meters on each side of the railway line. They identified commercial and business sites (37), places of worship (38), public services (27, specifically education and health-related), parks and recreational spaces (15), natural places of interest, including rivers (9) and residential structures with potential heritage status (minimum 6). The report also identified human settlements along the track. The impact far exceeds that considered by the IISc study, which was carried out in merely four villages inside BMWS & NP.
- There has been no acknowledgement of forest-dwelling communities in the EIA. In KTR, there has been an ongoing relocation of families from the tiger reserve, including concerns regarding the breaching of recognition of rights under the Forest Rights Act, 2006. Any assessment for this project must give due consideration to the status of pending claims of forest dwellers under the Forest Rights Act 2006, who face compounded harm, losing access to both forest-based livelihoods and their habitation, whether from 'inviolate areas' or infrastructure projects. Failure to conduct social research is harmful, given the impact that climate change has on marginalised communities (Sultana 2022). It is imperative to adhere to the rigour required of social research around informed consent to understand or assess issues of social justice and human rights of the communities whose livelihoods are dependent on the region to be affected, as failure to do so erodes the rigour of ecological studies more broadly (St. John et al. 2014).
- There has been a complete omission of how the proposed project impacts human-nature relationships and ecosystem services. For example, there is no mention of how the construction of the railway line will affect water quality and the subsequent impacts on river-based livelihoods and subsistence fishing.

Comparison of the EIAs by IISc and WII

The new EIA by WII addresses some gaps in the old EIA conducted by IISc, such as in the vegetation survey, but introduces even more gaps in biodiversity assessments due to methodological deficiencies (Table 1). For example, in their review of the old EIA, Punjabi et al. (2020) pointed out that the methods used in the mammal survey do not account for issues with species detection. However, in the new EIA, the mammal survey continues to ignore this. In another example, the old EIA mentions the use of medicinal plants in the region but fails to assess the railway's impact on these plants, despite concerns for their protection being raised by members of the Kulem Panchayat during a public consultation with the EIA team. The new EIA fails to mention the use of medicinal plants by people within the area.

DISCUSSION

A fundamental flaw in the environmental governance process is that an independent, scientific peer review of EIAs or Biodiversity Assessments is not legally mandated, even though the decision-making process depends on a rigorous assessment of environmental and socio-economic risks of the proposed project. An independent, scientific peer review can act as an important safeguard to prevent biased and poorly applied science from causing irreversible environmental and human harm (Hughes et al. 2024). The paper provides an example of a rigorous peer review of an EIA for the proposed railway double-tracking project through BMWS & NP in Goa and KTR in Karnataka— both part of the Western Ghats biodiversity hotspot. This is the second peer review of the same project; the first one was conducted by Punjabi et al. (2020), for the previous IISc EIA.

Although positioned as a more comprehensive EIA, the 2025 WII EIA repeats many critical shortcomings of the 2017 IISc EIA while introducing new gaps. Across taxa, assessments remain fragmentary and inconsistent: fungi, insects, arachnids, and freshwater fishes are entirely excluded; herpetofauna, bird, and mammal surveys are temporally restricted and taxonomically narrow; and ecosystem-level perspectives like connectivity, functional diversity, and barrier effects are absent. Social impacts, including public health concerns, receive no attention,

Image 2. Sambar and Gaur rail kill photos from the railway line near Tinaighat along the existing railway line in Karnataka, sourced through a Right to Information (RTI) application to the Karnataka Forest Department (Belagavi division) in 2021.

despite being flagged in the earlier EIA by Punjabi et al. (2020). A critical omission is an acknowledgement of the likely harmful impacts of air pollution, particularly caused by the expansion of coal transportation through the study area. Moreover, the EIA was funded by the project proponent, creating an inherent conflict of interest. Such arrangements risk biasing the study to favour approval, as seen in recommendations for mitigation, despite evidence of irreversible ecological damage. Independent assessments are critical to ensure objectivity and accountability.

These findings mirror widespread critiques that EIAs often fail due to weak baseline biodiversity assessments and superficial social impact analysis. Poor scientific design and negligible regulatory effect of baseline studies have been reported in Brazil (Dias et al. 2022). Canadian EIAs show low biodiversity content and mitigation rigour (Gannon 2021), while EIAs for the Great Barrier Reef have been criticized for lacking serious science and robust baselines (Sheaves et al. 2016). Social dimensions are frequently inadequate and lack rigour (Burdge 2002), and systemic inaccuracies and failures remain common in biodiverse regions (Laurance 2022). In India, such concerns were highlighted previously, and with regard to this specific infrastructure project by Punjabi et al. (2020) yet were unaccounted for in the WII EIA. Poor quality EIA studies have also been reported from other irreplaceable, biodiverse parts of India, like the Dibang Valley (Sheth et al. 2020) and the Great Nicobar Island (Perincherry 2022).

Although the WII EIA begins by stating "a pressing need for conservation and development to go hand in hand, complementing—rather than conflicting with each other" (Page 7), its subsequent neglectful analyses appear heavily skewed in favour of ecologically destructive development. This reflects the limitations of the exercise, given that railway projects, like several linear projects, are not mandated to conduct cumulative social or environmental impact assessment studies (Ghosh 2020). The goal of a technical report such as the WII EIA then is found to be restricted to suggestions of mitigation measures even when they themselves caution that their efficacy is subject to complete compliance to these measures. Interestingly, in the vegetation survey, the authors state: "If a new railway line is built parallel to the existing alignment, then it will certainly have a negative impact on the population of endemic and threatened species, most of which are trees and other woody lifeforms such as climbers and shrubs. Since the proposed alignment will be laid by clear felling the strip of vegetation along this stretch, no mitigation measure will help in reducing the negative impact of the proposed railway line on the native vegetation (WII 2025a, page 42)". However, they go on to recommend restoration in another degraded forest patch to "offset" the effects of the doubling project (WII 2025a, page 43). Similarly, in the herpetofauna survey, the authors argue that the railway line between Tinaighat to Kulem drastically impacts amphibians and reptiles throughout the year but go on to suggest mitigation measures in the construction phase (WII 2025a, page 56).

The push for mitigation measures, despite their own evidence regarding the detrimental implications of the project, reflects a global precedent that projects that undergo EIA studies are rarely rejected and are often approved with conditions for mitigation (Fonseca & Gibson 2021). This is concerning amidst globally acknowledged needs to reduce environmental degradation and climate change impacts, and at the least, towards sustainable development. Notably, in its recent meeting dated 26 March 2026, the REC reviewed the WII EIA and observed that the assessment was solely focused on proposing mitigation measures and failed to include a comprehensive analysis of the project's impact on the biodiversity and ecology of the PAs (REC 2026).

In EIAs, mitigation should follow a clear hierarchy of avoid, minimise, restore, and compensate (Arlidge et al. 2018). Impacts must be avoided by reassessing alignments and design options to bypass ecologically sensitive stretches. Only if avoidance is demonstrated to be unfeasible, impacts should be minimised through reduced clearing, seasonal restrictions on construction and introduction of early warning systems to facilitate wildlife crossings, slope-stabilisation and drainage measures to limit erosion and habitat fragmentation (Muliya et al. 2026). Compensatory measures such as biodiversity offsets or compensatory afforestation should be employed only after all avoidance, minimization and restoration options have been demonstrated to be unfeasible. The EIA has failed to propose any avoidance measures, even when their findings caution of irreversible damage. This again points to a policy gap, since the mitigation hierarchy is not codified to the environmental legislation, thereby creating a loophole where conditional approvals for projects can be granted solely by proposing mitigation measures.

In their report, the CEC had observed that "the railway line cuts across the most important animal corridor in the Western Ghats landscape between Karnataka and Maharashtra through the State of Goa and will be a serious impediment for movement of long-ranging animals like tiger and elephant (CEC 2021, page 58)". The objectives of the EIA have not been met as it does not quantitatively predict or assess key anticipated impacts, including loss of landscape connectivity, fragmentation of wildlife corridors, changes in human–wildlife interactions, impacts on human health, impairment of hydrological systems, or increased risks of landslides and erosion in a topographically complex and rainfall-intense region (Karlson et al 2014). The absence of such predictive assessments limits the report's ability to inform decision-making, particularly for a linear infrastructure project traversing a biodiverse and socially inhabited landscape (Cumming & Tavares 2022). While a comprehensive evaluation of these dimensions lies beyond the scope of the present paper, their omission underscores the need for EIAs to move beyond species inventories and towards a robust, integrative impact assessment.

CONCLUSION

The analysis reveals serious scientific shortcomings, including species misidentifications and inaccurate reporting, which raise deep concerns about the credibility and integrity of the assessment process. This paper highlights broader systemic issues like the absence of a legal mandate for including social impact assessments in railway projects and compliance with the mitigation hierarchy. This paper serves as a local response, grounded in field-based observations and contextualized within the broader ecological and societal challenges associated with linear and mega-infrastructure developments—particularly within PAs.

The review of the WII EIA for the railway double-tracking project in BMWS & NP, Goa and KTR, Karnataka raises broader questions around environmental justice as the authors in this paper find themselves contending with the same problem raised five years ago (see Punjabi et al. 2020). Commitments to environmental protection need to be rooted in scientific rigour, accountability and transparency. As scientists and citizens of India, we are also gravely concerned by the inadequacy of the EIA reports, which lack rigour in terms of the science presented.

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Appendix I. New species records from Bhagwan Mahavir Wildlife Sanctuary and National Park and Kali Tiger Reserve (January 2021–August 2025). The list is compiled from peer-reviewed journal articles and government reports.

	Name	Scientific name	Reference
1	Chalcid Wasps	*Antrocephalus dividens*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
2	Chalcid Wasps	*Hockeria manii*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
3	Chalcid Wasps	*Kriechbaumerella pulvinata*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
4	Chalcid Wasps	*Psilochalcis carinigena*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
5	Chalcid Wasps	*Brachymeria bengalensis*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
6	Chalcid Wasps	*Brachymeria euploeae*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
7	Chalcid Wasps	*Brachymeria jambolana*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
8	Chalcid Wasps	*Brachymeria megaspila*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
9	Chalcid Wasps	*Dirhinus anthracia*	Gawas, S.M. & A. Gupta (2024). Taxonomic studies on chalcid wasps (Hymenoptera: Chalcidoidea: Chalcididae) of Goa, India, with an illustrated key to genera and species. *Journal of Natural History* 58(9–12): 342–381. https://doi.org/10.1080/00222933.2024.2315671
10	Gall Midge	*Lasioptera sharma*	Vasanthakumar, D., R. Loganathan & P. Senthilkumar (2024). *Lasioptera sharma*, a new species of gall midge (Diptera: Cecidomyiidae) feeding on *Leea indica* (Vitaceae) in India. *Journal of Threatened Taxa* 16(6): 25465–25469. https://doi.org/10.11609/jott.9036.16.6.25465-25469
11	Lichen	*Malmidea upretii*	Adhikari, R., R. Ngangom, K.K. Ingle, S. Joseph & S. Nayaka (2024). New species and additional records in the lichen genus Malmidea from India. *The Lichenologist* 56(2–3): 47–59. https://doi.org/10.1017/S0024282924000082
12	Lichen	*Pyrenula dissimulans*	Randive, P., G.K. Mishra, S. Nayaka, D.K. Upreti & M. Janarthanam (2021). Pyrenocarpous lichens in Goa with five new records to India. *Plant Science Today* 8(4): 889–899.
13	Beetle	*Sandracottus mixtus*	Deb, R. & K.A. Subramanian (2023). New Record of *Sandracottus* Species (Coleoptera: Dytiscidae) from Western Ghats of India. *Uttar Pradesh Journal of Zoology* 44(21): 10–15.
14	Beetle	*Sandracottus dejeanii*	Deb, R. & K.A. Subramanian (2023). New Record of *Sandracottus* Species (Coleoptera: Dytiscidae) from Western Ghats of India. *Uttar Pradesh Journal of Zoology* 44(21): 10–15.
15	Orchid (Orchidaceae)	*Zeuxine seetharamii*	Betageri, S. & K. Kotresha (2025). *Zeuxine seetharamii* (Orchidaceae): a new species from the Western Ghats, India. *Asian Journal of Research in Botany* 8(1): 152–163 . https://doi.org/10.9734/ajrib/2025/v8i1251
16	Crab	*Ghatiana dvivarna*	Pati, S.K., T. Thackeray, P.P. Bajantri & G.D. Hegde (2022). A new species of the freshwater crab genus *Ghatiana* Pati & Sharma, 2014 (Brachyura: Gecarcinucidae) from the Central Western Ghats, India. *Nauplius* 30: 1–10. https://doi.org/10.1590/2358-2936e2022019
17	Katydid	*Ducetia rohinii*	Banerjee, D., C. Raghunathan, A.N. Rizvi & J. Sengupta (2024). Animal discoveries 2023: new species and new records. Zoological Survey of India, Kolkata, 356 pp.

Appendix II. Large mammal rail kill records from the existing railway line (Hospet-Tinaighat-Vasco). This list was compiled using online news reports in English from the year 2015 to 2025.

Date	News article title	Species	No. of animals	Location	Link
21.ix.2015	Rail lines becoming a death trap for wild animals	Elephant calves	2	near Nagargali and Tavaragatti, Belagavi	https://www.thehindu.com/news/national/karnataka/rail-lines-becoming-a-death-trap-for-wild-animals/article7672505.ece
17.iv.2016	No action on animal Kills on railway tracks	Gaur	`6	Londa-Tinaighat railway line	https://timesofindia.indiatimes.com/city/%20hubballi/no-action-on-animal-kills-on-%20railway-%20tracks/articleshow/51859697.cms
10.x.2017	Elephant dies after being hit by train	Adult elephant	1	near Tavargatti, Belagavi	https://timesofindia.indiatimes.com/city/%20hubballi/elephant-dies-after-being-hit-%20by-train/articleshow/61015190.cms
26.vii.2018	Five animals killed on railway tracks in five years at Mahavir Sanctuary	Sloth Bear, Leopard, Gaur	5	Collem, Bhagwan Mahavir Wildlife Sanctuary	https://timesofindia.indiatimes.com/city/goa/five-animals-killed-on-rly-tracks-in-five-years-at-mahavir-sanctuary/articleshow/65140679.cms
01.iv.2021	Sloth bear found dead on rail tracks	Sloth Bear	1	near Dudhsagar Falls, Mollem National Park	https://timesofindia.indiatimes.com/city/goa/sloth-bear-found-dead-on-rail-tracks/articleshow/81793258.cms
14.iii.2025	Indian gaur killed in rail accident near Londa	Gaur	1	near Londa, Belagavi	https://www.deccanherald.com/india/karnataka/indian-gaur-killed-in-rail-accident-near-londa-3447130

Author contributions: M.M.C. conceived the study, initiated the manuscript, coordinated the overall collaboration and contributed to writing and revisions. S.D. conceived the study and contributed to early development, writing and revision of the work. M.M. co-coordinated the collaboration, expanded the author team, and helped with writing and revision. N.V. conceived the study, provided mentorship and inputs to manuscript development and writing. A.R., N.B., V.A., R.S., J.D., A.K., A.D., A.P., A.G., K.T. contributed thematic expertise, literature synthesis, and drafted specific sections of the manuscript. G.K., P.B., A.B., K.F., O.D., and P.R. contributed thematic expertise.

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ARTICLE

Regional, ecological and biodiversity context of the Kashmir Valley, northwestern Himalaya, India

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Abstract: The Kashmir Valley (Kashmir region) part of the western Himalaya of India is an intermontane basin with an area of around 16,000 km². The valley forms a biogeographic transition between the Palearctic and Oriental realms of the world. The elevation of the valley ranges from 1,100 m to >5,000 m, and the lowest area of the valley is Uri sector, from where the water drains. Due to the strong elevational and climatic gradients, the valley forms a mosaic of temperate forests, subalpine scrub, alpine meadows, glaciers, and a network of internationally important wetlands, including Hokera/Hokersar and Wular. Despite the 19 terrestrial protected areas including national parks and multiple wildlife sanctuaries and conservation reserves, large portions of the species' habitats occur outside formal protection. They are highly exposed to land-use change, unregulated grazing, infrastructure expansion, human-wildlife conflict, and poaching. This study compiled data from published literature, government records, and field-based ecological insights from field studies. This study provides a concise, regional profile of the Kashmir Valley for biodiversity and threatened species study and conservation. The valley's physiography, climate and hydrology, major habitat types and land-use zones, wetlands are summarized. This study also focuses on, the protected-area network, and key conservation priorities for threatened species such as the Hangul (Kashmir Stag) *Cervus hanglu hanglu*, Kashmir Musk Deer *Moschus cupreus*, and Kashmir Markhor *Capra falconeri*. This study aims to support standardized reporting of Kashmir as regional area context and to inform landscape-scale conservation planning that extends beyond protected areas in the Kashmir Himalaya.

Keywords: Biogeographic transition zone, climate refugia, habitat connectivity, human wildlife interactions, landscape conservation, land-use change, Palearctic Oriental transition, protected-area network, Ramsar wetlands, threatened ungulates, transhumant pastoralism.

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Geographic and ecological overview of Kashmir Valley

The Kashmir Valley in India, often called the Vale of Kashmir, is an intermontane basin located in the northwestern Himalaya between 33°20′ - 34°54′ N and 73°55′ - 75°35′ E . The landscape is bounded by the Pir Panjal Range on the south-west, by the Shopian Gulmarg area and the Greater Himalayan Zanskar Range to the north-east, and by the Kishtwar Valley on the south. The valley stretches approximately 235 km in length from southern Kashmir to northern Kashmir, spanning an area of about 16,000 km². The area shows variation in altitude, landscape, and habitat pattern over a very short distance, with a mosaic of habitats occurring within as little as 1 km². Elevations of the landscape ranges from 1,100 m in Uri at the western most point of northern Kashmir. The city and surrounding area have elevation of around 1,500 m which forms the Jhelum River floodplains near Srinagar and Baramulla. The highest elevation regions are towards the Zanskar range to over 5,000 m at the mountain passes in Gurez and Sonmarg. The Jhelum River which serves as the major waterbody originating from a spring at Verinag in southern Kashmir traverses the whole valley and exits at the Uri sector in the northwestern side of Kashmir. The area is the valley's only drainage outlet towards the Indus system (Khajuria et al. 1999; Romshoo et al. 2020). Along its course, the Jhelum River feeds multiple lakes and wetlands, including Wular, Dal, Anchar, Hokersar, and Shallabugh, several of which are designated Ramsar Sites due to their international ecological importance (Jamal et al. 2022). These wetlands of Kashmir are ecologically important and serve as crucial stopover habitats for migratory waterfowl. They form a part of the Central Asian Flyway, hosting hundreds of thousands of migratory birds during winter (Javid & Ahmad 2023; Rahmani & Javid 2023). The climate is temperate, with warm summers and cool to cold winters. There is strong spatial variation in climate, the surrounding mountains experience heavy snowfall often >2–3 m in winter at higher elevations and remains for months to years. The valley floor city and low altitude areas of Srinagar, Bandipora and Baramulla have milder winters with less snowfall and most of the precipitation is in spring and summer. In human dominated landscapes, snow remains on the ground for a week with an average accumulation of less than 0.5 m. This variability, in landscape, is coupled mainly with steep elevational gradients, creating a mosaic of habitats in a relatively compact area.

Biogeographically, the Kashmir Valley lies at southern most end of the palearctic region and northern most end of oriental region (Image 1). The valley is climatically temperate and lies at the crossroads of the western Himalaya and the trans-Himalayan/Central Asian regions. It is part of the Himalayan biodiversity hotspot (Myers et al. 2000) and harbors ecologically important and endemic biodiversity. Due to differences in the climate, the Valley harbors different species than the rest of the country. The valley's floor, low altitude landscape and lower slopes 1,500–1,800 m were historically covered by temperate broadleaf forests and wetlands. Most of the area of this altitude has been modified into habitation, horticulture, farm plantation and agriculture over the centuries (Raza 2011). Middle elevations 1,800–3,000 m are dominated by coniferous forests, e.g., *Cedrus deodara*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana* mixed at some places with broadleaf species *Aesculus indica* and *Juglans regia*. *Quercus* spp., is restricted to few patches in Dachigam National Park. At higher elevations around 3,200–3,500 m, the mix conifer forests give way to subalpine scrub and alpine meadows, stands of birch *Betula utilis* with rhododendron understory mark the tree line zone. Beyond the tree line, grasslands, and summer pastures are the open landscapes and harbor hundreds of seasonal herder families with their livestock in summer season. The pastures end up with the rougher and rocky landscape and seasonal and permeant snow-clad peaks. Floristically, the region is rich with an estimated 3,000+ herbaceous plant species, which have been recorded in Jammu & Kashmir (Dar & Khuroo 2020). The herbaceous strata, include medicinal and endemic plants (Kaul 1997). Some of these form as livelihood for locals by collecting and selling the medicinal plants some of which cost around $100 to 500 /kg.

Traditional land-use practices like transhumant grazing and terrace farming towards the Gurez and Lolab Valley have shaped the landscape in a way that still supports significant wildlife outside dense forests. Expanding human population tourism expansion and agricultural development have led to deforestation and important wetland loss like Shallabugh, Mirgund in parts of the valley. The valley floor around the capital of Jammu & Kashmir, Srinagar City, and the southern districts mostly Pulwama and Shopian, large tracts of forest buffer and wetland buffers have been converted to orchards or settlements over the past few decades; and wetlands like Hokersar have shrunk due to siltation and land reclamation (Mir et al. 2014; Ahmad et al. 2015). Studies indicate that built-up area around protected forests is rapidly increasing, around Dachigam National Park, urban expansion of ~325% was observed over 55 years, contributing to high habitat fragmentation

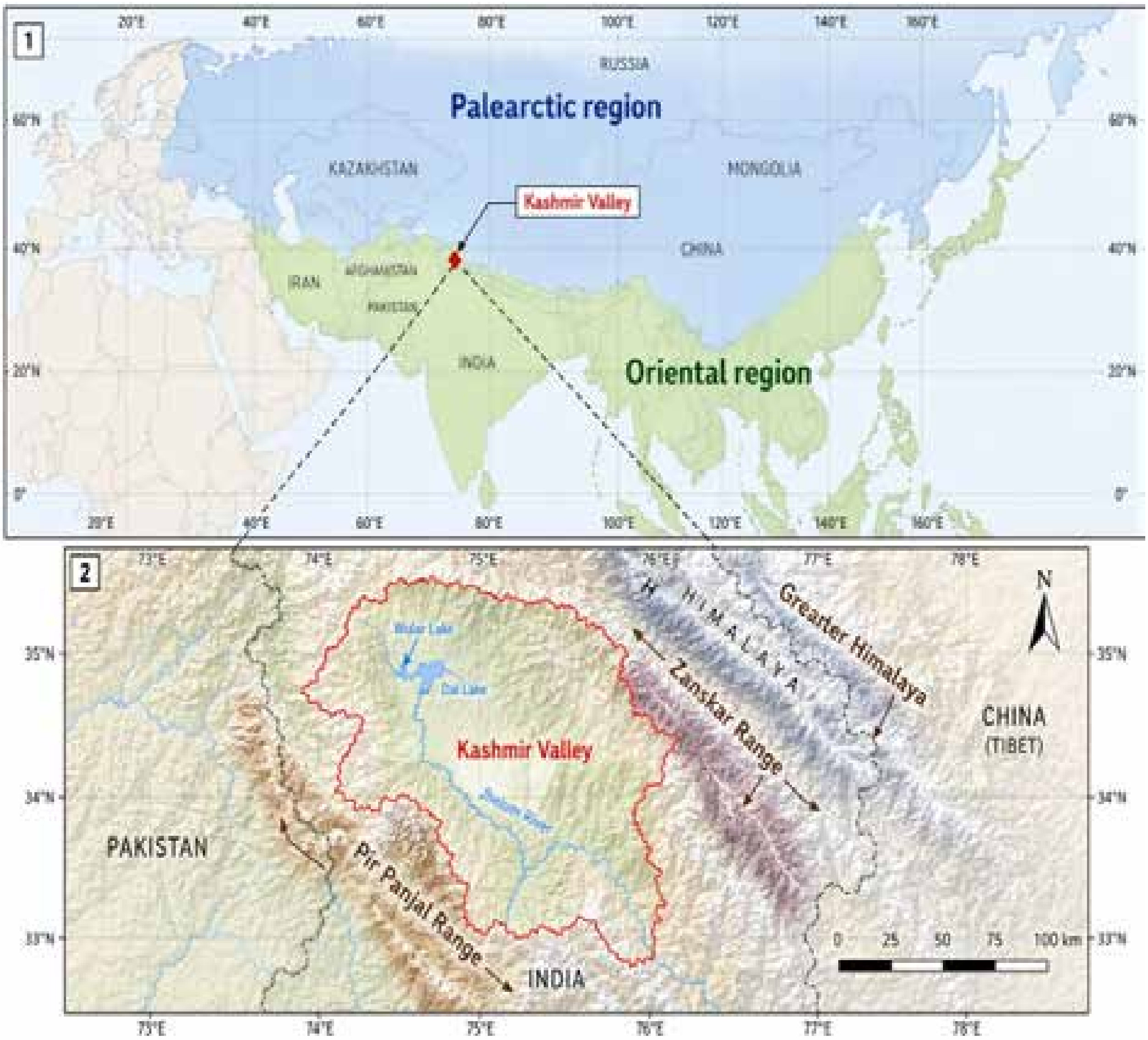

Image 1. Biogeographic position of the Kashmir Valley at the interface of the Palearctic and Oriental regions.

(Aneaus et al. 2023).

Despite these increasing pressures, and land-use conversion about half of the Kashmir Valley remains under natural vegetation cover. Based on the India State of Forest Report (FSI 2021), the Kashmir region has around 50% forest cover, one of the highest proportions in India (Kashmir Life 2024). The forests and other natural habitats of the region support a high diversity of fragile fauna, making the valley a critical refuge for Himalayan wildlife. Some of the species are close to the bottle neck extinction if proper steps are not being taken on time.

Faunal diversity and key species

The Kashmir Valley's diverse and rich habitats support ecologically important assemblage of wildlife, including endemic, charismatic and threatened species. The region is the last stronghold of the Kashmir Stag or Hangul *Cervus hanglu hanglu*, a Critically Endangered only southern Asian red deer species found in and around Dachigam National Park (Ahmad et al. 2016). Hangul migrate seasonally and shows the altitudinal migration between low-elevation riverine forests and highland meadows. Their population has dwindled to few hundreds due to poaching and habitat loss. Dachigam and connected landscapes like Wangat conservation reserve and Tral Wildlife Sanctuary are important landscapes for their long-term survival. Another flagship species is the Kashmir Markhor *Capra falconeri cashmiriensis*, a wild goat with spectacular curved horns. In India, Markhor are now confined to the region only and in Kashmir, further restricted to north-western Kashmir Valley around the Kazinag range along the Line of Control. Kazinag National Park was established to protect the Markhor's last habitat in the valley, and this area also holds other mountain ungulates like Kashmir Musk Deer *Moschus cupreus* and Himalayan Grey Goral *Naemorhedus goral*. Goral is restricted to Lachipora Wildlife Sanctuary and parts of Kazinag National Park.

The Kashmir Musk Deer *Moschus cupreus* is an endangered ungulate endemic to the Western Himalaya (Timmins & Duckworth 2015; Singh et al. 2020). The species is a shy, crepuscular animal known for the male's musk gland. It inhabits high-altitude temperate and subalpine forests, generally between the altitudes of 2,500-4,000 m. Musk Deer are habitat specialists; they prefer dense understory, often in birch-rhododendron, scrub near tree line and steep rugged terrain where they can escape predators. The species occurs patchily throughout the Kashmir Valley and was recorded throughout the valley in upper Dachigam, Sindh Valley thajwas, in the Pir Panjal Range of southern Kashmir, and in Gurez Valley. Reliable data on its distribution and status have historically been scarce due to the inaccessibility of its habitats and decades of sociopolitical conflict in some areas. Camera trapping effort provided new insights, confirming musk deer presence in all major landscapes of Kashmir, including the areas outside formal reserves. Gurez valley was the high abundance zone of the species and lies outside the formal protection. Poaching for musk pods and habitat fragmentation from logging and fuelwood collection are thought to be primary threats to musk deer (Rashid et al. 2015; Jain et al. 2025). Emerging threats from climate change, shifting the tree line and vegetation structure of its habitat will also impact the species over the time (Singh et al. 2020).

Himalayan Ibex *Capra sibirica* is distributed towards the Zanskar Range, including the upper parts of the Sindh Valley and the whole of the Gurez Valley. They prefer the sharp cliffs, and the whole of the population lies outside the protected area network. The abundance of the species gets concentrated in the lower parts of the valley during winter and migrates over the alpine meadows in summer. Our camera traps have documented the species in overlap with musk deer in Gurez Valley and with hangul in the Mammar area of Sindh Valley outside the boundary of Wangath Conservation Reserve. The Himalayan Serow *Capricornis thar* is a rare and secretive goat-antelope inhabiting the forests of Kashmir. Classified as 'Near Threatened', this unusual mammal shows a striking blend of goat-, donkey-, and pig-like features. It prefers steep, rugged slopes in places such as Dachigam National Park and Overa-Aru, and is rarely seen because of its timid behavior and the dense woodland habitat it occupies. The ungulate in Dachigam was sited only during the field survey in April 2023 and a single capture in a camera trap from the Brain Nishat Conservation Reserve.

The Indian Muntjac or Barking Deer *Muntiacus muntjak* is a rare and highly elusive ungulate inhabiting the forested areas of Jammu & Kashmir. Its recent rescue in the Uri sector of northern Kashmir, Baramulla, by the Wildlife Department of Kashmir confirms its presence in the region, although it remains very rarely documented. During the field surveys, this species was not encountered directly, and it was also not recorded in the camera-trap data. This indicates that the Indian Muntjac is either extremely uncommon in the study area or occurs in habitats where the probability of detection is very low. Besides ungulates the Kashmir Valley harbors diversity of other threatened mammals. Asiatic Black Bear *Ursus thibetanus* and Himalayan Brown Bear *Ursus arctos* are both present, at different locations and come in contact in some seasons in landscape of Gurez and upper Sindh valleys. The black bear is common in forest foothills and often raid orchards and villages, whereas the brown bear is found in alpine meadows of upper Sindh and Gurez valleys. The black bear migrates with the herders in late spring and comes back in autumn along with the herd. It escapes the valley heat during summer and the harsh winter in high altitudes. The migration also impacts the brown bear as it migrates further high during summer. Common Leopards *Panthera pardus* and Himalayan Wolf *Canis lupus chanco* are the top predator of the region and have a widespread distribution. Both the predators are distributed throughout the valley but the Himalayan Wolf prohibits to come in direct interaction with humans and avoids the human habitation areas. The negative interactions with the leopard exists throughout the valley and drastic increase in child lifting have happened over the past few years towards the forest fringe villages (Javid et al. 2024a). Occasional reports of the Snow Leopard *Panthera uncia* come from the high mountain passes of Kolahoi, Harmukh, especially in winter when they may descend closer to human habitations, but our camera survey did not capture any Snow Leopard in the valley during 2023–2025. Other carnivores include the Leopard Cat *Prionailurus bengalensis*, Jungle Cat *Felis chaus*, Red Fox *Vulpes vulpes*, Golden Jackal *Canis aureus indicus*, and Yellow-throated Marten *Martes flavigula*. They are distributed throughout the valley and are enemies of the poultry rearing in Kashmir, usually the local farmers who raise in homes. The Eurasian Otter

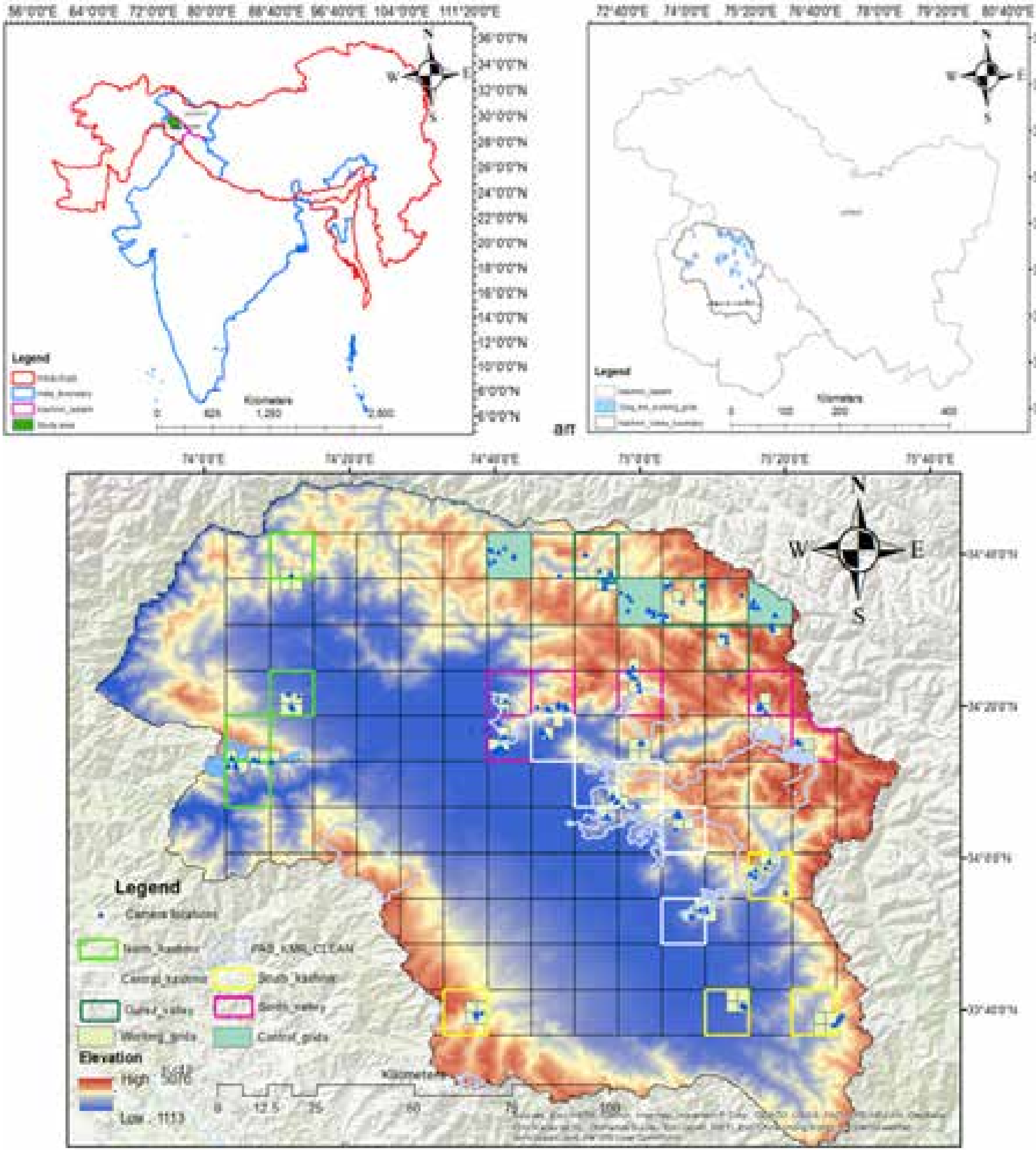

Image 2. Map of the Indian Kashmir Valley showing the five landscape strata, camera trap locations, and major protected areas.

Lutra lutra indicates a healthy trophic web in many areas. It is distributed throughout the valley streams, the highest population is observed in Wular Lake. The diversity of small mammals like pikas, marmots, rodents, bats, and herpetofauna in the valley is less documented but likely high, given the habitat range, the Himalayan Marmot is common in alpine meadows of Sonamarg and Gurez. Other than mammals, eight bat species have been recorded from the Kashmir valley by Malik & Gupta (2020). The checklist of Jammu & Kashmir, including Ladakh, on mammals has reported 112 species of mammals: including 34 globally threatened, with one Critically Endangered, six Endangered, 12 Vulnerable, and eight Near Threatened species (Ahmad et al. 2020). The checklist of Jammu & Kashmir UT has documents 111 species across eight orders and 28 families, with 94 species verified by specimens and 70 by photographic records (Kichloo et al. 2025).

Avifauna of the valley equally important and the valley is home to over 300 bird species (Dar & Khuroo 2020).

The valley harbors species ranging from high-altitude specialists like the Himalayan Snowcock and Golden Eagle, to forest birds like the Himalayan Monal, Western Tragopan, Koklass Pheasant, and the Kashmir Flycatcher an endemic breeder, and migratory and residential wetland birds in the valley's lakes. A comprehensive updated checklist that covers both Jammu & Kashmir Union Territory has documented 599 bird species (Kichloo et al. 2024). Earlier including Ladakh (before reorganization) the checklist has reported 555 birds in 76 families (Suhail et al 2020). The wetlands of Kashmir Wular, Hokersar, Haigam, Shallabugh, and Mirgund are of international importance; they support millions of migratory ducks, geese, swans, and shorebirds in winter and are breeding grounds for species such Mallard, Coot, and Moorhen. The Shallabugh wetland at the mouth of Sindh River, hosts tens of thousands of waterfowl each autumn and spring, making it a vital link in the migratory network (Rahmani & Javid 2023; Javid et al. 2024a). Upland game birds like Chakor Partridge and Himalayan Snow Partridge occur on open slopes.

The Kashmir Valley's fauna reflects its position as a biogeographic transition zone and a Himalayan biodiversity rich region. Many species of the migratory birds Mallard, Northern Showler, Bar-headed Goose use the valley as a corridor and transit between the Himalaya and the plains or between different Himalayan sub-regions. This underscores the importance of maintaining habitat connectivity across the landscape (MOEFCC, 2018; Mukharjee et al. 2021).

Landscapes and land use zones in the valley

For the purposes of ecological sampling and landscape level representation, we stratified the Kashmir Valley into five broad landscapes, based on physiography, land use, and administrative blocks to ensure coverage of the valley's environmental heterogeneity (Image 2). These landscapes are: (i) central Kashmir, (ii) northern Kashmir, (iii) southern Kashmir, (iv) Sindh Valley, and (v) Gurez Valley. They also reflect management units for the presence/absence of species, protected areas distribution and biogeographic differences within the landscape.

Central Kashmir (Central Valley floor) landscape comprises the central part of the valley around the capital city Srinagar, extending southward to the foothills of the Pir Panjal and northward up to the Sindh Valley's mouth. The landscape comprises of the Zabarwan Hills, Dull Lake and other important landscapes. It includes human-dominated areas towns, agricultural land and important protected areas on the fringes. Key area includes Dachigam National Park and its surrounding reserves Bren-Nishat Conservation Reserve, Dara and Khrew areas, which protect the Dachigam landscape and support Hangul, Musk Deer, Himalayan Black Bear, and other fauna. The nearby Tral Wildlife Sanctuary was also included that is situated on the southeastern fringe in the Pulwama District under central Kashmir as that is connected through the upper Dachigam and is similar to the area in context of ecology and habitat. The landscape is characterized by moderate elevation forests (1,600–3,000 m), dominated with orchards, rice fields on the valley floor. The area also comprised the urban and rural areas around Srinagar. The area covering an elevational range from about 1,500 m in city and goes up to 4,500 m. in the nigberan area of upper Dachigam towards Narstan, Zuastan area of Tral tehsil of Pulwama District. Despite being relatively developed in the culture and infrastructure; this central landscape still retains pockets of wilderness. The data shows ~24% of central Kashmir grid samples were alpine meadows or grasslands and ~13% shrubland, often on the higher slopes of Dachigam and Tral. Forest cover (broadleaf and conifer combined) accounted for roughly 26% of this landscape by area, while agriculture and orchards covered ~9% based on our LULC map of the region.

Northern Kashmir (Jhelum Valley & northwestern highlands), the landscape covers northwestern part of the Kashmir Valley along the Jhelum River downstream of Baramulla, extending to the Line of Control (LoC) with Pakistan. It includes the Uri area, Lachipora, Limber area and Kazinag National Park. The area includes the famous Bangus Lolab, Keran Valley in Kupwara District. The Shamsbari range divides the Karnah and Kupwara region. Northern Kashmir is mountainous terrain, excluding the area around the Wular Lake, furcated by the Jhelum and its tributaries. Kazinag National Park (89 km²) lies on the northern bank of the Jhelum River, protecting dense conifer forests and alpine cliffs that are the last viable habitat of the Kashmir markhor in India. Adjacent to Kazinag are the Limber and Lachipora wildlife sanctuaries, also serving as a buffer to the Kazinag National Park and the Naganari Conservation Reserve. Limber and Lachipora hold an abundance of Markhor and Goral, and can act as the best place in Kashmir to start up with nature tourism. In Lachipora, from the terrace of houses, the Markhor and Goral are seen easily and best accessible place to photograph the Markhor. To the west, near the LoC, towards the Tangdar side of Kupwara, is the Bangus valley, a high-altitude grassland basin ringed by forests, known for its meadows. This study explored the area for the first time

Table 1. Ramsar sites and important bird areas of Kashmir, with area, region, habitat significance, and representative avian species of conservation importance.

Site	Region	Area	Bird-importance note	Representative avian species and status
Wular Lake	Kashmir Valley floodplain, northwestern side of Srinagar / Sopore side	18,900 ha	Ramsar since 1990; current BirdLife/ KBA factsheet describes it as an important wintering and stopover wetland that regularly holds >20,000 waterfowl.	Pallas's Fish-Eagle *Haliaeetus leucoryphus* - EN; also supports large numbers of ducks and geese, plus Koklass Pheasant and Himalayan Monal in surrounding habitats.
Hokera Wetland (often written Hokersar/ Hokarsar in bird-area sources)	Western side of Srinagar	1,375 ha	Ramsar since 2005; major resident and migratory waterfowl site, with KBA notes recording up to 25,000 wintering ducks at one time and very large winter counts in some surveys.	Pallas's Fish-Eagle - EN; Ferruginous Duck *Aythya nyroca* - NT; also, Common Teal, Northern Pintail, Mallard, Pheasant-tailed Jacana.
Hygam Wetland Conservation Reserve	Northern side of Kashmir / Baramulla-Sopore side	802 ha	Ramsar since 2022; BirdLife lists Haigam Rakh (marshes) under IBA criteria A1, A4iii. Studies describe it as a major reedbed-waterfowl wetland.	Recent/regularly reported birds include Common Teal, Northern Pintail, Eurasian Wigeon, Mallard; earlier site reports also note Ferruginous Duck (NT) and Pallas's Fish-Eagle (EN) among species recorded from the wetland.
Shallbugh Wetland Conservation Reserve	Central Kashmir / Srinagar-Ganderbal fringe	1,675 ha	Ramsar since 2022; KBA factsheet describes it as an important staging and wintering marsh, with >150,000 ducks and geese recorded at one time.	Ferruginous Duck - NT; also, Northern Pintail, Eurasian Wigeon, Mallard, Garganey, Northern Shoveller, Red-crested Pochard.

for wildlife through camera traps and has documented western tragopan, along with the other important wildlife species. The area has no official protected status yet, and is also home for endangered Kashmir Musk Deer, also a buffer to the Kazinag Markhor Landscape. People revealed that they have sighted Markhor in the area in earlier times. Northern Kashmir experiences harsh winters with snow up to 2 m at higher elevations and pleasant summers. The area covering elevation ranges 1,100–4,500 m. The lowest altitude point of the valley also falls in this landscape, from where the whole water of the Jhelum catchment drains to Pakistan. Land cover is a mix of coniferous forests and alpine meadows, with relatively less agriculture than the central or southern landscapes. Most farming is confined to narrow river valleys like Uri and Teetwal. The environmental analysis indicates the human footprint is moderate here mean human footprint index of ~11,800, intermediate among landscapes. Most of the population lives in rural villages and a high army presence along the LoC, but large tracts of forest and pasture still remain roadless. Wildlife in northern Kashmir from our cameras confirmed species like Common Leopard, Black Bear, Red Fox, Markhor, Coral, Musk Deer in this region.

Southern Kashmir (Pir Panjal Range) towards the Anantnag, Shopian, and Kulgam. The landscape covers the southern end of the valley and the Pir Panjal Mountain ranges that separate Kashmir from the Jammu region. The landscape gives two entry passes to the Kashmir from rest of the India, through Banihal towards the Ramban side and Mughal Road towards Rajori side. The area connects Kashmir with the Kishtwar Valley through Simthan top, the part of the Rajparian Wildlife sanctuary. It is a region of steep valleys and include Lidder, Bringhi, Veshu draining into the Jhelum, and hosts some important protected areas. Overa-Aru Wildlife Sanctuary (near Pahalgam in Anantnag District), Rajparian Wildlife Sanctuary (Daksum in the Bringhi Valley), and Hirpora Wildlife Sanctuary (a high-altitude reserve in Shopian District along the Mughal Road). These protected areas range from temperate forests to alpine meadows and collectively form a crucial habitat for Hangul in Overa-Aru, which is connected with Dachigam and a secondary Hangul site. This is considered the old corridor of Hangul connecting the Kishtwar landscape. The landscape serves as the habitat for Kashmir Musk Deer, Kashmir Markhor in the Hirpora towards Mughal road and Tatakuti, brown bear in the upper range of the Pehalgam area. Southern Kashmir also has heavily populated areas and significant human pressures, for example, the Achabal Conservation Reserve (CR) and Khiram CR cover foothill forests surrounded by a mosaic of orchards, pasture, and military establishments in Achabal. The area ranges in altitude from 1,600 m at Anantnag urban area to 4,800 m towards the Pir Panjal Mountain range. The area spans over the farmlands to alpine pastures in mosaic habitat conditions. This region showed a relatively high wilderness index (mean ~0.75) despite human presence. The high wilderness value is because of the presence of the inaccessible Sanctuary areas like upper Hirpora and Overa Aru, and the Simthan region that is closed for part of the year and that has limited road access to most of the regions. Still, lower elevations of southern Kashmir are quite impacted, e.g. the Anantnag has extensive apple orchards and villages. The land cover analysis for our South Kashmir grids showed ~33% alpine meadows/shrub, ~10% dense conifer forest, and over 15% agriculture/horticulture, especially in the lower Lidder and Shopian areas. The South Kashmir's Pir Panjal meadows are the entry point for the seasonal herders in the valley and receive the herders from late spring when herders enter the valley to late autumn when herders leave the valley. The area is seasonally used by large numbers of nomadic herders (Gujjars and Bakarwals) who bring flocks of sheep and goats in summer for grazing and escape the harsh summer of the Jammu region of Jammu & Kashmir. This seasonal grazing is a prominent land-use in the Pir Panjal range and has implications for wildlife like musk deer, markhor, leopard, wolf, and bears.

Sindh Valley (Sind River Basin), throughout the Ganderbal District. The area is a distinct sub-valley branching north-east from central Kashmir, following the Sindh River. The valley starts from the Jhelum at Shadipora up to the Zojila Pass towards Ladakh. It is often considered the ecological backbone of central Kashmir due to its connectivity and habitat diversity. Elevations in Sindh range from ~1,600 m at the mouth near Shallabugh area to ~3,600–4,500 m at Sonamarg and Baltal, where it gives pass to Ladakh with surrounding peaks over 5,000 m. The valley is flanked by the Zanskar Range to the northern side and a corridor through the Thajwas Glacier to the Pir Panjal in the south. The Sindh Valley contains a mix of coniferous forests mix deodar and Wallichiana forests in the lower reaches, alpine meadows like Sonamarg's famous grasslands and the connecting Gurez landscape, which forms a long stretch of grass meadows. The area harbors high altitude lakes like Gangabal and Vishansar. The human settlement is concentrated along the Sindh River, forming a stretch of habitation over a 70 km length. It is a crucial corridor for trade and wildlife. Historically the Zojila Pass at its head was part of ancient trade routes connecting Kashmir with Tibet and Central Asia. Key protected areas in the Sindh region include Thajwas Baltal Wildlife Sanctuary near Sonamarg, and Wangath Conservation Reserve in a side valley, Naranag Pandaw Temple. The Sindh Valley also adjoins the Overa-Aru and pehalgam landscape through the Baltal area via mountain passes, making it a potential wildlife corridor. Land cover in Sindh sampling was quite varied: dense forests in some lower segments, but a high proportion of alpine pastures (~36%) and shrublands (~11%) at middle-high elevations, plus rocky areas at the high-altitude landscape. Increased human footprints are present towards the tourist area villages like Kullan, Gund, Sonamarg tourist hub, and a highway to Ladakh, but large areas remain wilderness (mean wilderness index ~0.71). The Sindh Valley is rich in wildlife the cameras recorded Musk Deer, Hangul, Leopard, Black Bear, Brown Bear, Martin, Marmot, Himalayan Ibex and Red Fox frequently. The area favors movement of Hangul Deer between Dachigam and Wangat Sindh area through connecting ridges. The valley's high-altitude lakes, Gangbal, Gadsar, Vishansar, Krishansar, and Satsar lakes and alpine meadows, Mohan Marg, Lal Marg, Mengandob, Gangbal, Salnai around Harmukh Range are used by herders in summer. The meadows are culturally important, but raises concern of competition with wild herbivores and disturbance. The dogs with the herd are of main concern for wildlife conservation and pose a significant threat.

Gurez Valley, the extension to the Nelam Valley of Pakistan, (high northwestern frontier) forms the northernmost extension of Kashmir. The valley is an isolated high-elevation landscape running parallel to the main Sindh Valley but separated by the vast Harmukh Range. The Razdan Pass is the highest pass that connects the valley with other parts of Kashmir region through Bandipora. The valley remains detached from other parts of Kashmir during winter and the army operated helicopters are the only source of transportation. Gurez is drained by the Kishanganga River and in Pakistan its Neelum River. The river flows westward from the Kabul Gali the valley west most point into Pakistan. Elevations in inhabited villages of Gurez range from ~2,300 m at Dawar (the main town) to ~3,500 m at the highest village Checkwali towards the west most point. The valley is surrounded by mountains exceeding 5,000 m. This valley is particularly remote and wild it lies along the Line of Control and until 2019 it was mostly off-limits to tourism. There is not a single notified wildlife protected area in Gurez, yet while as it harbors some of the highest quality habitats and threatened flora and fauna in the region. Extensive birch forests, present in rills of the small narrow valley alpine shrublands, and undisturbed meadows characterize Gurez valley. The human population density in the area is very low, villages are small and scattered and the locals migrate to other parts of Kashmir during winter. From our survey about 65% of the families migrate in winter to district Ganderbal and Bandipora. Livelihoods traditionally revolve around subsistence agriculture (potatoes, pulses) and pastoralism (Sultan et al. 2019). Most of the youth is working with army as porters and daily labors, this study found that people are interested in ecotourism through homestay and nature guides. Gurez had the highest wilderness index of all

Table 2. Protected areas and wetlands of the Kashmir region with their area.

	Protected area / wetland	Category	District	Area (km²)
1	Dachigam National Park	National Park	Srinagar / Pulwama	141
2	Kazinag National Park	National Park	Baramulla	90
3	Overa-Aru Wildlife Sanctuary	Wildlife Sanctuary	Anantnag	425
4	Rajparian (Daksum) Wildlife Sanctuary	Wildlife Sanctuary	Anantnag	20
5	Gulmarg Wildlife Sanctuary	Wildlife Sanctuary	Baramulla	180
6	Limber Wildlife Sanctuary	Wildlife Sanctuary	Baramulla	21
7	Lachipora Wildlife Sanctuary	Wildlife Sanctuary	Baramulla	37
8	Hirpora Wildlife Sanctuary	Wildlife Sanctuary	Shopian	341
9	Thajwas (Baltal) Wildlife Sanctuary	Wildlife Sanctuary	Ganderbal	203
10	Tral Wildlife Sanctuary	Wildlife Sanctuary	Pulwama	154
11	Achhabal Conservation Reserve	Conservation Reserve	Anantnag	20
12	Khrew Conservation Reserve	Conservation Reserve	Pulwama	50
13	Khonmoh Conservation Reserve	Conservation Reserve	Pulwama	67
14	Brain-Nishat Conservation Reserve	Conservation Reserve	Srinagar	16
15	Khimber-Dara-Sharazbal Conservation Reserve	Conservation Reserve	Srinagar	34
16	Wangat Conservation Reserve	Conservation Reserve	Ganderbal	12
17	Ajas Conservation Reserve	Conservation Reserve	Bandipora	48
18	Naganari Conservation Reserve	Conservation Reserve	Baramulla	22
19	Salim Ali City Forest National Park	National Park	Srinagar	8.69
20	Hokera / Hokersar Wetland Reserve	Ramsar wetland	Srinagar / Budgam	14
21	Hygam Wetland Reserve	Ramsar wetland	Baramulla	8
22	Shallabugh Wetland Reserve	Ramsar wetland	Ganderbal	17
23	Mirgund Wetland Reserve	Wetland Reserve	Baramulla	4
24	Malgam Wetland Reserve	Wetland Reserve	Bandipora	3
25	Chatlam Wetland Reserve	Wetland Reserve	Pulwama	0.426
26	Manibugh Wetland Reserve	Wetland Reserve	Pulwama	0.053
27	Kranchoo Wetland Reserve	Wetland Reserve	Pulwama	0.064
28	Freshkori Wetland Reserve	Wetland Reserve	Pulwama	0.1525
29	Wular Lake	Ramsar wetland	Bandipora / Baramulla	189

landscapes mean index of ~0.82, with most of the areas virgin and essentially pristine. Over one-third of the Gurez landscape is open meadows, and another ~25% is alpine scrub or bare rock; forest cover is patchy (~13% combined conifer and mixed forest) and largely confined to lower slope birch/conifer groves. Despite the lack of formal protection, Gurez serves as a vital refuge for wildlife. These surveys and other recent studies show Kashmir Musk Deer thrives in Gurez's birch forests and subalpine zones, which likely represent some of the best remaining musk deer habitat. Other species documented in camera are Himalayan Brown Bear, Himalayan Ibex, Eurasian Otter, Yellow-throated Martin. There are some local evidences of Snow Leopard but our camera traps did not record. The Snow Leopard is well reported and more frequently recorded just across the LoC in Pakistan's Neelum Valley. The absence of large-scale development has kept Gurez ecologically intact. Apart from a hydroelectric project on the Kishanganga and its associated infrastructure development residential and administrative, is increasing the fragmentation in the landscape. Being outside the protected area network, it does not remain distant from conservation programs but also implementation of the wildlife laws. The high wilderness value of Gurez underscores the importance of integrating such unprotected valuable landscapes into regional conservation planning.

Protected areas and land management

From the early maharaja time the Kashmir Valley have, many bird and animal protected areas where were conserved for royal hunting only. After recognizing the Kashmir Valley's ecological significance, a network of protected areas (PAs) has been established throughout the valley over the past century. These areas include national parks, wildlife sanctuaries, conservation reserves, and wetland reserves. As of 2025, the valley contains three national parks and eight wildlife sanctuaries, along with 13 conservation reserves and several Ramsar wetlands and IBA sites (Farooq et al. 2021). The total area under this wildlife protection network in region is about 2,171 km², which forms approximately 13.57% of the geographical area of the Kashmir Valley. This is slightly below the current Kunming–Montreal GBF Target 3 (30% by 2030) for terrestrial protection, but comparable to the average for mountainous regions in India. The PAs in Kashmir are not contiguous, they are distributed throughout the landscapes in pockets mentioned above, often separated by valleys with human settlements.

Major protected areas Dachigam National Park (141 km², established in 1981), situated on Srinagar's outskirts, is the flagship park of Kashmir, famous for Hangul Deer. Dachigam ranges 1,700–4,200 m, encompassing habitats from riverine forest to alpine meadow (Ahmad et al. 2016). It is IUCN Category II and has a well-defined core zone closed to grazing, surrounded by buffer conservation reserves. The Dachigam's upper catchment extends into Thajwas CR, Tral wildlife sanctuary and Sindh Valley. Despite legal protection, Dachigam faces pressures from encroachment and resource extraction on its fringes mostly in Upper Dachigam area.

Kazinag National Park (90 km², est. 2007) in Baramulla district along the LoC, was created by merging some part of the Lachipora and Limber Sanctuaries and adjacent forests. Kazinag harbors the only viable Indian population of Markhor. It's terrain (1,800–4,300 m) includes steep cliffs and river gorges. Due to security restrictions, access is limited, which has inadvertently kept human disturbance low. But in the Lachipora B area and Harbaji Bahak, the area is invaded by the seasonal herders. Kazinag is part of a larger transboundary conservation landscape contiguous with protected areas in the Hattian Bala District of Pakistan-occupied Kashmir, with the Qazinag Game Reserve.

Overa-Aru WS (425 km²) in Pahalgam area of Anantnag District, which, despite its name, covers a large area of the Lidder basin including forests and alpine zones of Aru and Olvera. The sanctuary is an Important Bird Area also. Hirpora WS (341 km²) in Shopian, covering the high-altitude Pir Panjal meadows and known as a corridor for markhor moving between Kashmir and Jammu regions Tatakuti WS. The efforts have not captured Markhor in camera trap over a survey period of two months March–April 2025. Tral WS (154 km²) in south-central Kashmir, protecting forest hills in Pulwama. The sanctuary is the second top refuge for Hangul and conservation breeding programme for Hangul have been started there in shikargah area of the Sanctuary. Gulmarg WS (180 km²) in the Pir Panjal northwestern side of Srinagar, is known for its alpine pasture and fauna like Kashmir Musk Deer and pheasants. The sanctuary is highly fragmented by the tourism and the Gandola (cable car) service, snow seeking and ATV operation make it un available for most of the wildlife. Thajwas Baltal WS (203 km²) at the western most point of Sindh Valley around Sonamarg tourist spot, which protects glaciers and meadows on the way to Zojila. The sanctuary is important corridor for the wildlife and harbors the highest abundance of the Musk Deer in sarbal area. Rajparian WS (20 km² official, though an expansion has been proposed) in the southeastern valley, important for musk deer connectivity. The sanctuary is highly disturbed by the presence of sheep form the sheep husbandry department. The sheep farm lures the Himalayan Wolf and can serve the best spot to work the Himalayan Wolf. In addition, there are wetland reserves, Hokersar, Shallabugh, Haigam, and Mirgund, each just a few to a few dozen square kilometers, designated to protect waterfowl habitats. But the fluctuation in the seasonal waters and encroachment have disturbed them to the maximum of its possible extent.

The Wildlife (Protection) Act 1972 provides for community co-managed areas called Conservation Reserves (CR). In Kashmir, these include forest patches and earlier maharaja time game reserves like Bren Nishat CR (16 km²) and Khimber-Dara CR on Srinagar's periphery (buffering Dachigam), Ajas CR (48 km²) in Bandipora, Naganari CR (22 km²) in Baramulla (buffer to Kazinag), Achabal CR (20 km²) in Anantnag and others. These CRs often serve as buffer corridors for NP and WS and corridors to connect larger PAs or protect smaller habitat fragments. Although legally protected, the level of protection is low compared to national parks/ sanctuaries, traditional activities and even development can occur, subject to proper permission from authorities.

Overall, the protected area network in Kashmir is ecologically representative of the region's biodiversity to an extent. But requires policies on herder movement and their carrying capacity. Protected areas cover alpine zones, temperate forests, and wetlands. They harbor threatened and endemic species (Hangul, Markhor, Musk Deer, Himalayan Brown Bear, Western Tragopan, pheasant) find refuge in these PAs. The network also has gaps and need to be addressed in future for long term conservation. Entire landscapes like Gurez valley remain unprotected, and some PAs are small isolated (e.g., the wetland reserves, Naranag, Ajas, Achabal CR and Gulmarg, Rajparian WS). Furthermore, most PAs in Kashmir were delineated several decades ago, and there is evidence that environmental conditions have since changed. Some protected areas are facing the highest rate of exploitation from the tourism; these areas should be delaminated from the wildlife protected areas and a new area nearby should be delaminated in exchange. Forest cover and tree line have shifted upward in some areas due to climate change (Pandit et al. 2014), and intense development has occurred around PA boundaries (leading to edge effects). Some wildlife populations have moved outside original PAs in response to these changes or due to population recovery in surrounding areas. Hangul Deer once thought confined to Dachigam (Ahmad et al. 2023), this study has recorded Hangul in adjoining landscapes™ like Tral WS and even outside PAs in Wangath and Kangan areas of Sindh Valley, likely dispersing in search of suitable habitat for future sustenance. Similarly, our camera-trap data show Kashmir Musk Deer more presence in unprotected forests of Gurez and Tulail, highlighting that viable habitats exist beyond the current PA network (Table 2).

In context of landscape level assessment the study treats the entire Kashmir Valley as a single, integrated landscape for conservation analysis. While protected areas are crucial cornerstones but differences between sites inside vs outside PAs were not evaluated, focusing solely on PAs would overlook large portions of wildlife habitat in the valley and may ignore the species presence outside the PAs. Animal do not know the boundaries they search for the quality habitats. High-quality habitats and wildlife occurrences even fall in multiple-use zones or community lands. In fact, quantitative analysis of a wilderness index was made from remoteness and human footprint. The index which reveals that Gurez Valley, with no formal protection, has the highest wilderness score then all other landscapes (mean index ~0.82), exceedingly even the well-protected Dachigam landscape scored (~0.66). This indicates that some unprotected areas in Kashmir are as undisturbed or even less disturbed than the protected areas. Focusing conservation only within PAs boundaries is not sufficient for long-term biodiversity conservation in the region.

Another factor is climate change, which is expected to alter species distributions in the Himalayas. A recent modeling study by Singh et al. (2020) projected that by 2050s–2070s, suitable climate habitats for Kashmir Musk Deer will shift, and only about 4% of the species future climatic refugia lie within the current protected area network. This stark finding implies that ~96% of musk deer's potential refugia under climate change are outside present PAs network. This underscores the need for connectivity and protection beyond existing PA boundaries. As temperatures rise, many species in Kashmir may move to higher elevations or more northerly which are less disturbed areas in the valley. Species ensure that they can safely move through corridors like the Sindh Valley or the Pir Panjal range, and that destination habitats like Gurez are safeguarded, is critical.

Over the past decade, intensive land- use change happened due to human greed, the conversion of the fallow and fodder cultivation land to horticulture. This decreased the buffer between the habitation and forests, which provided the pseudo-habitat for the wildlife species. Protected areas also adopted changes in land use and habitat quality since PAs were established due to climate change in precipitation. Logging is prohibited inside PAs, but often continues in adjacent forests, which changes the microclimate inside the protected areas. The change sometimes makes the habitat inside PAs actually less favorable. Unmanaged vegetation is more susceptible for the natural fire which can act as deterrent for wild animals like bears compared to surrounding lightly used forests where a mosaic of vegetation exists. Some protected stands have aged without much undergrowth, reducing forage for deer, whereas community-managed forests may still maintain varied structure due to controlled grazing and extraction (Javid et al. 2024b). Managed and controlled grazing can be favorable for the vegetation in context of dispersal of palatable plant seeds (Sultan et al. 2019). In certain cases, wildlife especially wide-ranging herbivores and carnivores now spends significant time outside PAs in these surrounding landscapes which may offer ample forage or lower intra-specific competition. The Gurez and Tulail valleys, for example, have become safe zones for species like Musk Deer and Brown Bear simply because human presence is low. They lack legal protection, leaving them vulnerable to future development or poaching if not proactively managed.

Environmental covariates for the study were derived for each site from remote-sensing data using Sentinel-2 satellite imagery from October 2024 to quantitatively represent habitat differences (European

Space Agency 2015). Land use/land cover (LULC) for Kashmir was generated using supervised classification of the satellite imagery supported by ground-truthing (Maxwell et al., 2018). Topographic variables such as elevation and slope were derived from the ASTER global digital elevation model (ASTER GDEM) (Abrams et al. 2022). Anthropogenic variables, including distance to the nearest road and distance to settlements, were measured as Euclidean distances from road and village layers, while the human footprint index was extracted from a global human footprint dataset for 2020 across the landscape (Venter et al. 2016; Gassert et al. 2023). A wilderness index was computed for different landscapes, scaled from 0–1, by combining factors such as remoteness from roads and the lack of human modification, following established wilderness-mapping approaches (Radford et al. 2019). As noted, this index varied significantly among landscapes, with Gurez and parts of Sindh scoring very high, whereas central and north Kashmir scored lower in the analysis.

Major threats and conservation priorities

Key pressures on biodiversity in the Kashmir Valley include habitat fragmentation from road construction and human settlement growth. The seasonal herder grazing adds the fine scale competition between the livestock and wildlife. Livestock forms a major component of the rural and pastoral economy of Kashmir. According to the latest released official livestock data for Jammu & Kashmir from the 20th Livestock Census (2019), the Union Territory had cattle 2,539,240; buffalo 690,829; sheep 3,247,503; goats 1,730,218 (Department of Animal Husbandry and Dairying, 2021; PIB, 2023). Seasonal pastoralism is equally prominent practice in the Kashmir Himalaya, where transhumant Gujjar and Bakarwal herders move with their livestock from the Jammu region to the Kashmir Valley and high-altitude pastures in spring, and descend again in autumn with the onset of snowfall (Choudhary 2022; Daily Excelsior 2023). Government reporting on the autumn migration revealed that, in 2023, transport support was provided to 12,497 tribal families and 1,56,215 livestock moving from Kashmir Valley back to Jammu, highlighting the continuing scale and significance of this biannual herding system (HT Correspondent 2023; Daily Excelsior 2023). A proper root should be delineated for the herders to enter Kashmir all the landscapes should not be opened to the threat as the livestock carry diseases and pests. Madhaya pradesh grazing rules 1986 have proper delineated routes for the herders Published vide Notification No. F-7-1-84-10-3, dated 30 June1986, published in M.P. Rajpatra (Asadharan), dated 30 June 1986 at page 1057. The already framed policy should be revised for the Kashmir in context of the conservation of the threatened species.

The human wildlife negative interactions involving carnivore lifting child or livestock and crop-raiding is increasing over the time in the Kashmir Valley. This becomes a big challenge for wildlife department over the years. Human-wildlife negative interactions from Asiatic Black Bears and Common Leopards in the Kashmir region is a major conservation and livelihood issue (Choudhury et al. 2008; Moten et al. 2017). A decade-long study in the Kashmir Valley indicated a rise in interaction-related injuries, with bear attacks being the most prevalent, succeeded by leopard attacks (Moten et al. 2017). Autumn from August to October as the harvesting season is high risk season for people working outdoors in orchards (Javid et al. 2024b). A comprehensive assessment of the Kashmir Valley, involving over 200 victim interviews and more than 100 site visits, revealed that approximately 47.26% of bear incidents occurred in agricultural fields and orchards, while around 52% of leopard attacks transpired near human habitations. This study also identified bear-conflict hotspots in the Tral-Khrew and Kulgam regions, and leopard-conflict hotspots in Kupwara, Handwara, Bandipora, and Shangus (Choudhury et al. 2008). A household-level survey conducted around Dachigam National Park indicated that 44.82% of respondents experienced crop damage and loss of domestic animals, 26.25% reported a direct threat to humans, and livestock predation reached its highest point in summer at 58.4% (Dar et al. 2022). An 11-year study in and around Hirpora Wildlife Sanctuary found 634 cases of injury (Bhat et al. 2022). Black bears caused 56% of the injuries and leopards caused 44%. The study also found that injuries decreased as people moved away from forests (Tariq et al. 2022). Recent official numbers from Kashmir media show that human-wildlife negative interactions killed 264 people and hurt 3,164 people between 2006 and March 2024. A different report said that since March 2023, nine people have died and 51 have been hurt in Kashmir alone, showing that the problem is still very serious (The Tribune 2023; Kashmir Life 2024).

In 2022, under a National Mission on Himalayan Studies (NMHS)-funded waterfowl migration project, the Division of Wildlife Sciences, SKUAST-Kashmir, deployed satellite Platform Transmitter Terminals (PTTs) on selected migratory waterbirds. One transmitter was fitted to a Northern Shoveler *Spatula clypeata* and another to a Greylag Goose *Anser anser*. The transmitter attached to the Northern Shoveler remained operational for approximately four months; tracking data and subsequent field information indicated that the bird was killed in the Hajin area of Wular Lake. The Greylag Goose was also reportedly killed within one week of transmitter deployment, resulting in the premature termination of its tracking record due to poaching pressure. PTTs were installed on three Ibisbills *Ibidorhyncha struthersii* in 2023 and are functional from more than two years. The species is generally not targeted for poaching or human consumption.

Poaching is also a big threat; the winter migrant birds are on high threat in all the wetlands of Kashmir. Division of wildlife Sciences SKUAST-Kashmir installed PTT on waterfowl to study the migratory route of the species but unfortunately, they were killed by poachers in a month or two. Our camera traps revealed 16 photographs of active poachers from the field most of them were target poachers with proper professionalism. The poachers particularly threaten musk deer, pheasants and other high-value species. Wetlands face additional pressures from encroachment. The Jammu & Kashmir government has revealed that an area of 19,501.87 ha of forest land in J&K Union Territory has been encroached. Of the total forest land under encroachment, 5,891.49 ha of forest land is in Kashmir while the rest in Jammu region (Down to Earth 2026). Water and soil pollution, hydrological alteration, and invasive vegetation like Alternanthera *philoxeroides* (alligator weed), *Myriophyllum aquaticum*, and *Nymphoides mexicana* (Javid et al. 2024c). Ramsar-designated wetlands require sustained catchment-scale management to maintain their ecological character (MoEFCC 2025).

Climate change is expected to amplify risk to the wildlife and its habitat by shifting tree lines, altering snow regimes, and changing seasonal availability of forage and water. These changes may increase spatial overlap between wildlife and livestock and intensify conflict in forest mosaics and along forest edges. The distribution of seasonal herders and wildlife both depends in summer on water. Herders prefer the area where their livestock can drink freely and they make temporary shelters at the close water places. These shelters become deterrent for the wildlife and forces them to go beyond the area. Over the time water flow is decreasing in Kashmir and some of the permanent streams are becoming seasonal due to the change in show regime and early melting.

Priority actions for the region include: (i) identifying and safeguarding movement corridors for movement of wildlife without resistance from livestock between protected areas and high-value unprotected habitats; (ii) strengthening community-based governance for conservation reserves and wetland reserves; (iii) improving livestock management through seasonal zoning, grazing regulation, and disease-risk mitigation, and there migration routes; (iv) maintaining wetland ecological character through catchment-scale water and pollution management; and (v) standardizing landscape-scale biodiversity monitoring using repeatable designs and open reporting of sampling effort and context.

CONCLUSION

The Kashmir region is a globally significant Himalayan landscape that combines strong environmental gradients with high human dependence on natural resources. Its biodiversity values extend beyond the protected-area network and include wetlands of international importance and extensive unprotected forest and alpine habitats.

A standardized regional profile can improve comparability among studies and strengthen management relevance for threatened-species research in the Kashmir Himalaya. Long-term persistence of threatened species in the Kashmir region will depend on integrating protected-area management with connectivity conservation, wetland stewardship, and collaborative governance beyond protected areas.

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ARTICLE

Metabarcoding-based diet characterization of the Kolar Roundleaf Bat *Hipposideros hypophyllus* Kock & Bhat, 1994 (Chiroptera: Hipposideridae) and its peninsular Indian congeners

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Abstract: We used faecal DNA metabarcoding to analyse the diets of the Kolar Roundleaf Bat *Hipposideros hypophyllus*, and its three congeners (*H. durgadasi*, *H. fulvus*, & *H. speoris*) cohabiting a roost in Kolar District (Karnataka, India). We collected faecal pellets of these bats returning to the roost after the first feeding bout over three seasons between 2021 and 2022. The whole diet of all these species consisted of 7,309 Operational Taxonomic Units (OTU) belonging to phylum Arthropoda. Although no significant difference among the whole diets of the four species was found, *H. hypophyllus* consumed the most amount of insect taxa (4,114 species) compared to others. The core diets consisted of 48 taxa belonging to 10 orders, 37 families, and 46 genera. A significant difference was found between the core diets, with *H. hypophyllus* and *H. speoris* feeding on more diverse insects; diets did not overlap, hinting that the study species are diet specialists. Prey species belonging to orders Lepidoptera and Diptera were abundant in the diet of all four species of bats. The core diet of the Kolar Roundleaf Bat varied significantly between the seasons, with ≥70% intake of lepidopterans in the monsoon and winter seasons. All four species fed on medically and agriculturally significant insect pests as well, indicating their role as bio-controllers in this ecosystem. This study, the first of its kind in India, is an initial exploration of the use of non-invasive diet characterisation for enhancing our knowledge of the ecological interactions of endemic and threatened bat species in sensitive and diverse ecosystems.

Keywords: Biocontrollers, core diet, endemic and threatened, faecal analysis, *Hipposideros durgadasi*, *Hipposideros fulvus*, *Hipposideros hypophyllus*, *Hipposideros speoris*, insect pest, leaf-nosed bat, whole diet.

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INTRODUCTION

Comprising more than 1,500 species worldwide, bats constitute 22% of global mammalian diversity (Upham et al. 2024). The majority of bat species are insectivorous, consuming invertebrates up to 70–80% of their body weight during their numerous feeding bouts each night (Kurta et al. 1989; Kalka et al. 2008; Kunz et al. 2011). Much research has highlighted the beneficial effects of bats and their ecosystem services, especially as biocontrollers of pest insects (Leelapaibul et al. 2005; Cleveland et al. 2006; Boyles et al. 2011; Kunz et al. 2011; Wanger et al. 2014; Puig-Montserrat et al. 2015; Taylor et al. 2018; Kemp et al. 2019; Linden et al. 2019). Despite this diversity and ecological significance, there exists a shortfall in the knowledge of diets of most insectivorous bats (Adams & Sandbrook 2013; Tuneu-Corral et al. 2023).

Effective conservation prerequires an understanding of the ecological interactions of any species (Adams & Sandbrook 2013), and the diet of an animal is a vital interaction to understand (Whitaker Jr. 1988; Racey et al. 2003; Clare 2014; Groom et al. 2017; Cravens et al. 2018) as the quality and quantity of food resources available for an animal are crucial both for individual- and population-level survival (Eeva et al. 1997; Vickery et al. 2001; Taylor & Schultz 2008; Sorensen et al. 2009; Johnsen et al. 2017; Serrano-Davies & Sanz 2017). Due to their diverse diets and varied foraging ranges, bats consume diverse insect species, and the ecosystem services that they provide cannot be compensated by predators such as birds; the loss of such services leads to increased insect pest abundance, reduced crop production, increased use of pesticides, and deleterious effects on the health of the habitat, ecosystem, and humans (Maas et al. 2013; Maslo et al. 2017; Scholz & Voigt 2022). Additionally, bats provide value to the ecosystems as primary, secondary, and tertiary consumers sustaining both unmodified natural and human-dominated landscapes (Kunz et al. 2011). They help maintain diversity of the forests by seed dispersal, introduce novel plant species, maintain genetic diversity of flowering plants (especially those that bloom exclusively at night), and redistribute nutrients through their guano (Kunz et al. 2011).

However, identifying and analysing the diet of bats is complicated due to their highly mobile nature (Painter et al. 2009). The most widely used approach to assessing bat diets is through the analysis of faeces, either through 'classical' methods such as manual dissection of faeces, or more modern approaches including molecular analysis of DNA: bat faeces contain the DNA of the species that produced them as well as the remains (and consequently the DNA) of prey insects (Reed et al. 1997). As classical methods usually result in relatively coarse family- or even order-level identification of remains (with many unidentifiable fragments), DNA-based methods are increasingly used (Zeale et al. 2011; Clare et al. 2014; Krüger et al. 2014; Foo et al. 2017; Krauel et al. 2018; Scholz & Voigt 2022) mainly due to the higher taxonomic resolution and detection rates of rare or overlooked prey taxa (Clare et al. 2009, 2011; Ashrafi et al. 2011; Razgour et al. 2011; Krüger et al. 2012; Clare 2014; Vesterinen et al. 2013; Vesterinen et al. 2016; De Sousa et al. 2019; Gordon et al. 2019; Hayes et al. 2019).

Of the 153 species of bats extant in South Asia (Srinivasulu et al. 2025), only the Kolar Roundleaf Bat *Hipposideros hypophyllus* has been assessed to be 'Critically Endangered' by the IUCN Red List (Chakravarty et al. 2015). Its only known roost is a single subterranean cave on a granite hill in the vicinity of Hanumanhalli Village in the Kolar District of Karnataka, southern India, and the population has been estimated to be around 200 individuals (Srinivasulu et al. 2014). Since its 'rediscovery' in 2014, significant steps have been taken for its conservation, including the designation of the roost and its environs as a conservation reserve, and the inclusion of the species in the Indian Wildlife (Protection) Amendment Act, 2022, granting it the highest legal protection by the Government of India. It shares its roost with Durga Das' Roundleaf Bat *Hipposideros durgadasi* (VU; Mishra & Dookia 2016), the Fulvous Roundleaf Bat *Hipposideros fulvus* (LC; Srinivasulu & Srinivasulu 2018), and Schneider's Roundleaf Bat *Hipposideros speoris* (LC; Srinivasulu & Srinivasulu 2019). This study explores the diets and variations therein of the highly threatened Kolar Roundleaf Bat and congeners in its only known roost. It is an initial exploration of the potential dietary niche of this sensitive and endangered species alongside its congeners, aiming to provide a vital foundation for future conservation management and policymaking to ensure the continued survival of this species and the health of this multispecies colony and its surrounding ecosystem.

MATERIALS AND METHODS

Study area

The study site, Hanumanahalli Betta (near Hanumanhalli Village, Kolar District, Karnataka, India; 13.16° N, 78.29° E) is a monolithic granite hill with a single narrow subterranean cave housing the only known population of the 'Critically Endangered' Kolar Roundleaf Bat *Hipposideros hypophyllus* (Srinivasulu et al. 2014). The general habitat surrounding the hill is comprised of scrublands with scattered boulders and hills, agricultural lands, and patches of reserve forest dominated by tropical dry deciduous and tropical thorny forest vegetation (Champion & Seth 1968; Srinivasulu et al. 2014), with small rain-fed waterbodies located just beside the hill and scattered in the study area.

Fecal sample collection

Between April 2021 and March 2022, individuals of each of the four study species (*Hipposideros hypophyllus* (Image 1), *H. durgadasi* (Image 2), H. *fulvus* (Image 3), & *H. speoris*) (Image 4) were captured from the cave using mist-nets and were handled strictly according to the ethical and responsible handling practices outlined in the American Society of Mammalogists guidelines (Sikes & American Society of Mammalogists 2016 – importantly including double-layered gloves and masks) to ensure minimal stress and exposure. All collections and surveys were conducted under express permission from the Karnataka State Forest Department (No. PCCF(WL)/E2/CR/2016-17, dated 19.i.2022 vide Government Order No. FEE 404 FWL 2014, dated 20.i.2015), Government of Karnataka. The experimental protocols and procedures were reviewed and approved (59A/CBCS/OU/2021-22) by the Research Committee of Centre for Biodiversity and Conservation Studies, Osmania University, Hyderabad. The study is reported in accordance with ARRIVE guidelines.

Mist-nets were erected after the bats had completed their emergence and were returning from their feeding bouts. Bat emergence times were initially determined based on Srinivasulu et al. (2014) and confirmed based on active echolocation call analysis. Echo Meter Touch 2 Pro (Wildlife Acoustics Inc., USA) and u384 USB ultrasound microphone (Pettersson Elektronik, AB, Uppsala, Sweden) ultrasound detectors were used at the entrance/exit points to determine bat species identity based on call frequencies, corroborated by published data (Srinivasulu et al. 2016). We captured four individuals of each species, which were safely held in clean cloth bags for 30 minutes or until they voided 3–5 faecal pellets each, and were then released back near the roosting site. The pellets were pooled by species (and by season for *Hipposideros hypophyllus*) and placed in vials filled with RNAlater stabilization solution (Invitrogen) for DNA extraction.

DNA extraction

DNA was extracted from bat faecal samples using Qiagen QIAamp fast DNA stool mini kit. The method of DNA extraction involved bead-beating, use of QIAamp fast DNA Stool Mini Kit and RNase treatment. From the collected faecal samples, an aliquot of the stool sample (500 µl) was pipetted into a micro-centrifuge tube using a cut tip. About 3.1 ml of InhibitEX buffer was added to each stool sample and vortexed continuously for one minute until thoroughly homogenized and sample was incubated at 70°C for 10 minutes. The samples were treated with 200 µl of lysozyme (10 mg/ml) and incubated at 37°C for 30 minutes. Around 4–5 stainless steel beads were added, and bead-beating was performed for five cycles (Vortex at maximum speed for one minute, resting time 5 minutes). The tubes were allowed to cool on ice for 2–3 minutes and centrifuged at 16,000 xg for 5 minutes at 4°C. The supernatant was transferred to a fresh 2 ml Eppendorf tube. To the cell pellet 200 µl of lysozyme was added, followed by incubation at 37°C for 30 minutes. The bead-beating step was repeated for three cycles in the following scheme: vortex at maximum speed for one minute, resting time five minutes. The Eppendorf tube was centrifuged at 16,000 xg for 5 minutes at 4°C and the supernatant was transferred to a fresh 2 ml Eppendorf tube. The supernatant obtained from the earlier steps was pooled, and 20 µl proteinase K and 200 µl buffer AL was added, the tubes vortexed for 15 seconds and incubated at 56°C for 2 h. The supernatant was treated with 30 µl of RNase A and incubated at 65°C for 30 minutes. The lysate was thoroughly mixed with half volume of absolute ethanol and loaded into a QIAamp spin column placed in a 2 ml collection tube. The collection tube was then centrifuged at ≥ 6,000 xg for one minute and the flow-through was discarded. To the column, 500 µl Buffer AW1 was added and centrifuged for one minute at ≥ 6,000 xg and the flow-through was discarded. 500 µl of Buffer AW2 was added and centrifuged for one minute at 20,000 xg and the flow-through was discarded. This step was repeated twice. The QIAamp spin column was placed in a new 2 ml collection tube, and a dry spin was performed by centrifuging at 20,000 xg for one minute. The QIAamp spin column was then transferred into a new labelled 1.5 ml microcentrifuge tube, and the DNA was eluted by adding pre-warmed 30-50 µl 10 mM Tris HCl (pH 8.0), directly on the QIAamp membrane and incubated at room temperature (25°C) for 5 min. The microcentrifuge tube was centrifuged at 20,000 xg for one minute, and the DNA pellet was retained. The concentration and purity of genomic DNA was quantified using a nanodrop

Image 1. *Hipposideros hypophyllus.*

Image 2. *Hipposideros durgadasi.*

Image 3. *Hipposideros fulvus.*

Image 4. *Hipposideros speoris.*

spectrophotometer. The integrity of DNA in the sample was confirmed using gel electrophoresis and the DNA concentration was quantified using a Qubit dsDNA HS assay kit.

Library Preparation

Genomic DNA was amplified for COI gene using ANML LCO1490 and COI-CFMRa primers with KAPA HiFi

HotStart PCR Master Mix (KAPA Biosystems, USA). The forward and reverse primer concentrations were kept at 5 µm each. A 25 µl PCR was setup using 12.5 µl of the 2X KAPA HiFi HotStart Ready mix, 10.5 µl of the genomic DNA and nuclease-free water and one µl each of the forward and reverse primers using a two-step protocol: 94°C for one minute for initial denaturation, followed by 94°C for one minute, 45°C for one minute 45 seconds and 72°C for one minute and 15 seconds for five cycles; 94°C for one minute, 51°C for 30 seconds, 72°C for one minute and 15 seconds for 35 cycles followed by a final extension step of 72°C for 5 minutes. The amplicons were visualized on 1.2% agarose gel and purified using Sera-MagTM Select beads (Cytiva). Sequencing libraries were prepared with Illumina-compatible NEXTflex Rapid DNA sequencing Bundle (BIOO Scientific, USA) at Genotypic Technology (Bangalore, India). 100 ng of Qubit quantified purified amplicons were end-repaired, adenylated, and ligated to Illumina multiplex barcode adaptors as per NEXTflex Rapid DNA sequencing bundle kit protocol. Illumina universal adapters used in the study were:5'-AATGATACGGCGACCACCGAGATCTACACTCTTT CCCTACACGACGCTCTTCCGATCT-3' and index adapter: 5'-GATCGGAAGAGCACACGTCTGAACTCCAGTCAC [INDEX] ATCTCGTATGCCGTCTTCTGCTTG-3'.

Adapter-ligated fragments were purified using Sera-Mag™ select beads (Cytiva). Resultant fragments were amplified for six cycles of PCR using Illumina-compatible primers provided in the NEXTflex Rapid DNA sequencing Bundle. Final PCR products (sequencing library) were purified with Cytiva beads followed by library quality control. Sequencing libraries were quantified by qubit fluorometer (ThermoFisher Scientific, USA) and the fragment size distribution was analysed on Agilent 2200 TapeStation. The libraries were paired-end sequenced on Illumina HiSeq X Ten sequencer (Illumina, USA) for 150 cycles following the manufacturer's instructions. The raw sequencing data was demultiplexed using bcl2fastq software v2.20 (Illumina, USA). The sequencing quality (base call accuracy and adapter contamination) was assessed using FastQC v0.11.8 software (Andrews 2010). The adapter sequences were trimmed using TrimGalore (Felix 2015) and bases above Q30 were considered for downstream analysis. The high-quality processed reads were stitched using Fastq-join (Aronesty 2013).

The centrifuge tool (Kim et al. 2016) was used to align the trimmed reads against centrifuge-NT database. This database is designed to facilitate the classification and identification of sequences in metagenomic and microbiome datasets. It contains reference sequences from a wide range of organisms, including bacteria, archaea, viruses, and eukaryotes, classifying from kingdom to higher taxonomic ranks. Centrifuge is a very rapid and memory-efficient system which uses a novel indexing scheme based on the Burrows-Wheeler transform (BWT) and the Ferragina-Manzini (FM) index, optimized specifically for the metagenomic classification. Pavian (Breitwieser & Salzberg 2020) was later used to estimate and interactively explore the taxonomic content. Only matches with a similarity level of 95% or higher were considered significant and retained during the alignment process. The sequences generated in this study are deposited in NCBI database (BioProject accession number PRJNA1281322).

From the classified report, OTU IDs were assigned using kraken-biom Python tools. kraken-biom parses the k-reports, counts for each operational taxonomic unit (OTU), and includes lineage information. The extracted OTU from the kraken-report is then stored in a BIOM (Biological Observation Matrix) table, linking each count to the respective sample and OTU. The final obtained OTU-specific read abundance was used for further analysis. The frequency of occurrence of each OTU (or taxa) in the diet of each bat species studied was calculated as percent relative abundance (i.e., each OTU's read abundance divided by total read abundance of each bat species multiplied by 100).

Niche overlap and niche breadth

Pianka's niche overlap and Levins' niche breadth were calculated using spaa package in R (Zhang & Ma 2014). The values of the niche breadth obtained were standardised to get values between zero and one using the Levins' index equation (B_A= B-1/n-1; (Levins 2020)). We performed a non-parametric analysis of variance of relative prey-item read abundance (number of reads for a prey species divided by total number of reads) grouped by bat species (for both whole and core diets) to investigate if the dietary composition differed between the four species of bats, and diversity indices (for both whole and core diets) to investigate the diet breadth of each species in PAST statistical software (Hammer et al. 2001). We used RAWGraphs 2.0 (Mauri et al. 2017) to visualize the whole diet and the core diets of the four species of hipposiderid bats across three seasons (summer, monsoon, & winter).

RESULTS

Of the 18,483,216 raw reads generated, only those with a taxonomic identity match percentage of > 95%

were retained, resulting in 17,360,540 reads post-processing. The final processed reads were further checked against the records available from India on the public data portal of the BOLD and GenBank databases. We obtained 17,179 records corresponding to 4,177 species (combined data from BOLD and GenBank databases), which were further filtered to obtain a final 7,309 OTUs (Supplementary Tables 1,2).

Table 1. Niche overlap (Pianka's overlap index – 0 indicates no overlap, 1 indicates full overlap; top right values represent the whole diet; bottom left values represent the core diet) of the four *Hipposideros* bat species in the study.

Species	*H. hypophyllus*	*H. durgadasi*	*H. fulvus*	*H. speoris*
H. hypophyllus	-	0.03183	0.02088	0.00086
H. durgadasi	0.02586	-	0.00012	0.00110
H. fulvus	0.01580	0.0	-	0.00116
H. speoris	0.0	0.0	0.0	-

Dietary analysis

The final dataset of whole diets of the four hipposiderid species revealed that our samples of *Hipposideros hypophyllus* comprised the most insect diversity (4,114 species), followed by *H. durgadasi* (2,410 species), *H. fulvus* (1,945 species), and *H. speoris* (1,160 species). No significant difference among the diets of the four species of bats was found (Kruskal-Wallis $H[2] = 5.407$; $p > 0.05$).

From the whole diet dataset, we filtered out frequently consumed prey-items (≥ 1% frequency of occurrence); this was classified as the core diets of the four species of hipposiderid bats. In the core diets of the four species, we identified 48 taxa belonging to 10 orders, 37 families, 46 genera, and 48 species. A significant difference was found among the core diets of the four hipposiderid species (Kruskal-Wallis $H[2] = 22.81$; $p < 0.05$). Variation between the core diets of the four study species accounted for 22.8% of the total

Image 5. Prey taxonomic diversity in the core diet of *Hipposideros hypophyllus*. The circles represent taxonomic ranks (Order, Family, Genus).

variation, while the rest (77.2%) was due to within-group variance. *Hipposideros hypophyllus* and *H. speoris* consumed 17 taxa each, while *H. durgadasi* consumed eight taxa, and *H. fulvus* consumed six taxa of insects. Pairwise comparisons using Dunn's test highlighted a significant difference ($p < 0.05$) between the diet of *Hipposideros speoris* and that of *H. hypophyllus* and *H. fulvus*. There was no overlap in the whole and core diets between the four study species (Table 1), and all four species showed a high degree of specialization in the dietary items they consumed in both whole and core diets (Table 2).

Core diets

In the core diets of all four hipposiderid bat species, prey belonging to orders Lepidoptera and Diptera were consumed to a greater extent in comparison to other insect orders which is common for any bat species (Ingala et al. 2021). The core diet of *Hipposideros hypophyllus* consisted of four insect orders with lepidopterans figuring majorly in its diet with six families followed by the three other insect orders (Image 5). The core diet of *Hipposideros durgadasi* consisted of taxa exclusively belonging to the orders Lepidoptera (4 families) and Diptera (1 family) (Image 6). *H. fulvus* fed on five insect orders including two families of lepidopterans and the other insect orders in equal measure (Image 7). While the core diet of *H. speoris* was very diverse and comprised eight insect orders lepidopterans were fed upon more in comparison to the rest of the insect orders (Image 8).

Amongst the lepidopteran families consumed by these four species of hipposiderid bats, the most consumed was the family Noctuidae, followed by Pyralidae, Gelechiidae, Geometridae, Papilionidae, and Elachistidae. The least consumed families were Tineidae and Nolidae (Image 9). *Hipposideros hypophyllus* preferred prey items belonging to the family Noctuidae (30.90%), followed by Papilionidae (7.89%), Elachistidae (6.70%), Pyralidae (5.03%). Prey items belonging to families Geometridae and Nolidae combined contributed to 3.59% of the diet of this species. *H. durgadasi*

Image 6. Prey taxonomic diversity in the core diet of *Hipposideros durgadasi*. The circles represent taxonomic ranks (Order, Family, Genus).

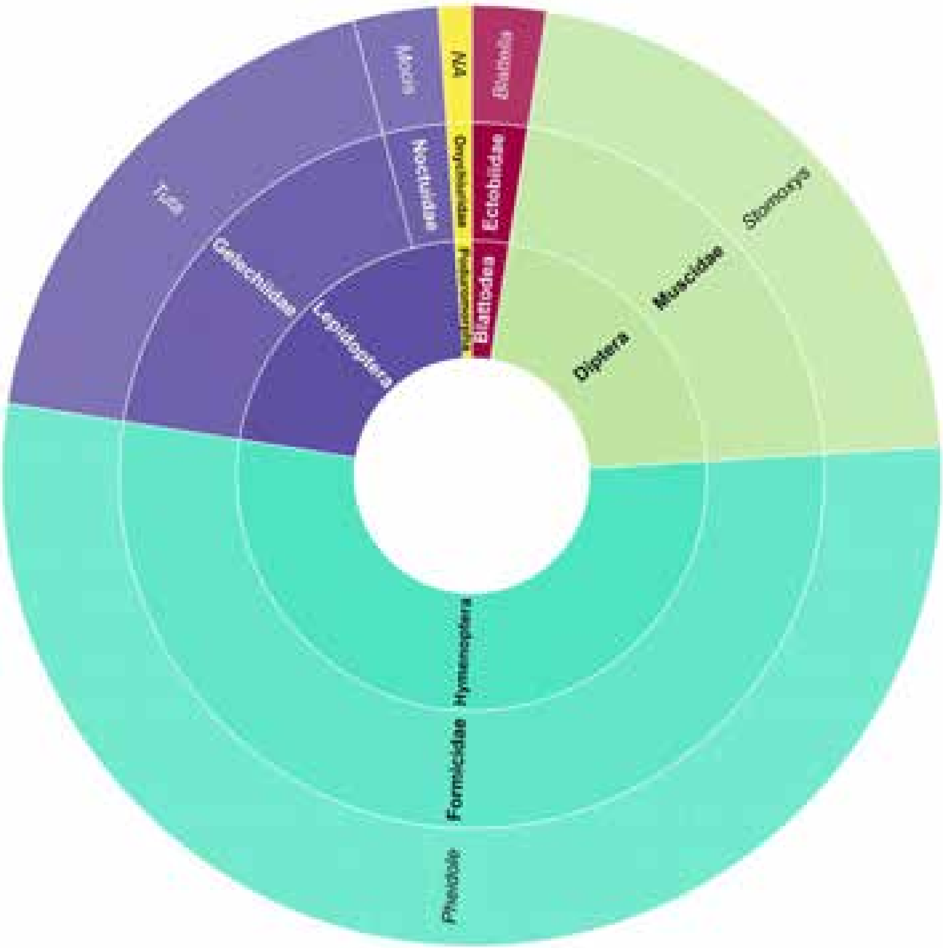

Image 7. Prey taxonomic diversity in the core diet of *Hipposideros fulvus*. The circles represent taxonomic ranks (Order, Family, Genus).

consumed prey items belonging to the family Pyralidae (43.9%), followed by Noctuidae (25.85%), Geometridae (10.58%), and Tineidae (1.65%). *H. fulvus* consumed prey items belonging to the family Gelechiidae (16.95%), followed by Noctuidae (2.67%). The least consumption of lepidopteran prey was by *H. speoris* with the family Pyralidae (3.39%), Gelechiidae (1.78%), and Noctuidae and an unclassified family (combined amounting to 2.05%).

Among the dipteran families, these hipposiderid bat species consumed families Chironomidae, Muscidae, Culicidae, Asilidae, Calliphoridae, Sciaridae, and Tabanidae (Image 10). *Hipposideros hypophyllus* consumed the family Chironomidae (16.20%), followed by Asilidae (2.88%), and Sciaridae (1.35%). *H. durgadasi* consumed the least number of dipterans and fed only on the family Calliphoridae (2.30%). Similarly, *H. fulvus* fed only on the family Muscidae (19.68%), while *H. speoris* fed on Culicidae (5.86%), Chironomidae (3.94%), and Tabanidae (1.10%).

Table 2. Niche breadth (Levins' index – 0 indicates specialism, 1 indicates generalism; top row represents the whole diet, bottom row represents the core diet) of the four *Hipposideros* bat species in the study.

Species	*H. hypophyllus*	*H. durgadasi*	*H. fulvus*	*H. speoris*
Whole diet	0.00237	0.00134	0.00115	0.00448
Core diet	0.42540	0.25349	0.28695	0.21752

Diversity indices

The degree to which a species influences other species in the community (or makes up most of the biomass) is quantified by the dominance index (Di), where Di ≤ 0.50 indicates no species dominates, 0.50–0.75 indicates moderate dominance of a given species, and 0.75–1 indicates high dominance. None of the study species were found to be dominant in their whole diet [Di (*H. fulvus*) = 0.31; (*H. durgadasi*) = 0.23; (*H. speoris*) = 0.16; (*H. hypophyllus*) = 0.09]. Diet species diversity

Image 8. Prey taxonomic diversity in the core diet of *Hipposideros speoris*. The circles represent taxonomic ranks (Order, Family, Genus).

is quantified by Simpson's diversity index, where an index of ≤ 0.50 indicates low diversity, between 0.50–0.75 indicates moderate diversity, and between 0.75–1 indicates high diversity. Simpson's diversity index for the whole diet showed a high diversity of diet in *Hipposideros hypophyllus* (0.91), followed by *H. speoris* (0.84), and *H. durgadasi* (0.76). However, the diet of *H. fulvus* was relatively less diverse (0.69). Shannon's H index of species diversity ranges between 1.5 and 3.5 and rarely exceeds 4.5; the Shannon index of the prey species in the four study species' whole diets shows that *Hipposideros hypophyllus* (H = 3.05) fed on highly diverse dietary items, followed by *H. speoris* (H = 2.75), *H. durgadasi* (H = 2.38), and *H. fulvus* (H = 1.75).

In the core diets of the four study species, the dominance index (Di) showed no dominant species [Di (*H. fulvus*) = 0.37; (*H. durgadasi*) = 0.33; (*H. speoris*) = 0.21; (*H. hypophyllus*) = 0.12]. Simpson's diversity index showed a high diversity in the core diets of *H. hypophyllus* (0.87) and *H. speoris* (0.79), and moderate diversity in *H. durgadasi* (0.67) and *H. fulvus* (0.63). Shannon's H index showed that *H. hypophyllus* (H = 2.39) and *H. speoris* (H = 2.05) had a diverse diet, while *H. durgadasi* (H = 1.44) and *H. fulvus* (H = 1.22) had a relatively low diversity of insect species in their core diets. The core diets of *H. hypophyllus* and *H. speoris* included six species of pest insects each, while that of *H. durgadasi* and *H. fulvus* included three insect pest species each (Supplementary Table 3).

Seasonal variations in Hipposideros hypophyllus diet

The whole diet of our sampled *H. hypophyllus* individuals (N = 4) over summer, monsoon, and winter seasons showed no significant difference (Welch F-test: $F = 2.79$, $p > 0.05$). In the summer season, the diet was dominated by lepidopteran prey species (35.81%), followed by the orders Diptera (31.80%), Blattodea (20.72%), Coleoptera (2.96%), Mantodea (2.52%), followed by other insect orders. The monsoon diet was dominated by Lepidoptera (92.80%), followed by Diptera (1.5%) and other insect orders. The winter

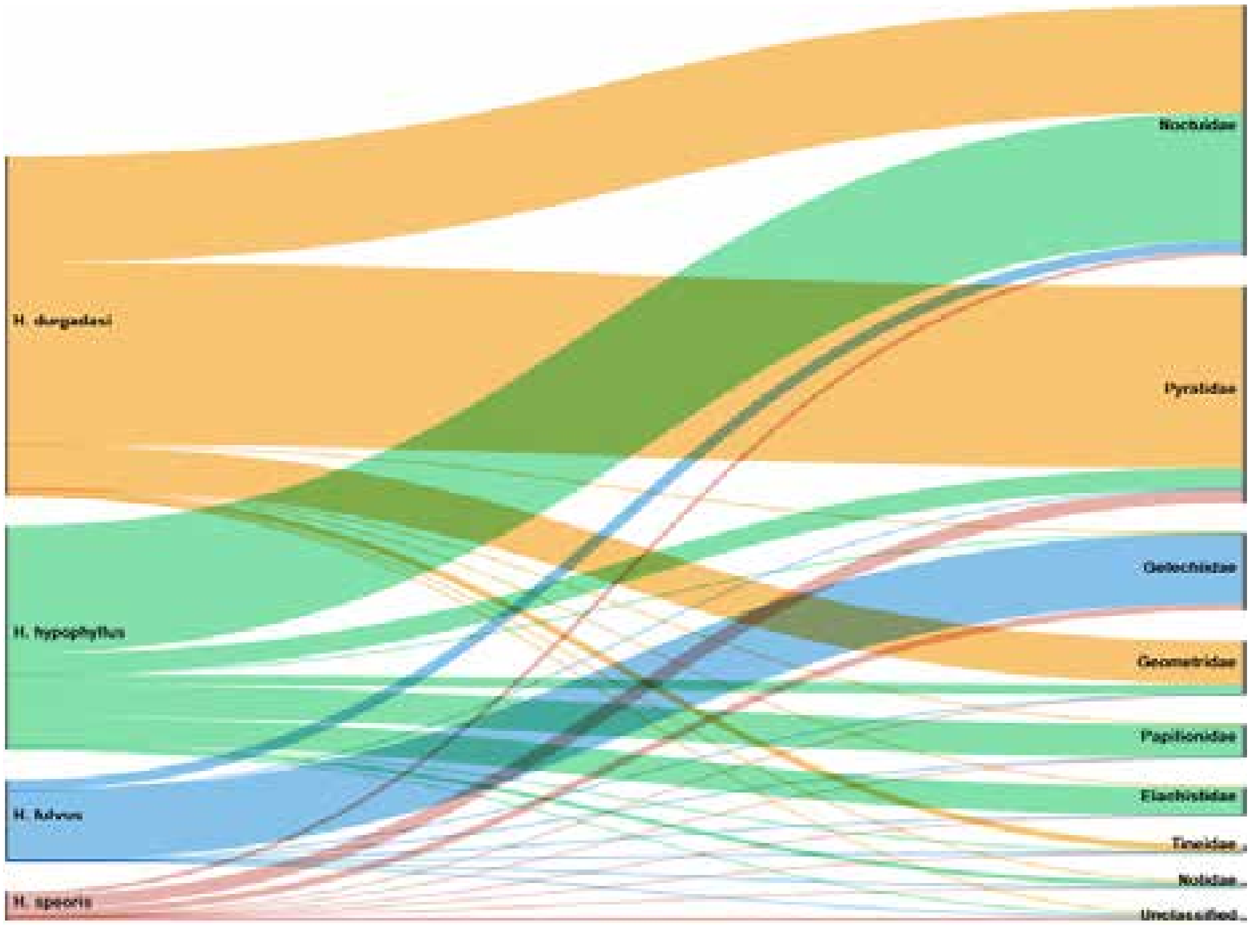

Image 9. Associations between bats (left) and lepidopteran insect prey taxa summarized at the taxonomic level of family (right). The connecting bar width represents the relative read abundance of each insect family between each bat and each dietary item.

diet was similarly dominated by the order Lepidoptera (85.82%), followed by Diptera (12.86%) and other insect orders (Image 11). The core diet of *H. hypophyllus* over the three seasons showed a significant difference (Welch F-test: $F = 3.99$, $p = 0.05$). The summer diet of *H. hypophyllus* sampled in the study period was dominated by the order Lepidoptera (32.70%), followed by Diptera (29.37%), Blattodea (20.72%), and Coleoptera (2.12%). In the monsoon, the diet was comprised mostly by lepidopteran prey (74%), while in the winter it consisted of orders Lepidoptera (82.68%) and Diptera (12.58%) (Image 12).

DISCUSSION

Despite the diversity of insectivorous bats in southern Asia (Srinivasulu et al. 2025), studies on insectivorous bat diets are sporadic and scattered, often employing either gut content analysis (Advani 1981) or faecal pellet dissection (Whitaker Jr. 1988), which is more common due to its non-invasive nature (Kunz & Whitaker Jr. 1983; Dickman & Huang 1988; Whitaker Jr. 1988). Studies conducted on the faecal pellets or echolocation of some roundleaf bats in southern Asia have provided a broad understanding of their diets. For instance, studies based on the flight behaviour and echolocation calls of *H. fulvus* mentioned that it may prefer feeding on cockroaches and beetles, and on insects of intermediate size to avoid competition with other sympatric species such as *H. ater* and *H. speoris* (Madhavan et al. 1978; Jones et al. 1994). Khajuria (1980) states that the diet of *H. durgadasi* is similar to *H. fulvus*, and they likely feed on small insects such as beetles and small crickets. *H. speoris* was observed to feed on mosquitoes and flies (Brosset 1962), and beetles and other low-flying insects, especially termites (Phillips 1980). Jones et al. (1994) predicted it to feed on large-bodied insects based on its echolocation. There have been no studies yet on the diet of the Kolar Roundleaf Bat, however, Kock & Bhat (1994)

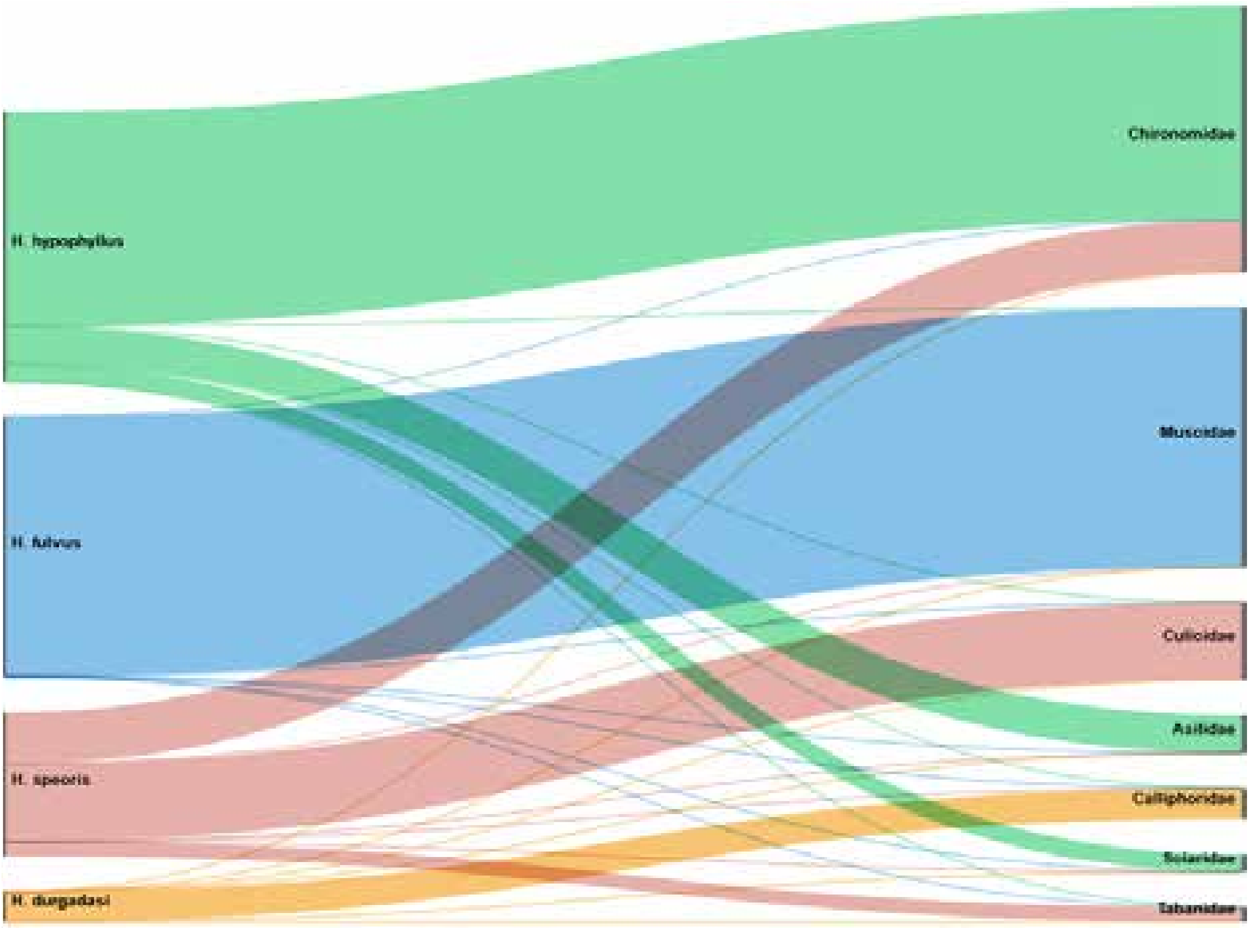

Image 10. Associations between bats (left) and dipteran insect prey taxa summarized at the taxonomic level of family (right). The connecting bar width represents the relative read abundance of each insect family between each bat and each dietary item.

mention that they observed fat deposits at the base of the tail of the species between the months of November and February.

The number of identifiable insect taxa is limited in a microscopic examination of faecal pellets due to the level of fragmentation of insect parts, making it rarely possible to identify insect remnants beyond order and, at times, family level (Hubancheva et al. 2023). DNA metabarcoding of bat guano provides higher-resolution appraisal of diet, often up to species level (Hubancheva et al. 2023; Liu et al. 2023; Ling et al. 2025). This has resulted in faecal DNA analysis becoming increasingly common in ecological, dietary, spatial, and phylogenetic studies (Thuo et al. 2019; Ando et al. 2020; Guan et al. 2020; Ingala et al. 2021; Hubancheva et al. 2023; Liu et al. 2023; Treloar et al. 2023; Ling et al. 2025), emphasising its effectiveness in helping to make informed conservation decisions. However, metabarcoding studies are not without limitations. Metabarcoding analyses of diet are still in the nascent stages in southern Asia, and none yet have been conducted on Indian bats. This technique is limited by resource and equipment costs, human resource expenditure, and computational limitations due to the need to effectively analyse many gigabytes of data – these costs are significantly lower in physical faecal dissection-based diet analyses. However, with the advent of more accessible and portable technologies (e.g., nanopore sequencing), this suite of techniques may grow more methodologically and economically feasible in southern Asia in the near future.

Our exploration of the diets of some individuals of the Kolar Roundleaf Bat *Hipposideros hypophyllus* and its congeners, the Fulvous Roundleaf Bat *H. fulvus*, Khajuria's Roundleaf Bat *H. durgadasi*, and Schneider's Roundleaf Bat *H. speoris* revealed highly similar whole diets, likely due to sharing a colony and therefore a resource space, but significant differences between the core diets (i.e., the most frequent prey items) in *H. hypophyllus* & *H. speoris* and *H. speoris* & *H. fulvus*. Further, no species dominated in terms of prey abundance, and Simpson's

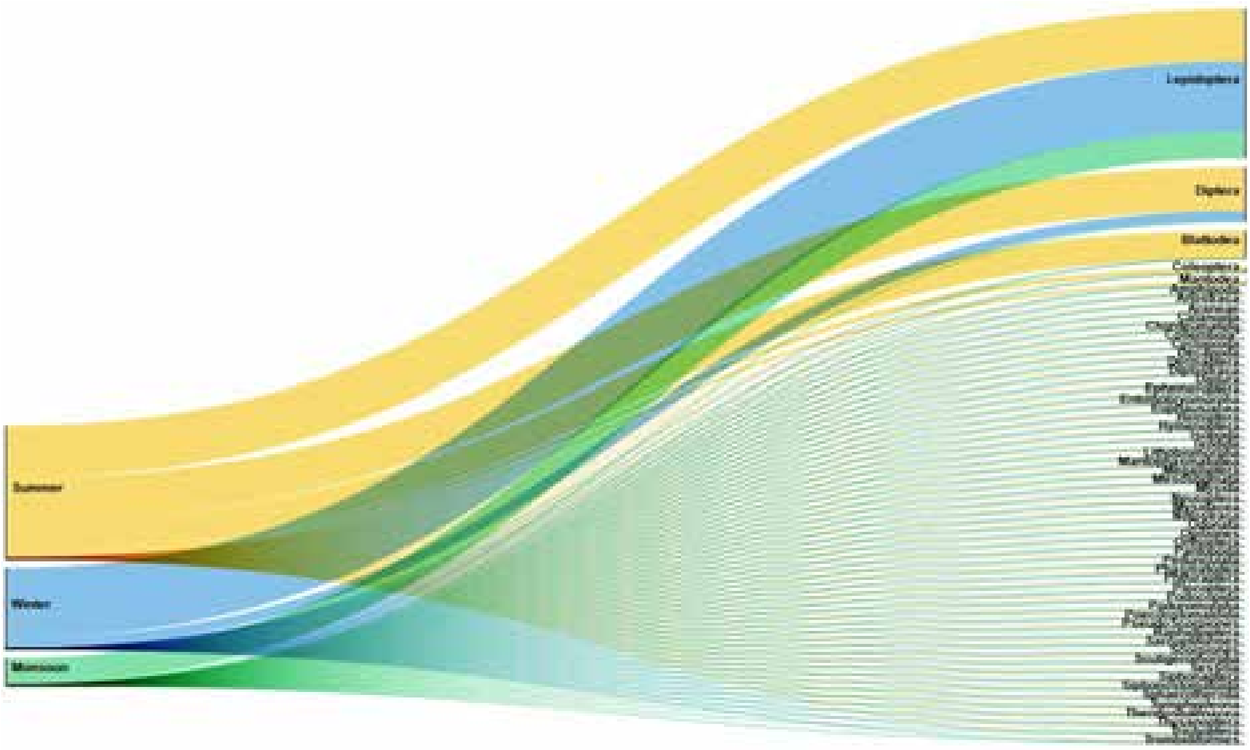

Image 11. Representation of the prey taxonomic diversity in the whole diet *Hipposideros hypophyllus* over three seasons and insect prey taxa summarized at the taxonomic level of order (right). The connecting bar width represents the relative read abundance of each insect order consumed over the seasons.

and Shannon's diversity indices of prey species in core diets indicated that the Kolar Roundleaf Bat likely preys on a wide diversity of invertebrate species. The core diet of the Kolar Roundleaf Bat also varied significantly between the three seasons (Summer, monsoon, & winter) sampled across one year, but in all seasons was dominated by lepidopteran prey.

Interestingly, there were some medically and agriculturally significant pests seen in the prey diversity of the four study species. For instance, all species were seen to feed on mosquitoes of *Aedes*, *Anopheles,* and *Culex* genera, known to carry various significant diseases (Achee et al. 2015; Choo & Blackwood 2017; Wilkman et al. 2023; Lim et al. 2025). *Hipposideros durgadasi* was the biggest suppressor of *Tetranychus urticae* (Trombidiformes: Tetranychidae), a mite that infests many vegetable crops and *Withania somnifera*, a medicinal plant (Mason 2001). Cockroaches, vectors of many viral and bacterial diseases (Donkor 2020), were majorly fed upon by *H. hypophyllus* and *H. fulvus. Hishimonus phycitis* (Hemiptera: Cicadellidae), a major hemipteran pest of citrus and brinjal (EFSA Panel on Plant Health et al. 2017), was suppressed mostly by *H. speoris*. Finally, the tomato leafminer *Tuta absoluta* (Lepidoptera: Gelechiidae), a highly invasive tomato pest (Biondi et al. 2018), was majorly predated upon by *H. fulvus* and *H. hypophyllus.* However, natural predators of pests were also fed upon by our study species, including predatory mosquitoes *Lutzia fuscana* (Diptera: Culicidae; Surendran et al. 2013; Mudi et al. 2025), hatchet wasps *Prosevania* sp. (Hymenoptera: Evaniidae) which are predators and parasites of cockroaches (Tee & Lee 2017), Ichneumonid wasps of the genus *Leptobatopsis* (Hymenoptera: Ichneumonidae; Quicke et al. 2023), and *Megastigmus viggianii* (Hymenoptera: Megastigmidae), a natural suppressor of the Eucalyptus gall wasp *Leptocybe invasa* (Mendel et al. 2017). However, the bats sampled were seen to suppress pests much more effectively than their insect predators.

It is important to note that this study is only an initial exploration of the diets of these four species, limited to a small sample of four individuals per species per season, and three seasons over one cycle in one site – such a small sample size inherently leads to potential biases in prey species detectability through primer bias, and the diversity reported in our study may not represent the entire dietary breadth of our study species. Given the nascent state of DNA metabarcoding as a method for non-invasive assessment of biodiversity in southern Asia, a limited sample size also hampers the generalisability of

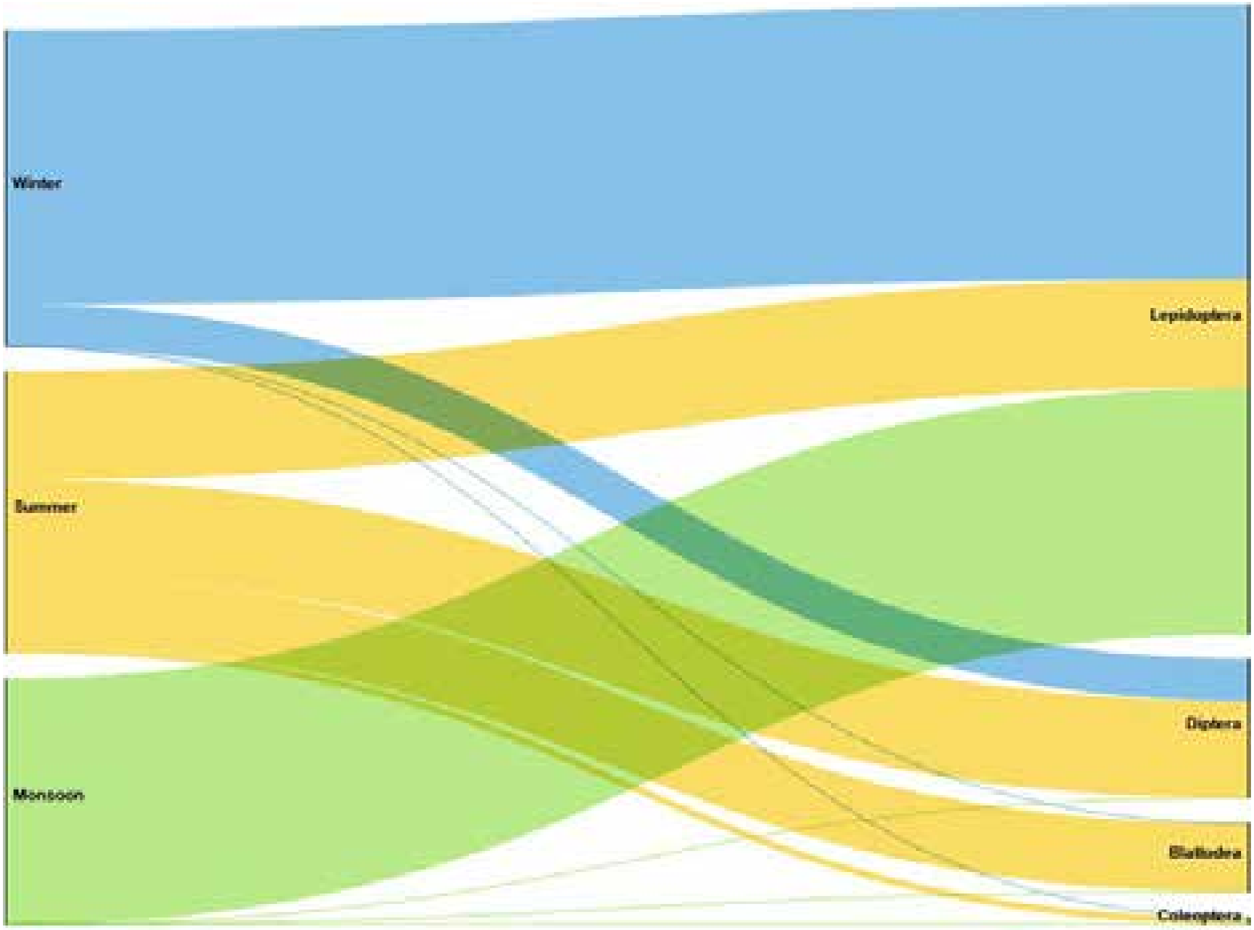

Image 12. Representation of the prey taxonomic diversity in the core diet *Hipposideros hypophyllus* over three seasons and insect prey taxa summarized at the taxonomic level of order (right). The connecting bar width represents the relative read abundance of each insect order consumed over the seasons.

this study, which insofar may only serve as a foundational piece of research on bat diets using genetic techniques. Further research using DNA metabarcoding is needed to clarify and confirm prey diversity patterns and seasonal variations in these and other bat species, and replicated metabarcoding studies are required across peninsular India and southern Asia as a whole to establish standard practices for these techniques. Our study explores the diets of these four roundleaf bats, identifying their importance as suppressors of medical and agricultural pests, and emphasising the effectiveness and importance of non-invasive assessment of bat diets in helping to guide future conservation research and planning. In the case of such sensitive roosts as Hanumanhalli Betta and threatened species such as the Kolar Roundleaf Bat and Durga Das' Roundleaf Bat, a non-invasive approach towards understanding their ecological interactions, appraising their ecosystem services (especially pest suppression in the case of insectivorous bats), and assessing these against the threats they face is vital for effective conservation, ensuring the long-term survival of these irreplaceable species.

Data availability statement

All relevant data are within the manuscript and its Supporting Information files. The BioProject accession number is PRJNA1281322

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ARTICLE

A decadal study on the waterbirds and an analysis of the declining species in Perur-Sundakamuthur Lake, Coimbatore, Tamil Nadu, India

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Abstract: The results of a decade-long systematic monthly monitoring of birds in Perur-Sundakamuthur Lake, an urban wetland in Coimbatore, Tamil Nadu, conducted from May 2014 to April 2024, are presented. The status and population trends of 129 species that comprise 51 waterbirds and 78 non-waterbirds were analysed. The analysis was focused solely on 37 species of waterbirds by categorising them into 10 guilds. Of these, seven species were each treated as a separate category based on their distribution status. Among them, 65% of the species were present in high numbers when the water level was medium. Also, about 78% of the winter migrant ducks and shorebirds were present only during the aforesaid condition, feeding on the shallow pools and moist mudflats. The abundance of 73% of the analysed waterbird species declined, ranging from 3% to 99%. The population of shorebirds and winter migrant ducks declined by 67% and 99.5%, respectively. From the findings, it is believed that maintaining full water levels in the wetland to aid commercial fishing is the most probable reason for the decline of these winter migrants. Monthly bird counts are suggested in the wetlands of greater Coimbatore to expand the scope of long-term monitoring of the urban avian population.

Keywords: Anthropogenic disturbance, avian population trends, foraging guilds, habitat heterogeneity, long-term monitoring, migratory waterfowl, wetland management.

சுருக்கம்: கோவை நகரப்பகுதியில் அமைந்துள்ள பேரூர்-சுண்டக்காமுத்தூர் குளத்தில், மே 2014 முதல் ஏப்ரல் 2024 வரை மேற்கொள்ளப்பட்ட பத்தாண்டு மாதாந்திரப் பறவைக் கணக்கெடுப்பின் தரவுகள் பகுப்பாய்ந்துத் தரப்பட்டுள்ளது. இவ்வாய்வில், 51 நீர்ப்பறவை இனங்கள் மற்றும் 78 நீர் சாராப் பறவை இனங்கள் உட்பட மொத்தம் 129 பறவை இனங்களின் பரவல் நிலையும் எண்ணிக்கை மாற்றங்களும் ஆய்வு செய்யப்பட்டன. அவற்றுள் 37 நீர்ப்பறவை இனங்கள் பத்துக் குழுக்களாக வகைப்படுத்தப்பட்டு சீராய்வு செய்யப்பட்டன. மேலும், எண்ணிக்கைப் பரவல் தன்மையின் அடிப்படையில் ஏழு இனங்கள் தனித்தனியாக ஆய்வு செய்யப்பட்டன. குளத்தின் நீர்மட்டம் நடுத்தரமாக இருந்த காலங்களில், 65 விழுக்காடு நீர்ப்பறவை இனங்கள் அதிக எண்ணிக்கையில் பதிவாகியுள்ளன. இந்நீர்மட்டத்தில் உருவாகும் ஆழமற்ற நீர்ப்பகுதிகளும் சேற்றுச் சமவெளிகளும் இரைதேடுவதற்கு ஏற்ற வாழிடங்களாக அமைவதால், வலசை வரும் வாத்துகள் மற்றும் கரையோரப் பறவைகளில் 78 விழுக்காடு இனங்கள் இந்நிலையிலேயே பதிவாகியுள்ளன. ஆய்வுக் காலத்தில் சீராய்வுக்கு உட்படுத்தப்பட்ட நீர்ப்பறவை இனங்களில் 73 விழுக்காடு இனங்கள், எண்ணிக்கையில் 3 முதல் 99 விழுக்காடு வரை சரிவைக் காட்டியுள்ளன. கரையோரப் பறவைகளும் வலசை வரும் வாத்துகளும் முறையே 67 விழுக்காடு 99.5 விழுக்காடு குறைந்துள்ளன. இந்தத் தரவுகள், வணிக மீன்பிடிப்பு நடவடிக்கைகளும், அதனைத் தொடர்ந்து குளத்தில் செயற்கையாக அதிக நீர்மட்டம் நீடித்துப் பராமரிக்கப்படுவதும், நீர்ப்பறவைகளின் எண்ணிக்கைக் குறைவுக்கான முக்கிய காரணிகளாக இருக்கக்கூடும் என்பதைக் காட்டுகின்றன. எனவே, கோவை மற்றும் அதன் சுற்றுவட்டாரப் பகுதிகளில் உள்ள ஏரிகள் மற்றும் குளங்களில் நீண்டகால மாதாந்திரப் பறவைக் கணக்கெடுப்புகளை மேற்கொள்வது, நீர்ப்பறவைகளின் எண்ணிக்கை மாற்றங்களையும் வாழிட மாற்றங்களையும் கண்காணிப்பதற்கு இன்றியமையாததாகும்.

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INTRODUCTION

Many ecosystems, at scales ranging from local to global, are now heavily human-influenced and are undergoing large, far-reaching changes that have extremely negative consequences for human well-being (Millennium Ecosystem Assessment 2005a; Biggs et al. 2010; Intergovernmental Panel on Climate Change (IPCC) 2021; Mundkur et al. 2023). The loss of habitat through human action and resource extraction impacts wildlife population, including birds (Şekercioğlu et al. 2004; Lees et al. 2022; Parameswaran et al. 2023a; Byju et al. 2024a).

Birds contribute many important ecological functions through their roles as predators, pollinators, scavengers, seed dispersers, and ecosystem engineers. Many of these ecosystem functions also translate to ecosystem services such as supporting fish and fibre, water purification, climate and flood regulation, along with recreational opportunities (Millennium Ecosystem Assessment 2005b; Whelan et al. 2008; Şekercioğlu 2010). The abilities of birds to fly and migrate long distances enable them to respond to eruptive resources and to connect varying landscapes in ways that other organisms cannot (Şekercioğlu et al. 2016), as they are one of the reliable indicators of biodiversity and ecosystem health (Frazier 1999; Gregory et al. 2003; Gregory & Van Strien 2010; Fraixedas et al. 2020; Mundkur et al. 2023).

Wetlands constitute some of the most productive ecosystems in India, and their health is often correlated with the waterbird communities that play vital roles in their effective functioning (Millennium Ecosystem Assessment 2005b; Raju 2015). In urban areas, inland wetlands remain some of the last natural ecosystems that not only provide refuge to a wide variety of flora and fauna but also offer important space for humans to interact with nature (Raju 2015). Also, inland wetlands are extremely important for migratory waterbirds either as resting locations or wintering grounds (Mundkur et al. 2023). Although many urban wetlands in India are extremely polluted, they still attract a large number of birds (Parameswaran et al. 2023a). Urban wetlands are also continuously disturbed by development activities, which affect their bird populations (Fluet-Chouinard et al. 2023). In Tamil Nadu, fast-growing cities like Coimbatore still have some wetlands with a good bird population. A few earlier studies relating to birds on some of the Coimbatore lakes are from Singanallur (Reginald et al. 2007; Guptha et al. 2011), Ukkadam (Guptha et al. 2011; Kumar et al. 2014), Perur (Parameswaran & Sivashankar 2018; Parameswaran et al. 2023a), Kuruchi, Valankulam, and Sulur (Guptha et al. 2011), and Chinnavedampatti (Kumar et al. 2025).

The primary aim of this study is to monitor the waterbird population and their changes in terms of conservation perspective in Perur-Sundakamuthur Lake (hereinafter, Perur Lake), Coimbatore, for a decade. In order to effectively analyse the data, a methodology was devised to define the distribution status of the waterbird species, focusing on common waterbirds that frequent the lake. The population changes of the common waterbird species were closely analysed in association with local threats occurring at the lake. Perur Lake was chosen for its size and accessibility to conduct continuous bird monitoring, representing one of the lakes in a fast-developing urban area.

Study area

Perur Lake (10.970º N, 76.928º E) lies in the southwestern corner of metropolitan Coimbatore, Tamil Nadu. It is a freshwater wetland and part of a network of approximately 30 interconnected lakes constructed during the Kongu-Chola regimes in the 8th–9th centuries CE within the Noyyal River basin (Pragatheesh & Jain 2013). These lakes were designed to regulate monsoon floods, store surface runoff, and enhance groundwater recharge in this semi-arid region. Over time, this wetland of the Noyyal Basin has developed into an ecologically important habitat supporting diverse assemblages of birds, fishes, molluscs, and other aquatic biota. In addition to supplying irrigation water, they provide ecosystem services such as flood mitigation, groundwater recharge, nutrient retention, water purification, and biodiversity conservation. In short, its ecological function is primarily to act as a flood plain for the river Noyyal Basin with its attendant flow.

The lake has a catchment area of 5.768 km² and receives inflow through a single channel from the Kuniyamuthur Anicut, which conveys surplus water from the upstream Ganganarayanasamudhram Lake. The wetland has seven outlets (one weir and six sluices) and a surplus escape channel of 35.67 m. Water levels fluctuate seasonally depending on rainfall, influencing habitat structure and waterbird assemblages (Pragatheesh & Jain 2013). The eastern margin of the lake is bordered by a crescent-shaped bund, approximately 2 km in length, which was formerly vegetated and walkable but has since been converted into a two-lane roadway with a containment wall that partially encroaches into the wetland. The southwestern shoreline supports trees and emergent vegetation used by birds for roosting and occasional nesting, and remains largely inaccessible except during dry periods. The western edge of the lake gradually transitions into agricultural land (Parameswaran et al. 2023a).

Owing to the absence of major industrial activity and sewage inflow, Perur Lake remains relatively unpolluted (Mohanraj et al. 2000; Chandra et al. 2009). Invasive aquatic macrophytes such as *Eichhornia crassipes* are absent, although floating plants, including water lilies (Nymphaeaceae), occur sporadically. This lake is subjected to anthropogenic pressures such as sandmining, commercial fishing (ongoing), road construction and encroachment (Pragatheesh & Jain 2013; Parameswaran et al. 2023a).

MATERIALS AND METHODS

Perur Lake was monitored once a month from May 2014–April 2024, usually on second Saturdays by walking on a fixed 2 km road transect in the morning at 0700–1000 h, counted all birds that were seen or heard and recorded the information in a checklist. This method can be characterized as a "total count". Binoculars (Nikon 10 x 42.5, Zeiss 10 x 42 & Eagle Optics 10 x 42), a spotting scope (Bausch & Lomb 20–80 x magnification), and cameras were used for the monitoring and documentation. The number of volunteers who participated in the count on any given day varied from three to eight. During the decade, there were 108 actual monthly counts conducted, amounting to c. 900 h of volunteer time. Of the counts missed, four were due to sand mining operations between June and September 2017, and the rest were due to COVID-19 restrictions in 2020 and 2021.

The standard field guides (Ali & Ripley 1968a,b,c,d; Hayman et al. 1986; Kazmierczak 2000; Ali 2002; Paulson 2005; Grimmett et al. 2011; Rasmussen & Anderton 2012) were used to identify birds. Birds were categorised as follows: resident (R): a species that stays year-round but also breeds in the area (e.g., Indian Spot-billed Duck *Anas poecilorhyncha*). Local migrant (LM): a species that stays in the area throughout (or most of) the year and whose adult population moves outside the area to breed. Occasionally, when resources are available, these species may also breed in the area (e.g., Lesser Whistling Duck *Dendrocygna javanica*). Winter migrant (WM): a species that spends its non-breeding winter months (mostly from September–April) in the area (e.g., Wood Sandpiper *Tringa glareola*). Passage migrant (PM): a species that is present between February–April and September–November in the area. Uncertain (U): a species that occasionally visits an area and whose pattern cannot be discerned (e.g., Woolly-necked Stork *Ciconia episcopus*). To enable integrated analysis of waterbird population, especially winter migrants, the 'wetland year' is calibrated from May of the current year to April of the succeeding year.

To quantify and determine the distribution status of each species, a method was adopted based on the field experience (Parameswaran et al. 2023a). The bird categories were split into two, namely, waterbirds and non-waterbirds. Parameters such as reporting frequency (RF) and mean count (MC) were defined as follows:

RF = No. of surveys that have the species / Total no. of surveys

MC = Total count of the species in all surveys / Total no. of surveys

By multiplying MC and RF, the benchmark value for each species was obtained. The species with the highest benchmark value for that category (waterbird / non-waterbird) was designated as the Benchmark species. The population index (PI) of each species was calculated as PI = mean count of the species / mean count of the benchmark species. Finally, the distribution status given as a percentage is calculated by the formula [(RF + PI)/2] * 100 (Table 1A), and the distribution status of each species is determined. Some examples of waterbirds and non-waterbirds are provided in Table 1B.

Prior to the start of every count, the water level is estimated visually (Table 2). We then obtained the corresponding mean count (MC) for every water level, which was calculated using the formula given below:

MC of a species per water level = Sum of all counts of a species in that water level / Number of surveys in that water level.

During surveys, potential threats (threat events) were documented within the wetland and associated the threats with the months. Both waterbird species diversity were compared, as well as population numbers before and after a threat event, to assess the impact of the threat. For this analysis, we eliminated the species whose distribution status is rare, because they are

Table 1A. Distribution status codes.

Distribution status	Percentage
Abundant	≥ 90 %
Common	60–89 %
Fairly Common	30–59 %
Uncommon	10–29 %
Rare	< 10 %

Table 1B. Examples of distribution status calculation.

Species	Total count of birds	MC (Total count / 108)	No. of sightings	RF (No. of sightings / 108)	Benchmark value (MC * RF)	PI (MC / MC of species with highest benchmark value)	Distribution status [(RF+PI)/2]*100%	
							%	Distribution status
Waterbirds								
Indian Spot-billed Duck#	4542	42.05	102	0.94	39.72#	1.00	97%	Abundant
Little Cormorant	3843	35.58	98	0.91	32.29	0.85	88%	Common
Common Sandpiper	414	3.83	72	0.67	2.56	0.09	38%	Fairly Common
Little Grebe	608	5.63	44	0.41	2.29	0.13	27%	Uncommon
Striated Heron	15	0.138	12	0.11	0.02	0.0005	6%	Rare
Non-waterbirds								
House Crow#	6228	57.67	108	1.00	57.67#	1.00	100%	Abundant
Common Myna	3690	34.17	107	0.99	33.85	0.59	79%	Common
Rock Pigeon	1354	12.54	93	0.86	10.80	0.22	54%	Fairly Common
Black Drongo	148	1.37	61	0.56	0.77	0.02	29%	Uncommon
Paddyfield Pipit	25	0.23	16	0.15	0.03	0.004	7.7%	Rare

MC—mean count | RF—reporting frequency | PI—population index.
Indian Spot-billed Duck *Anas poecilorhyncha* is the benchmark species for waterbirds as House Crow *Corvus splendens* for non-waterbirds.

less than 10% of the distribution status (Table 1A) and categorized the rest of the waterbirds into guilds (Pearce et al. 2007), primarily based on order and secondarily on their yearly mean population trend. Some individual species are treated separately and not included in the guilds, as their yearly mean population trend is significantly different from that of the waterbirds in the same order.

The mean of their population counts was calculated for the first five years (May 2014–April 2019) and the next five years (May 2019–April 2024) and used the difference in their percentages to show the population decline. A sparkline or a trend line graph of the annual mean over the decade was drawn for all guilds and individual species. The annual population change with the standard error and compared it with the global trends from the International Union for Conservation of Nature's Red List of Threatened Species (IUCN 2025-2) and national current annual trends during 2014–2020 available from the State of India's Birds (SoIB 2023). The IUCN 2025-2 and SoIB 2023 were chosen because their periodicity significantly overlaps with our study.

A detailed annotated checklist with bar charts that represents the presence/absence of the species across the year, line graphs depicting population trends, and notable differences from existing literature are provided in the supplementary dataset archived on Zenodo (Parameswaran et al. 2025). The software used to plot graphs and visualizations are Microsoft Power BI and Microsoft Excel.

RESULTS

Around 129 species of birds (Table S5 in the supplementary dataset (Parameswaran et al. 2025) were recorded in Perur Lake, including 51 species of waterbirds (Table 3). The 51 waterbird species comprise 14 residents, 14 local migrants, 13 winter migrants and 10 of uncertain status (Table 4). The list was pared down to 37 species by eliminating 14 species falling under the rare category. The 37 species are further categorized as 10 guilds comprising 30 species and seven species treated individually. The reason that five out of these seven species, such as Indian Spot-billed Duck *Anas poecilorhyncha*, Asian Openbill *Anastomus oscitans*, Eurasian Coot *Fulica atra*, Lesser Whistling Duck *Dendrocygna javanica*, and Glossy Ibis *Plegadis falcinellus*, were treated individually because their inclusion in a guild would dominate and mask the data of the entire guild (Adhurya et al. 2019). In the context of Perur Lake, the other two species, such as Little Grebe *Tachybaptus ruficollis* and Whiskered Tern *Chlidonias hybrida*, are singular by their very nature and therefore cannot be included with the rest of the analysed waterbirds.

The first year of the study, 2014–2015, had the highest mean waterbird population of 732 birds per month. This population dropped in subsequent years to the level of 123.5 in 2017–18 and followed by a slow revival from 2021–22 until the last year of this study, when the second-highest mean population of 629 birds per month was recorded in 2023–24. Similarly, the first two years, 2014–15 & 2015–16 registered the highest mean species diversity of 22.8 per month, dropping to the lowest of 15.4 in 2020–21 and increasing to 19.8 in 2022–23 and 2023–24. Image 1 provides the trend of monthly waterbird counts across the ten years and their corresponding water levels and threats due to anthropogenic actions. Image 2 provides the yearly waterbird population trend and waterbird species diversity over the decade.

Impact of water levels

The highest counts of waterbirds were obtained when the water level of the lake was ‘Medium’ (Image 3), when large flocks of dabbling ducks like Indian Spot-billed Duck *Anas poecilorhyncha*, egrets like Little Egret *Egretta garzetta*, and shorebirds like Wood Sandpiper *Tringa glareola* were seen feeding in the mudflats, shoreline and shallow water pools. Of the 37 waterbirds analysed, 24 (65%) are present in high numbers when the water level is Medium (Image 4).

Decline of waterbirds

The population of several waterbird species and their corresponding guilds declined steeply in Perur Lake during the study period, sometimes resulting in total disappearance (Table 5). Overall waterbird numbers declined by 14% during the decade. The decline was 60.4% during the first nine years, i.e., from May 2014 to April 2023 (Image 2).

From the analysis of data provided in Table 5 for the waterbird guilds and individual species, we would like to restate that 73% of the waterbirds have declined in population, ranging 3–99 % (Table 6). Winter migrant

Table 2. Description of water level.

Water level	Description
Dry	The absence of water in the lake or the presence of a negligible wet ground.
Low	The presence of a small amount of water in a few isolated puddles.
Medium	The presence of water in the whole lake with shoreline exposed in the periphery.
Full	The lake is completely filled with water without any exposed shoreline.

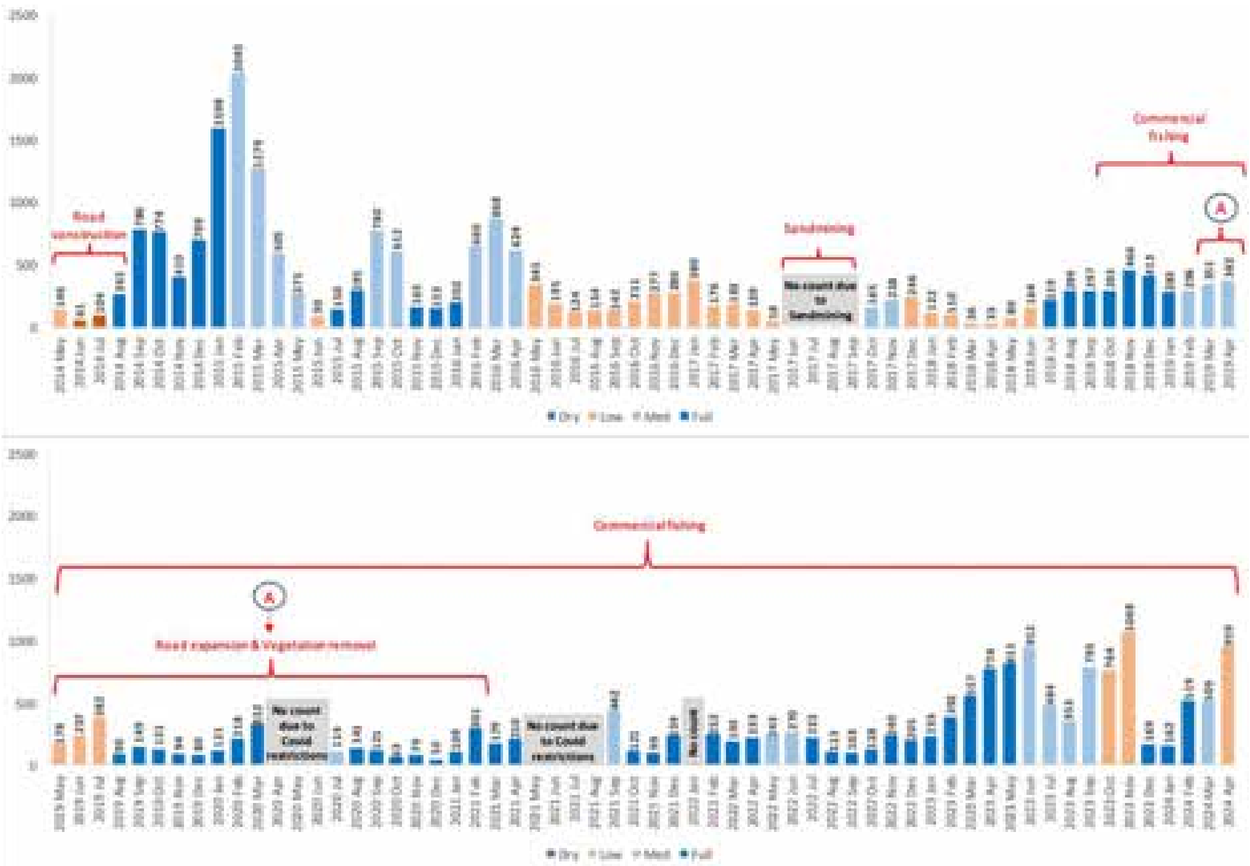


Image 1. Monthly trend from May 2014–April 2024 of the total number of birds and the various threats, colour-coded with water levels.

Table 3. Waterbirds of Perur Lake, Coimbatore.

	Common name	Scientific name	Status	Distribution status
	Anseriformes: Anatidae			
1	Lesser Whistling-Duck	*Dendrocygna javanica*	LM	Fairly Common
2	Cotton Pygmy-Goose	*Nettapus coromandelianus*	LM	Rare
3	Garganey	*Spatula querquedula*	WM	Fairly Common
4	Northern Shoveler	*Spatula clypeata*	WM	Uncommon
5	Northern Pintail	*Anas acuta*	WM	Uncommon
6	Common Teal	*Anas crecca*	U	Rare
7	Indian Spot-billed Duck	*Anas poecilorhyncha*	R	Common
	Podicipediformes: Podicipedidae			
8	Little Grebe	*Tachybaptus ruficollis*	R	Uncommon
	Gruiformes: Rallidae			
9	Common Moorhen	*Gallinula chloropus*	R	Uncommon
10	Eurasian Coot	*Fulica atra*	R	Common
11	Grey-headed Swamphen	*Porphyrio poliocephalus*	R	Fairly Common
12	White-breasted Waterhen	*Amaurornis phoenicurus*	R	Uncommon
	Charadriiformes: Recurvirostridae			
13	Black-winged Stilt	*Himantopus himantopus*	LM	Uncommon
	Charadriiformes: Charadriidae			
14	Red-wattled Lapwing	*Vanellus indicus*	R	Fairly Common
15	Kentish Plover	*Anarhynchus alexandrinus*	U	Rare
16	Little Ringed Plover	*Thinornis dubius*	R/ WM	Uncommon
	Charadriiformes: Jacanidae			
17	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	U	Rare
18	Bronze-winged Jacana	*Metopidius indicus*	U	Rare
	Charadriiformes: Scolopacidae			
19	Ruff	*Calidris pugnax*	U	Rare
20	Temminck's Stint	*Calidris temminckii*	WM	Rare
21	Little Stint	*Calidris minuta*	WM	Uncommon
22	Common Sandpiper	*Actitis hypoleucos*	WM	Fairly Common
23	Green Sandpiper	*Tringa ochropus*	WM	Uncommon
24	Common Greenshank	*Tringa nebularia*	WM	Uncommon
25	Marsh Sandpiper	*Tringa stagnatilis*	WM	Rare
26	Wood Sandpiper	*Tringa glareola*	WM	Uncommon

	Common name	Scientific name	Status	Distribution status
	Charadriiformes: Laridae			
27	Whiskered Tern	*Chlidonias hybrida*	WM	Uncommon
28	River Tern	*Sterna aurantia*	WM	Rare
	Ciconiiformes: Ciconiidae			
29	Asian Openbill	*Anastomus oscitans*	LM	Common
30	Asian Woolly-necked Stork	*Ciconia episcopus*	U	Rare
31	Painted Stork	*Mycteria leucocephala*	LM	Fairly Common
	Suliformes: Anhingidae			
32	Oriental Darter	*Anhinga melanogaster*	R	Fairly Common
	Suliformes: Phalacrocoracidae			
33	Little Cormorant	*Microcarbo niger*	R	Common
34	Indian Cormorant	*Phalacrocorax fuscicollis*	R	Fairly Common
35	Great Cormorant	*Phalacrocorax carbo*	LM	Uncommon
	Pelecaniformes: Pelecanidae			
36	Spot-billed Pelican	*Pelecanus philippensis*	LM	Uncommon
	Pelecaniformes: Ardeidae			
37	Yellow Bittern	*Botaurus sinensis*	U	Rare
38	Cinnamon Bittern	*Botaurus cinnamomeus*	U	Rare
39	Grey Heron	*Ardea cinerea*	R	Common
40	Purple Heron	*Ardea purpurea*	R	Fairly Common
41	Great Egret	*Ardea alba*	LM	Fairly Common
42	Intermediate Egret	*Ardea intermedia*	LM	Fairly Common
43	Little Egret	*Egretta garzetta*	LM	Common
44	Western Reef-Egret	*Egretta gularis*	U	Rare
45	Eastern Cattle-Egret	*Ardea coromanda*	LM	Fairly Common
46	Indian Pond-Heron	*Ardeola grayii*	R	Common
47	Striated Heron	*Butorides striata*	U	Rare
48	Black-crowned Night Heron	*Nycticorax nycticorax*	R	Uncommon
	Pelecaniformes: Threskiornithidae			
49	Glossy Ibis	*Plegadis falcinellus*	LM	Uncommon
50	Black-headed Ibis	*Threskiornis melanocephalus*	LM	Uncommon
51	Eurasian Spoonbill	*Platalea leucorodia*	LM	Uncommon

R—resident | LM—local migrant | WM—winter migrant | U—uncertain.

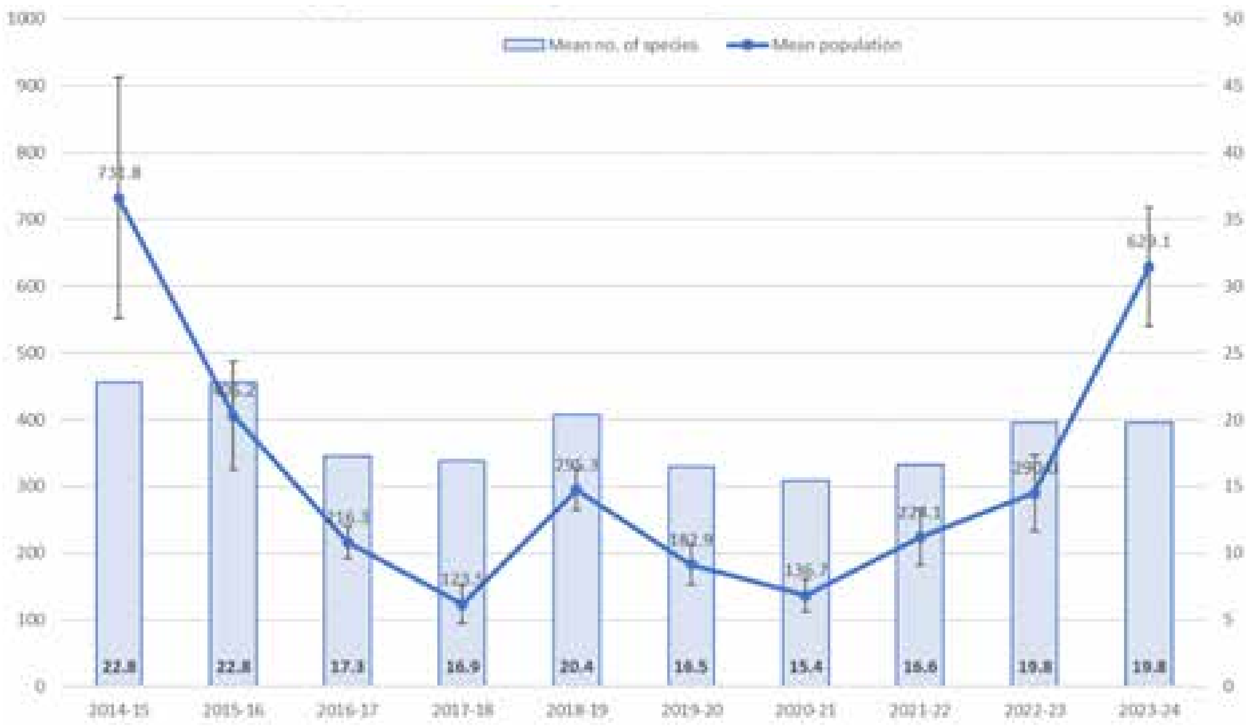


Image 2. Overall waterbird population trend and waterbird species diversity over the decade.

Table 4. Summary of waterbirds of Perur Lake.

Status	Total number of species & their %		Number of species by distribution status				
			Abundant	Common	Fairly common	Uncommon	Rare
Resident	14	27.5%	1	4	5	4	0
Local migrant	14	27.5%	0	2	5	6	1
Winter migrant	13	25.5%	0	0	2	8	3
Uncertain	10	19.5%	0	0	0	0	10
Total	**51**	**100%**	**1**	**6**	**12**	**18**	**14**
% by distribution status			**2%**	**12%**	**24%**	**35%**	**27%**

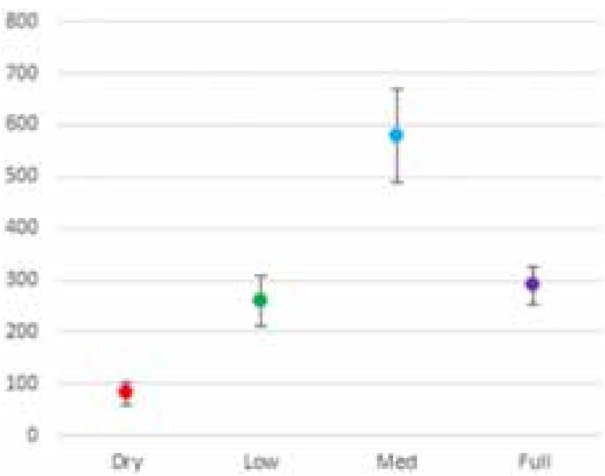


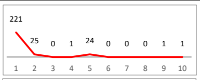
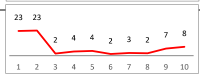
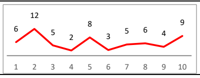
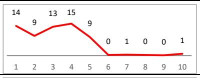
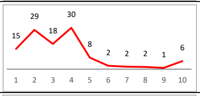
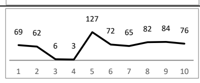
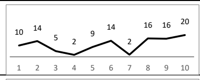
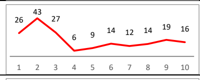
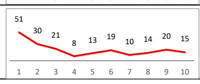
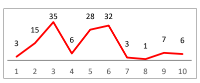
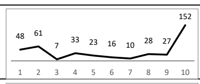
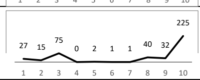
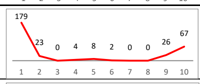
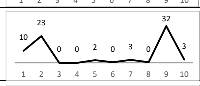
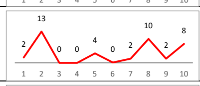
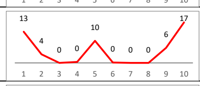
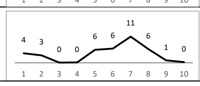
Image 3. Mean count of waterbirds based on water levels.

ducks and shorebirds are highly affected waterbirds with a population decline of above 85%.

DISCUSSION

The decadal study emphasizes the importance of monitoring common waterbirds. Their population levels and breeding status are good and reliable indicators of biodiversity and ecosystem health of wetlands (Gregory et al. 2003; Whelan et al. 2008; Gregory & Van Strien 2010; Parameswaran et al. 2023a; Byju et al. 2024b). The steep increase in the waterbird population during the tenth year is primarily due to the irruption in the

Table 5. Population trend of 10 waterbird guilds and seven individual waterbird species; their comparison with trend assessments from SoIB 2023, IUCN 2025-2.

Sno	Guild Name / Species Name	Population change in % (1st Y vs Last Y)	Population change 1st 5Y vs last 5Y in % (CI Lower bound, CI upper bound)	Trend of the mean population	Annual change in population (%) with SE at Perur Lake	Trend of other assessments		
						Status of Indian Birds 2023 - Current Annual Trend (in % with CI)	Status of Indian Birds 2023 - Current Annual Trend	IUCN 2025-2(Current Global trend)
G-I	Winter Migrant Ducks (Garganey, Northern Pintail and Northern Shoveler)	-99.51%	-99.10% (-185.29%, -12.92%)		Guild : -9.9% ± 3.7% Garganey : -9.9% ± 2.8% N. Shoveler : -10.0% ± 2.1% N. Pintail : -10.0% ± 1.6%	Garganey : -5.72% (-6.84,-4.6)% N. Shoveler: -7.03% (-8.02,-6.04)% N. Pintail : -7.09% (-8.23,-5.95)%	Garganey : Rapid decline N. Shoveler : Rapid decline N. Pintail : Rapid decline	Garganey : Decreasing N. Shoveler : Decreasing N. Pintail : Decreasing
G-II	Rails (Grey-headed Swamphen, Common Moorhen, White-breasted Waterhen)	-63.61%	-61.03% (-106.38%, -15.69%)		Guild : -6.3% ± 1.6% GH. Swamphen: -5.57% ± 1.4% C. Moorhen : -7.04% ± 0.9% WB. Waterhen : -8.41% ± 0.6%	GH. Swamphen: +1.13% (-1.16, 3.42)% C. Moorhen : +1.04% (-0.5, 2.57)% WB. Waterhen : +5.45% (2.52, 8.39)%	GH. Swamphen : Stable C. Moorhen : Stable WB. Waterhen: Inconclusive	GH. Swamphen : Unknown C. Moorhen: Decreasing WB. Waterhen: Unknown
G-III	Resident and Local Migrant Shorebirds (Red-wattled Lapwing, Black-winged Stilt)	+47.16%	-24.39% (-70.94%, +22.14%)		Guild : 4.7% ± 1.5% RW. Lapwing : 9.09% ± 1.1% BW. Stilt : 1.22% ± 1.3%	RW. Lapwing : +1.77% (0.46, 3.07)% BW. Stilt : -2.38% (-3.97,-0.8)%	RW. Lapwing & BW. Stilt: Trend Inconclusive	RW. Lapwing : Unknown BW. Stilt : Stable
G-IV	Small Shorebirds (Little Stint, Little Ringed Plover)	-93.89%	-96.18% (-146.76%, -45.60%)		Guild : -9.4% ± 1.8% L. Stint : -9.43% ± 1.2% LR. Plover : -9.37% ± 1.4%	L. Stint : -4.29% (-5.48,-3.09)% LR. Plover : -4.62% (-5.60,-3.63)%	L. Stint : Rapid decline LR. Plover: Rapid decline	L. Stint : Increasing LR. Plover: Decreasing
G-V	Winter Migrant Shorebirds (Common Sandpiper, Wood Sandpiper, Green Sandpiper, Common Greenshank)	-60%	-86.30% (-122.68%, -49.93%)		Guild : -5.9% ± 1.9% C. Sandpiper : -6.91% ± 1.1% W. Sandpiper : -8.91% ± 1.5% G. Sandpiper : -9.26% ± 0.6% C. Greenshank : 12.93% ± 0.9%	C. Sandpiper : -3.66% (-4.64,-2.69)% W. Sandpiper: -2.92% (-4.11,-1.73)% G. Sandpiper : -0.97% (-2.31,+0.36)% C. Greenshank : -4.46% (-5.58,-3.33)%	C. Sandpiper : Decline W. Sandpiper: Decline G. Sandpiper : Stable C. Greenshank : Rapid decline	C. Sandpiper : Stable W. Sandpiper: Unknown G. Sandpiper : Stable C. Greenshank : Stable
G-VI	Cormorants & Darter (Little Cormorant, Indian Cormorant, Great Cormorant & Oriental Darter)	+10.06%	+32.42% (-18.01%, +82.84%)		Guild : 1.0% ± 4.2% L. Cormorant : -4.21% ± 3.4% I. Cormorant : 140% ± 2.3% G. Cormorant : 135.83% ± 1.0% O. Darter : 0.26% ± 1.9%	L. Cormorant : +0.23% (-1.07, +1.53)% I. Cormorant : -2.27% (-3.46,-1.09)% G. Cormorant : -0.34% (-1.73,+1.06)% O. Darter : +0.20% (-1.26, +1.66)%	L. Cormorant : Stable I. Cormorant :Inconclusive G. Cormorant : Stable O. Darter : Stable	L. Cormorant : Unknown I. Cormorant :Unknown G. Cormorant : Increasing O. Darter : Increasing
G-VII	Large Herons (Grey Heron, Purple Heron)	+90.24%	+85.27% (+42.54%, +128%)		Guild : 9.0% ± 1.5% G. Heron : 18.16% ± 1.5% P. Heron : -5.74% ± 0.7%	G. Heron : -2.14% (-3.85,-0.44)% P. Heron : -0.28% (-1.60,+1.05)%	G. Heron : Inconclusive P. Heron : Stable	G. Heron : Unknown P. Heron : Decreasing
G-VIII	White Egrets (Little Egret, Intermediate Egret, Great Egret)	-38.56%	-35.43% (-86.43%, +15.56%)		Guild : -3.9% ± 2.6% L. Egret : -5.0% ± 2.3% I. Egret : 4.87% ± 1.2% G. Egret : -5.93% ± 0.9%	L. Egret : -1.98% (-3.04,-0.93)% I. Egret : -1.59% (-3.08,-0.1)% G. Egret : -1.37% (-2.64,-0.11)%	L. Egret, I. Egret & G. Egret: Trend Inconclusive	L. Egret : Stable I. Egret : Decreasing G. Egret : Stable
G-IX	Small Herons & Cattle-Egret (Indian Pond Heron, Black-crowned Night-Heron, Eastern Cattle-Egret)	-71%	-38.65% (-64.68%, -12.62%)		Guild : -7.0% ± 1.9% IP. Heron : -6.5% ± 1.7% BCN. Heron : -8.57% ± 0.7% EC-Egret : -8.49% ± 1.3%	IP. Heron : -0.8% (-1.89,-0.28)% BCN. Heron : +0.15% (-1.75, +2.04)% EC-Egret : -0.76% (-1.86,-0.34)%	IP. Heron : Stable BCN. Heron : Stable EC-Egret : Stable	IP. Heron : Unknown BCN. Heron : Unknown EC-Egret : Stable
G-X	(Black-headed Ibis, Eurasian Spoonbill, Painted Stork, Spot-billed Pelican)	+76.92%	-43.99% (-116.74%, +28.75%)		Guild : 7.7% ± 2.6% BH. Ibis : 250% ± 0.8% E. Spoonbill : -10.0% ± 0.9% P. Stork : 4.83% ± 2.0% SB. Pelican : -10.0% ± 1.6%	BH. Ibis : +0.86% (-0.61, +2.34)% E. Spoonbill : -6.84% (-7.77,-5.92)% P. Stork : -3.18% (-4.59,-1.76)% SB. Pelican : -10% ± 1.6%	BH. Ibis : Stable E. Spoonbill: Rapid Decline P. Stork : Decline SB. Pelican : Rapid Decline	BH. Ibis : Increasing E. Spoonbill: Increasing P. Stork : Increasing SB. Pelican : Decreasing
S-1	Indian Spot-billed Duck	+216.84%	+46.01% (-21.34%, +113.36%)		+21.7% ± 3.3%	-0.69% (-1.95, +0.56)%	Stable	Unknown
S-2	Asian Openbill	+718.74%	+154.28% (-12.22%, +320.79%)		+71.9% ± 3.8%	-2.19% (-3.34,-1.03)%	Trend Inconclusive	Increasing
S-3	Eurasian Coot	-62.85%	-52.10% (-126.47%, +22.26%)		-6.3% ± 3.2%	-3.54% (-4.57,-2.51)%	Decline	Increasing
S-4	Lesser Whistling Duck	-73%	+12.51% (-112.58%, +137.60%)		-7.3% ± 1.9%	+0.39% (-1.52,+2.3)%	Stable	Decreasing
S-5	Glossy Ibis	+259.11%	-4.22% (-110.26%, +101.81%)		+25.9% ± 1.6%	0% (-2.2, +2.21)%	Stable	Stable
S-6	Little Grebe	+30.00%	-3.71% (-88.54%, +81.11%)		+3.0% ± 1.4%	-1.5% (-2.72,-0.28)%	Trend Inconclusive	Unknown
S-7	Whiskered Tern	-93.87%	+62.23% (-103.5%, +227.95%)		-9.4% ± 1.7%	-5.47% (-6.43,-4.52)%	Rapid decline	Unknown

numbers of the two waterbirds, which are Indian Spot-billed Duck *Anas poecilorhyncha* (560% increase) and Asian Openbill *Anastomus oscitans* (700% increase). The possible explanation for this increase is due to the favourable water level condition over two-thirds of the period during the tenth year, i.e., either medium or low (Parameswaran et al. 2023a, 2025; Byju et al. 2025d). When these two birds mentioned above are removed from consideration, then the population decline of the rest of the waterbirds is 61.5% over the decade.

The winter migrants, which comprise exclusively of ducks and shorebirds, have declined the most in Perur Lake. This is also the trend nationally in India, according to SoIB (Table 5). The rate of decline is noticeably larger in

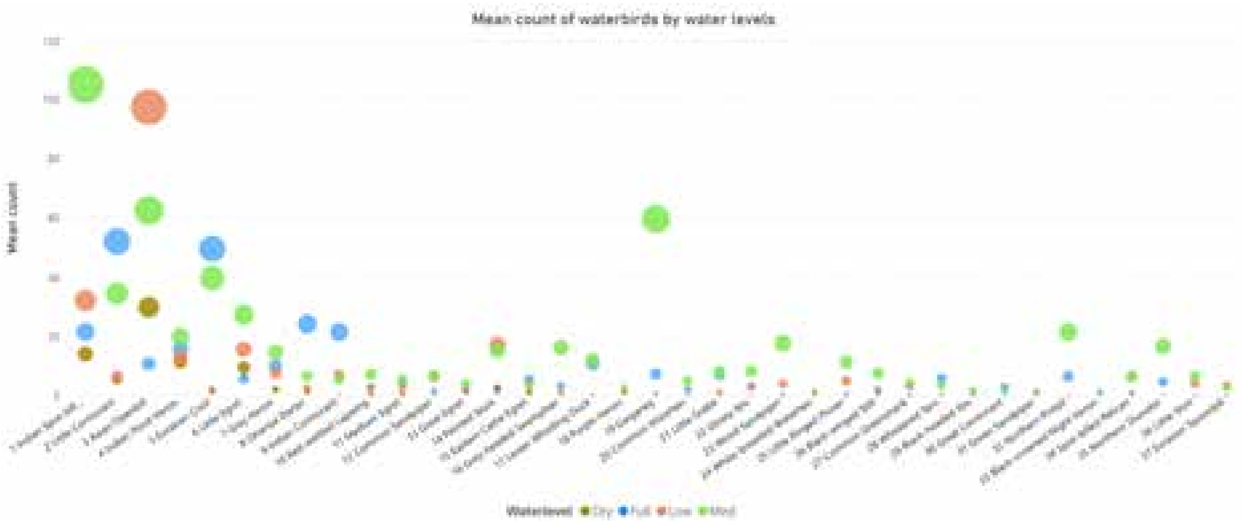


Image 4. Mean counts of individual waterbird species by water levels.

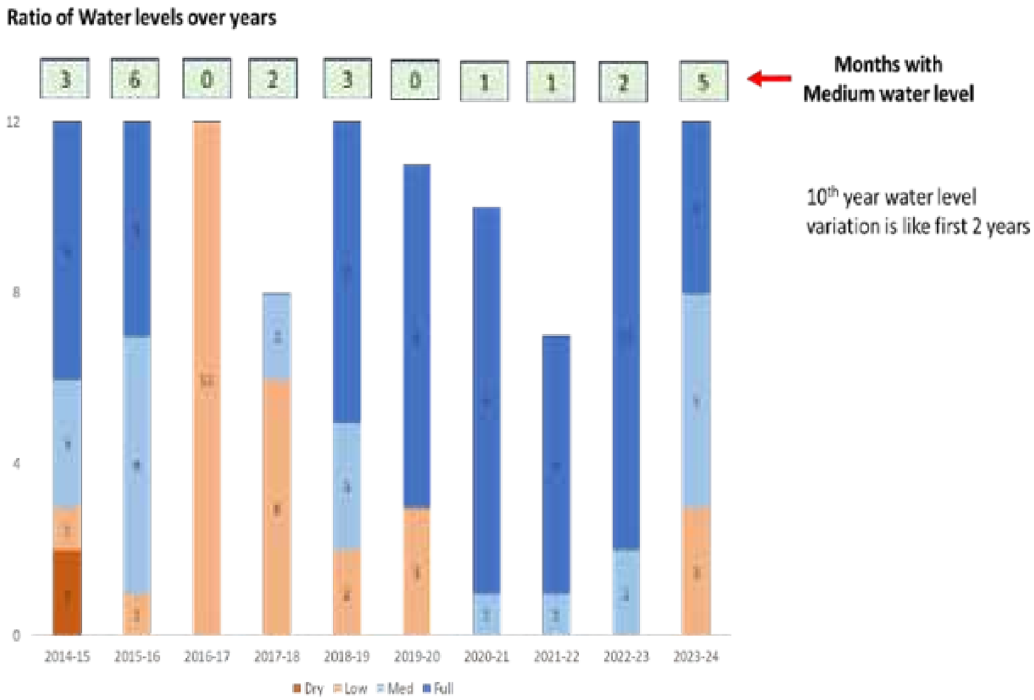


Image 5. Water level variations across the decade.

Perur Lake than national trends; for example, in the case of Garganey *Spatula querquedula*, the highest decline as per SoIB is 6.84% annually, whereas in Perur Lake it is 12.7%. Therefore, local anthropogenic activities have also most likely played a significant role in contributing to this decline (Parameswaran et al. 2023a; Byju et al. 2024a). According to Evans et al. (2008), local factors are more influential than regional ones and, by logical extension, national and international factors.

Table 6. Population decline in waterbirds of Perur Lake.

Guild / Species No.	Status of waterbirds	Total species	Range of population decline in % (1st 5 years vs last 5 years)
Guild I, IV and V	WM	9	86% to 99%
Guild II, X and S-3	R, LM	8	43% to 61%
Guild III, VIII and IX	R, LM	8	24% to 38%
S-5 and S-6	R, LM	2	3% to 4%

Table 7. Negative impact of commercial fishing on waterbirds of the lake.

Period	Number of surveys	Average number of waterbird species per month	Average number of waterbirds per month	Average number of winter ducks, winter shorebirds
May 2014 to Sep 2018 (Before commercial fishing)	49	20	373	92
Oct 2018 to Apr 2024 (Since commercial fishing)	59	18.5	313	11
Decrease	-	7.5%	16%	88%

Table 8. Negative impact of road expansion on waterbirds in the periphery of the lake.

Period	Number of surveys	Average number of waterbird species per month	Average number of waterbirds per month	Average number of rails	Average number of Eurasian Coot	Average number of Little Grebe
Mar 2019 to Feb 2021 (during road expansion)	21	17	177	2	1	0.1
Mar 2021 to Apr 2024 (After road expansion)	33	19	394	6	34	9
Increase in % after cessation of disturbance due to road expansion	-	12%	123%	300%	3400%	8900%

Impact of anthropogenic actions

Anthropogenic actions in Perur Lake can be broadly categorized as follows:

Commercial fishing

The commercial fishing operation was started in October 2018 and is primarily carried out in the eastern part of the wetland, covering approximately 69% of the water spread area, with occasional forays into the western area of the lake (Image 6). This operation was implemented in this core area of the wetland without any safety features for the bird population (Parameswaran et al. 2023a). This has significantly impacted the waterbird population, especially the Guilds I, IV & V comprising winter migrant ducks and shorebirds, and the Guilds III, VIII, IX & X comprising resident and local migrant waterbirds. This is true for birds found in the deeper water (Image 4) as well as those on the margins (Parameswaran et al. 2023a; Byju et al. 2025). The comparison of waterbird population before and after the commercial fishing shows 16% decline in the overall waterbird population and 88% decline in winter migrant ducks and shorebirds (Table 7). These results indicate a strong negative association between commercial fishing activity and the abundance of winter migrant waterbirds. The logical framework supporting this inference, along with the underlying hypotheses, is provided in the supplementary file (Parameswaran et al. 2025). Image 5 shows the annual variation of water level across the decade, indicating the higher water levels in the last five years to aid "Commercial fishing".

As per Lorenzon et al. (2017), "changes in hydrological fluctuation result in changes to the availability of food, because the prey for these waterbirds are affected by fluvial dynamics". This reference states that out of 21 species analysed, 12 species were negatively affected by rise in water levels in the Parana River in Argentina, which constituted eight shorebirds, one egret, one heron, one ibis, and the last one being Wood Rail, which is a result of loss of floodplains and beaches (mudflats). Similar long-term studies on shorebird population on Manoli Island, located in the Gulf of Mannar, Tamil Nadu, substantiates the studies (Byju et al. 2023). The significant difference is that the water level fluctuations in the Parana River are part of the ebb and flow of the river's ecosystem function, whereas in Perur Lake, they are caused by human action. The higher water level in the core area of Perur Lake makes food inaccessible to many waterbird guilds, especially winter migrant ducks and shorebirds. Globally, the modification of natural systems affects bird species, and the biological resource extraction, such as fishing, alone exceeds 200 species (Lees et al. 2022).

Some examples of waterbirds that prefer various water levels are (1) Asian Openbill *Anastomus oscitans* and Painted Stork *Mycteria leucocephala* for low, (2) Indian Spot-billed Duck *Anas poecilorhyncha* and Wood Sandpiper *Tringa glareola* for medium and (3) Indian Cormorant *Phalacrocorax fuscicollis* and Eurasian Coot *Fulica atra* for full.

Road expansion

From March 2019 onwards, the wetland was

Image 6. Commercial fishing using fixed nets and a coracle. © G. Parameswaran.

Image 7. Building of the containment wall in the wetland for road expansion during the dry season. © G. Parameswaran.

Image 8. The submerged containment wall during the monsoon season. © G. Parameswaran

Image 9. Sand mining in Perur Lake from June–September 2017. © G. Parameswaran

subjected to an encroachment in the form of expansion of the existing road (Images 7 & 8), which was finished in February 2021. This entailed the removal of vegetation and the appropriation of the wetland's area for a two-lane roadway. An estimated 0.1 km^2 (c. 9% of water coverage area) has been encroached for the construction of a containment wall of 1.5m in height along the perimeter of the wetland (Image 7). During this period, the birds that were dependent on the periphery of the wetland, like the Common Moorhen *Gallinula chloropus*, Eurasian Coot *Fulica atra*, Grey-headed Swamphen *Porphyrio poliocephalus* and White-breasted Waterhen *Amaurornis phoenicurus* declined sharply based on our data (Parameswaran et al. 2023a). Since the completion of the road expansion operation, Rails as a guild, Eurasian Coot *Fulica atra* and Little Grebe *Tachybaptus ruficollis* have recovered moderately (Table 8).

Nevertheless, this recovery has not attained the higher levels of the previous years, and it is evident that a road expansion has had a deleterious effect. A similar phenomenon was also noticed during the previous road construction operation from March 2014 to August 2014 (Parameswaran & Sivashankar 2018).

Sandmining

From June 2017 to September 2017, Perur Lake was subjected to sandmining, technically called reclamation (O'Connell 2000), which altered the character of the core area of the wetland. Deep pits and ravines that resulted from this operation altered 69% of the water spread area (Image 9). The topography of the gentle-sloping bowl-shaped wetland that was once hospitable to various waterbird groups like ducks, shorebirds, and egrets, deteriorated significantly (Parameswaran et al. 2023a).

Due to all these disturbances, there is an overall decrease in waterbird population from May 2014 to April 2024, and the low counts are a result of the superimposition of the above-mentioned anthropogenic actions (Image 1). Waterbirds usually avoid areas with extensive disturbance, choose roosting or foraging sites without them, and generally prefer wetlands with features that maximise the abundance and accessibility of their food (Khan et al. 2016; Lorenzon et al. 2017; Parameswaran et al. 2023a).

The most probable reasons for the decline of the winter migrant waterbird population are sand mining (executed between June–September 2017) and unregulated commercial fishing (from October 2018 and continuing to the present day). Both these anthropogenic disturbances executed in tandem maintained high water levels in the core area of the wetland, covering 69% of the water spread area to facilitate commercial fishing.

CONCLUSION & RECOMMENDATIONS

Based on the results of the data analysis of the decadal study in Perur Lake, the following conclusions are drawn:

1. Unregulated commercial fishing carried out in the core area of the lake, covering 69% of the water spread area, is most probably the principal reason for the decline of the waterbirds and especially the winter migrants.
2. Disturbances like sandmining in the core area of the wetland have more lasting impacts than the disturbances along the periphery, like road expansion.
3. Even though the impacts caused by road expansion are less than those of commercial fishing and sandmining, it also depresses the population of waterbirds, and it is not an endorsement to use the periphery of the lake as a transportation corridor.

The data in conjunction with the above-mentioned inferences emphasize the urgency of addressing the downward population trend in common waterbirds. It is demonstrated that the anthropogenic disturbances in an urban wetland are detrimental to the waterbirds it supports. While the decline in waterbirds can be correlated with the local disturbances, these threats may have acted in tandem with decline events outside the study area.

Results from the first six years have shown (Parameswaran et al. 2023a) that 12 common birds have declined overall from 43% to 100%. The current decadal study has expanded the scope by using the guild analysis and thereby demonstrated the decline of the waterbirds is more widespread and encompasses 73% of the waterbirds analysed.

Perur Lake was actively considered for the designation as a "bird sanctuary" due to the presence of a large number of migratory and resident birds (Mohanraj et al. 2000; Chandra et al. 2009). The establishment of buffer areas around the lakes could have reduced the anthropogenic pressures and augmented the natural purification processes in these systems, and improved the environmental quality of the wetland (Chandra et al. 2009). The non-implementation of those protective measures promptly has not only resulted in the reduction of bird population due to loss of habitat but also the overall deterioration in the functioning of the ecosystem.

The National Green Tribunal (NGT) took suo-moto cognizance (O.A. No. 84 of 2024, 18 September 2024) of the decline of waterbirds in Perur Lake based on our six-year study (Parameswaran et al. 2023a) and the associated article (Parameswaran et al. 2023b). The judgement instructed the Tamil Nadu government to designate Perur Lake as a wetland, but with no definite timeline.

By contrast, in the case of the Nanjarayan Tank, Tirupur District (11.212° N, 77.362° E), it was transferred from the Public Works Department (PWD) to the Forest Department for conservation, notified as a bird sanctuary (Gazette notification) in 2022, and designated a Ramsar Site in 2024. This represents a successful case of 'Navigating the back loop' (Biggs et al. 2010) where a transformative governance shift, rather than incremental change, helped in resolving existing stakeholder conflicts and integrated ecological conservation with socio-economic benefits.

The latest IPCC (2021) report titled "summary for policy makers", along with the Tamil Nadu wetland mission (2022), has multiple model possibilities for various scenarios for future conservation. From a wetland perspective, they indicate that continued "global warming will disrupt the global hydrological cycle and thereby influence the global monsoon precipitation and the severity of wet and dry events" with a high degree of certainty. The Millennium Ecosystem Assessment (2005b) on wetland and water recommends "wise use of wetlands by maintaining their ecological character for long-term sustainability". Therefore, the administrative institutions were urged whether national, state, or local, to manage the wetlands as responsible stewards rather than enablers for unsustainable resource extraction that seriously disrupts the wetland ecosystem. It is also recommended that the Tamil Nadu Government follow the successful administrative strategy used for "Nanjarayan tank" and designate Perur Lake as a wetland without any further delay.

Although limited to a single wetland, this study serves as an early warning indicator of progressive ecological degradation, especially in the wetlands of Coimbatore District. The ecological integrity of Perur Lake is best sustained when it functions as a floodplain extension of the Noyyal River riparian corridor supporting a diverse bird population, invertebrates, moderating floods, enabling groundwater recharge, and providing irrigation, rather than being managed as an impounded water storage system prioritizing extractive uses such as commercial fishing (O'Connell 2000).

It is important that coordinated, synchronous monitoring of birds of the adjacent wetlands is necessary to develop a landscape-level understanding of the ecological functions of the Greater Coimbatore wetlands. It is also proposed that the second Saturday of each month can be designated as wetland bird survey days to help with this effort.

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Author contribution: Parameswaran conceived the study, collected the data and references. R. Sivashankar handled the data, and its computational aspects. Vridhi. R co-authored and edited the manuscript of the Supplementary text with G. Parameswaran, while R. Sivashankar designed the species' data dashboard. All the authors contributed equally to the interpretation of the results, the preparation of the manuscript and its correction.

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ARTICLE

Diversity and habitat associations of avifauna in the Poovar Estuary, Kerala, India

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Abstract: This study assessed bird diversity in Poovar, a coastal wetland complex in Thiruvananthapuram district, Kerala, India, from August 2024 to July 2025. 88 bird species from 17 orders and 37 families were documented, encompassing both resident and migratory populations. According to the IUCN Red List, all species were categorized as 'Least Concern' except for the River Tern *Sterna aurantia* and Oriental Darter *Anhinga melanogaster,* listed as 'Vulnerable' and 'Near Threatened', respectively. Based on migratory status, 56 species were residents and 32 were winter visitors, highlighting the role of Poovar as a significant refuge for migratory waterbirds along the southwest coast of India. Feeding guild analysis showed that 34% of species were insectivorous, followed by carnivores and piscivores, reflecting the functional diversity of the community. Habitat association indicated waterbirds utilized varied habitats, showing overlap in habitat-specific assemblages such as backwater, mangroves, and beaches, emphasizing the influence of habitat heterogeneity on avian distribution. Urban areas showed a distinctive species composition having little overlap with farmland assemblages. The habitat mosaic of Poovar supports a diverse and dynamic avifaunal assemblage. Habitat association analysis indicated that waterbirds utilized a variety of habitats.

Keywords: Avifaunal list, biodiversity, backwater, beach, estuary, habitats, Kerala, migratory birds, species assemblage, urban birds.

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Author contribution: BSB—data collection, first draft writing; VR—research planning, data curation, writing and supervision; HM—data curation, analysis and writing; HB—supervision, planning, writing and editing.

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INTRODUCTION

Tropical coastal ecosystems are among the most productive and biologically rich environments globally, supporting a high diversity of avifauna that fulfil critical ecological roles (Rashiba et al. 2022). Birds make significant contributions to ecosystem functioning through processes such as pollination, seed dispersal, regulation of invertebrate and rodent populations, scavenging, and nutrient cycling (Şekercioğlu 2006; Archana et al. 2024). The composition and structure of avian communities in these dynamic landscapes are strongly influenced by habitat heterogeneity, resource availability, and seasonal hydrological fluctuations (Byju et al. 2024a, 2025a). Their specific habitat requirements and trophic positions make birds sensitive to environmental change and reliable bioindicators for assessing ecosystem health and the impacts of anthropogenic disturbances (Byju et al. 2024b; Kumar et al. 2025).

In the Indian subcontinent, coastal wetlands, estuaries, and mangrove systems along both the east and west coasts provide crucial habitats for a vast array of resident and migratory birds (Byju et al. 2023a,b, 2025b) and serve as vital stopover and wintering grounds within the Central Asian Flyway (CAF). Recent avifaunal studies from diverse coastal sites such as the Gulf of Mannar lagoons (Byju et al. 2025c,d), islands (Byju et al. 2023c), and Muthukkad backwaters on the eastern coast (Shree & Malathi 2024), and Changaram wetlands (Anand et al. 2023), on the western coast, highlight the regional significance of these understudied habitats for sustaining biodiversity. However, many smaller, ecologically complex estuaries remain under-surveyed, leading to gaps in our understanding of local species assemblages and their conservation needs.

The Poovar estuary, situated at the southern tip of Kerala on the southwestern coast of India, represents one such understudied coastal mosaic. This dynamic system, formed by the confluence of the Neyyar River, backwaters, the Arabian Sea, and fringing mangroves creates a heterogeneous landscape of sandbars, mudflats, freshwater marshes, and anthropogenically modified areas. The region is important along the CAF, providing critical resources for foraging, roosting, and breeding birds. In this context, systematic baseline studies are imperative for generating robust scientific data to inform conservation planning and sustainable management. This study represents the first systematic, habitat-based avifaunal assessment of the Poovar region. The research objectives are to compile a systematic checklist of bird species, documenting their relative abundance, habitat associations, and temporal occurrence, thus addressing a significant knowledge gap in the avifauna of Kerala's coast, and provide insights for local and regional conservation strategies.

MATERIALS AND METHODS

Study area

Poovar is a coastal village in the Neyyattinkara Taluk of Thiruvananthapuram District, Kerala, India (8.3002–8.3502 °N; 77.0336–77.0836 °E). It lies within the Poovar Grama Panchayat under the Parassala Block Panchayat. The area represents a unique ecological confluence of marine, estuarine, riverine, mangrove, and terrestrial ecosystems, supporting high habitat heterogeneity and avian diversity. Four distinct habitats were selected for the present study (Image 1): 1. Poovar Backwater: A 6-km stretch of the Neyyar River backwater (50–200 m wide), providing feeding and roosting habitats for waterbirds; 2. Poovar Beach: A ~12 km sandy shoreline where the Neyyar River meets the Arabian Sea, important for migratory shorebirds and coastal avifauna; 3. Poovar Mangroves: Estuarine fringes (5 km, 20–80 m wide) with dense mangrove vegetation, functioning as nurseries and foraging sites; and 4. Human-settled areas: Settlements, agricultural fields, and transport corridors (~7 km), supporting synanthropic species.

Bird surveys

Avifaunal surveys were conducted from August 2024 to July 2025. Point counts were conducted with fixed points established across habitats, using 10-minute observations within a 50-m radius (Bibby et al. 2000). Surveys were conducted monthly, once at 0700–1000 h and again at 1600–1800 h, coinciding with peak bird activity. Birds were observed using Olympus 8 × 40 binoculars and photographed with a Nikon Z6III and NIKKOR 200–500 mm lens. Double-counting was avoided by recording flight directions and repeated movements, and avoiding species count coming from behind the observer. Permanent survey routes and observation points across habitats were monitored once per month to assess temporal variation. Birds were identified using standard field guides (Grimmett et al. 2011). We followed the taxonomy, nomenclature and Indian Wildlife Protection Act (IWPA) status based on IOC World Bird List v.14.1 (Praveen et al. 2023; Gill et al. 2024). Conservation status was assessed using the IUCN Red List (IUCN 2025).

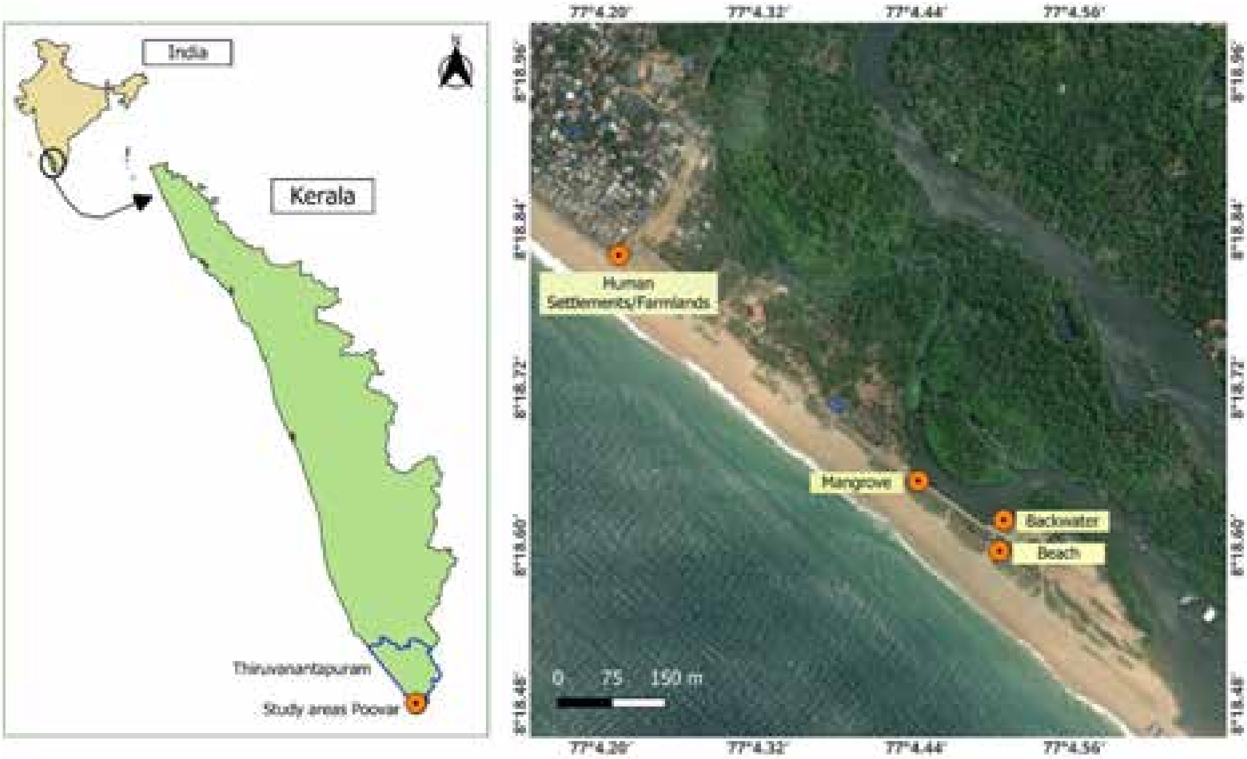

Image 1. Map of Poovar estuary regions study area.

Relative diversity index (RDi) of the avian families was calculated with the following formula (Torre-Cuadros et al. 2007):

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

Multiple correspondence analysis (MCA) was performed to analyze the association between bird species and habitat categories. MCA is an extension of correspondence analysis designed for multivariate categorical data, allowing simultaneous visualization of relationships between species occurrences and habitat types in a low-dimensional space (Greenacre & Blasius 2006).75% confidence ellipses were added around habitat groupings to represent the dispersion and overlap of species compositions within each habitat. Overlap among ellipses indicates shared species assemblages and distributions across habitats. The analysis was done using R software version 4.5.1. (R core team 2025).

RESULTS AND DISCUSSION

During the study period, a total of 88 avian species were recorded, representing 17 orders and 37 families, which included 70 genera. Poovar avifauna comprised 46 species of waterbirds and 42 species of landbirds. Among the waterbirds, order Charadriiformes predominated (n = 25 species), with four families, followed by Pelecaniformes (n = 12) with two families. Landbirds were majorly represented by Passeriformes (n = 24), with 14 families, followed by Coraciiformes (6 species) (Image 2).

The family-wise analysis of avifauna revealed variation in relative diversity. Laridae (14 species, RDi 16.0%) was the most dominant, followed by Ardeidae (9 species, RDi 10.2%) and Scolopacidae (6 species, RDi 6.8%). Alcedinidae, Charadriidae, & Sturnidae (4 species each, RDi 4.5%); Accipitridae, Corvidae, Cuculidae, Dicruridae, Motacillidae, & Threskiornithidae (3 species each, RDi 3.4%); and Ciconiidae, Cisticolidae, Meropidae, & Phalacrocoracidae (2 species each, RDi 2.2%), followed the dominance. The remaining 21 families recorded the lowest species richness (one species each and RDi 1.1%) (Image 3).

Feeding guild analysis showed that while 34% of the total avifauna were insectivorous (30 species), the remaining were carnivorous (22 species), omnivorous (18 species) and piscivorous (15 species). There were only two nectarivores, Pale-billed Flowerpecker *Dicaeum erythrorhynchos*, which is also a frugivore, and Purple-rumped Sunbird *Leptocoma zeylonica*. Another frugivore

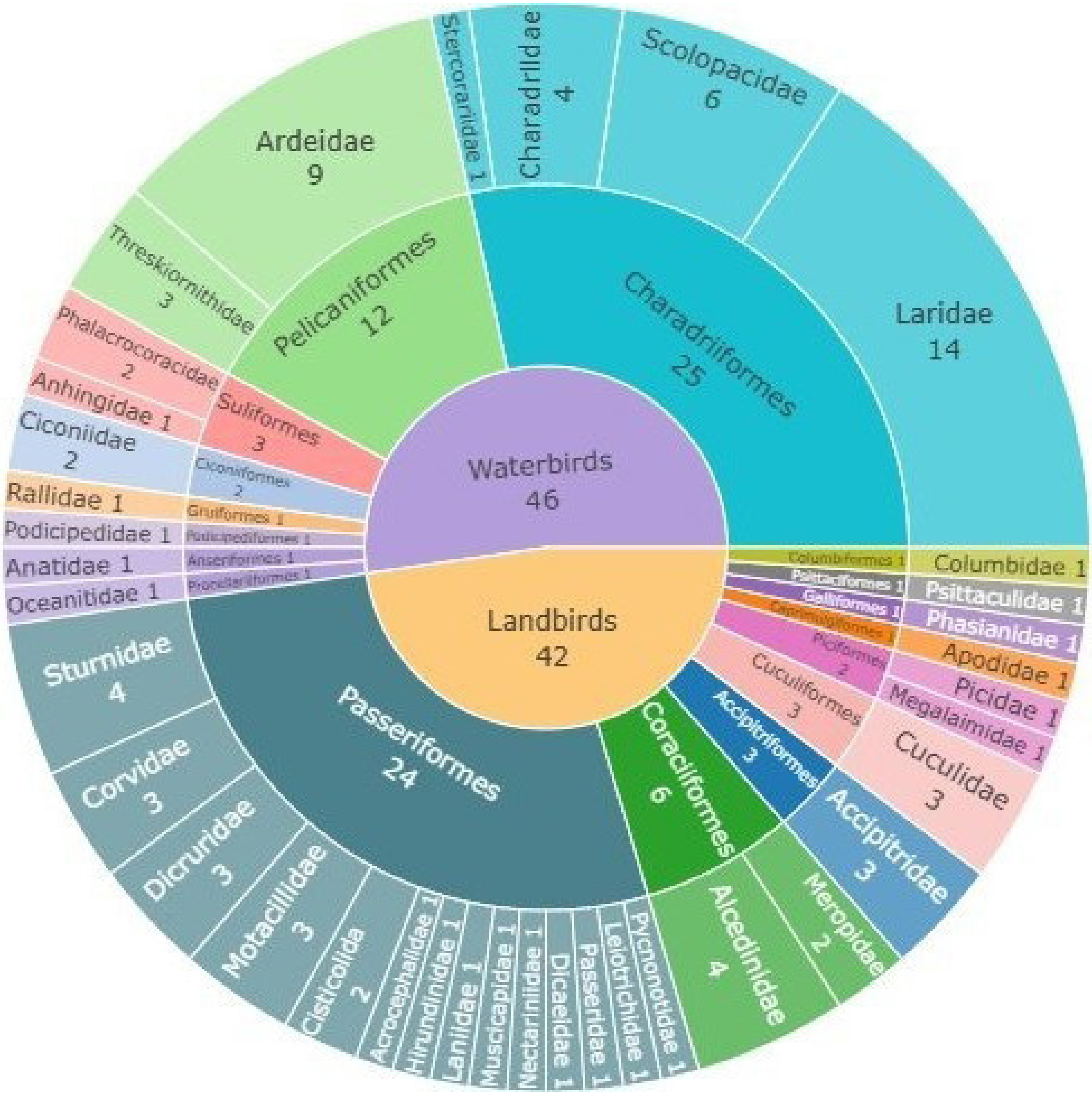

Image 2. Orders and families of waterbirds and landbirds, with the respective number of species recorded in Poovar.

recorded was Rose-ringed Parakeet *Psittacula krameri* (Image 4). According to migratory status, resident birds constituted 64% (56 species) of species, while winter visitors accounted for the rest.

Of the species documented, 86 were categorized as 'Least Concern', the Oriental Darter *Anhinga melanogaster* as 'Near Threatened', and the River Tern *Sterna aurantia* as 'Vulnerable'. As per the Indian Wildlife Protection Act (IWPA) 2022, eight species were under Schedule I, 79 species under Schedule II, and one species, House Crow *Corvus splendens*, is Not Scheduled (Table 1).

The peak counts of most of the birds recorded during the study period were from October to February. Black Kite *Milvus migrans* was the most abundant landbird species (n = 450 in December), followed by House Crow (n = 200 in July) and Brahminy Kite *Haliastur indus* (n = 156 in September). Both the kite species were recorded in all kinds of habitats - backwater, mangrove, urban and beach area, typical of their scavenging nature. One individual of another raptor, Shikra *Accipiter badius*, was recorded in November in the backwater and mangrove area. Among the waterbirds, the most abundant species were Glossy Ibis *Plegadis falcinellus* (n = 60 in

Table 1. Species list with IUCN Red List status, migration status, WPA status, along with feeding guilds and habitats.

Orders	Families	Common name	Scientific name	WPA Schedule	IUCN Red List status	Migratory status	Feeding guild	Major habitats
Accipitriformes	Accipitridae	Black Kite	*Milvus migrans* (Boddaert, 1783)	I	LC	R	C	BW, MG, BC, UA
		Brahminy Kite	*Haliastur indus* (Boddaert, 1783)	I	LC	R	C	BW, MG, BC, UA
		Shikra	*Accipiter badius* (Gmelin, 1788)	I	LC	R	C	BW, MG
Caprimulgiformes	Apodidae	Asian Palm Swift	*Cypsiurus balasiensis* (Gray, JE, 1829)	II	LC	R	I	UA, FL
Columbiformes	Columbidae	Rock Pigeon	*Columba livia* (Gmelin, JF, 1789)	II	LC	R	O	UA
Coraciiformes	Alcedinidae	Common Kingfisher	*Alcedo atthis* (Linnaeus, 1758)	II	LC	R	P	BC, BW, MG
		Pied Kingfisher	*Ceryle rudis* (Linnaeus, 1758)	II	LC	R	P	BW, MG
		Stork-billed Kingfisher	*Pelargopsis capensis* (Linnaeus, 1766)	II	LC	R	C	BW, MG
		White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	II	LC	R	C	BW, MG
	Meropidae	Asian Green Bee-eater	*Merops orientalis* (Latham, 1801)	II	LC	R	I	BW, MG
		Blue-tailed Bee-eater	*Merops philippinus* (Linnaeus, 1767)	II	LC	WV	I	BW, MG
Cuculiformes	Cuculidae	Asian Koel	*Eudynamys scolopaceus* (Linnaeus, 1758)	II	LC	R	O	UA
		Greater Coucal	*Centropus sinensis* (Stephens, 1815)	II	LC	R	O	UA
		Pied Cuckoo	*Clamator jacobinus* (Boddaert, 1783)	II	LC	WV	I	FL
Galliformes	Phasianidae	Peregrine Falcon	*Falco peregrinus* (Tunstall, 1771)	I	LC	WV	C	BC, UA
Passeriformes	Acrocephalidae	Blyth's Reed Warbler	*Acrocephalus dumetorum* (Blyth, 1849)	II	LC	WV	I	BW
	Cisticolidae	Ashy Prinia	*Prinia socialis* (Sykes, 1832)	II	LC	R	I	BW, UA
		Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	II	LC	R	I	UA
	Corvidae	House Crow	*Corvus splendens* (Vieillot, 1817)	Not sche-duled	LC	R	O	UA
		Large-billed Crow	*Corvus macrorhynchos* (Wagler, 1827)	II	LC	R	O	UA, BC
		Rufous Treepie	*Dendrocitta vagabunda* (Latham, 1790)	II	LC	R	O	BW
	Dicruridae	Ashy Drongo	*Dicrurus leucophaeus* (Vieillot, 1817)	II	LC	R	I	BW, FL
		Greater Racket-tailed Drongo	*Dicrurus paradiseus* (Linnaeus, 1766)	II	LC	R	I	BW, FL
		Black Drongo	*Dicrurus macrocercus* (Vieillot, 1817)	II	LC	R	I	BW, FL
	Hirundinidae	Barn Swallow	*Hirundo rustica* (Linnaeus, 1758)	II	LC	WV	I	BW, FL
	Laniidae	Brown Shrike	*Lanius cristatus* (Linnaeus, 1758)	II	LC	WV	I	BW, FL
	Motacillidae	Paddyfield Pipit	*Anthus rufulus* (Vieillot, 1818)	II	LC	R	I	BW, FL
		White-browed Wagtail	*Motacilla maderaspatensis* (Gmelin, JF, 1789)	II	LC	R	I	BW
		Grey Wagtail	*Motacilla cinerea* (Tunstall, 1771)	II	LC	WV	I	BW
	Muscicapidae	Oriental Magpie-Robin	*Copsychus saularis* (Linnaeus, 1758)	II	LC	R	I	BW, FL, UA
	Nectariniidae	Purple-rumped Sunbird	*Leptocoma zeylonica* (Linnaeus, 1766)	II	LC	R	N	BW, FL, UA
	Dicaeidae	Pale-billed Flowerpecker	*Dicaeum erythrorhynchos* (Latham, 1790)	II	LC	R	F/N	BW, FL, UA

Orders	Families	Common name	Scientific name	WPA Schedule	IUCN Red List status	Migratory status	Feeding guild	Major habitats
Passeriformes	Passeridae	House Sparrow	*Passer domesticus* (Linnaeus, 1758)	II	LC	R	O	FL, UA
	Sturnidae	Brahminy Starling	*Sturnia pagodarum* (Gmelin, JF, 1789)	II	LC	R	O	FL, UA
		Common Myna	*Acridotheres tristis* (Linnaeus, 1766)	II	LC	R	O	FL, UA
		Jungle Myna	*Acridotheres fuscus* (Wagler, 1827)	II	LC	R	O	FL, UA
		Rosy Starling	*Pastor roseus* (Linnaeus, 1758)	II	LC	WV	O	BW, FL, UA
	Leiotrichidae	Yellow-billed Babbler	*Argya affinis* (Jerdon, 1845)	II	LC	R	O	BW, FL, UA
	Pycnonotidae	Red-whiskered Bulbul	*Pycnonotus jocosus* (Linnaeus, 1758)	II	LC	R	O	BW, FL, UA
Piciformes	Megalaimidae	White-cheeked Barbet	*Psilopogon viridis* (Boddaert, 1783)	II	LC	R	O	BW, MG
	Picidae	Black-rumped Flameback	*Dinopium benghalense* (Linnaeus, 1758)	II	LC	R	I	BW, FL
Psittaciformes	Psittaculidae	Rose-ringed Parakeet	*Psittacula krameri* (Scopoli, 1769)	II	LC	R	F	FL, UA
Charadriiformes	Charadriidae	Greater Sand Plover	*Anarhynchus leschenaultii* (Lesson, RP, 1826)	II	LC	WV	I	BC
		Kentish Plover	*Anarhynchus alexandrinus* (Linnaeus, 1758)	II	LC	WV	I	BC
		Tibetan Sand Plover	*Anarhynchus atrifrons* (Wagler, 1829)	II	LC	WV	I	BC, BW
		Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	II	LC	R	I	BW, FL
	Laridae	Bridled Tern	*Onychoprion anaethetus* (Scopoli, 1786)	II	LC	WV	P	BC
		Little Tern	*Sternula albifrons* (Pallas, 1764)	II	LC	WV	P	BC, BW, MG
		Common Tern	*Sterna hirundo* (Linnaeus, 1758)	II	LC	WV	P	BC, BW, MG
		River Tern	*Sterna aurantia* (Gray, JE, 1831)	I	VU	R	P	BC, BW
		Greater Crested Tern	*Thalasseus bergii* (Lichtenstein, MHC, 1823)	II	LC	WV	P	BC, BW, MG
		Lesser Crested Tern	*Thalasseus bengalensis* (Lesson, RP, 1831)	II	LC	WV	P	BC
		Sandwich Tern	*Thalasseus sandvicensis* (Latham, 1787)	II	LC	WV	P	BC
		Gull-billed Tern	*Gelochelidon nilotica* (Gmelin, JF, 1789)	I	LC	WV	O	BC, BW, MG
		Whiskered Tern	*Chlidonias hybrida* (Pallas, 1811)	II	LC	WV	P	BC, BW, MG
		Caspian Tern	*Hydroprogne caspia* (Pallas, 1770)	II	LC	WV	P	BC, BW, MG
		Lesser Black-backed Gull	*Larus fuscus* (Linnaeus, 1758)	II	LC	WV	C	BC, BW, MG
		Black-headed Gull	*Larus ridibundus (Linnaeus, 1766)*	II	LC	WV	C	BC, BW, MG
		Brown-headed Gull	*Chroicocephalus brunnicephalus* (Jerdon, 1840)	II	LC	WV	C	BC, BW, MG
		Pallas's Gull	*Ichthyaetus ichthyaetus* (Pallas, 1773)	II	LC	WV	C	BC, BW, MG
	Scolopacidae	Common Sandpiper	*Actitis hypoleucos* (Linnaeus, 1758)	II	LC	WV	I	BC, BW, MG, FL
		Sanderling	*Calidris alba* (Pallas, 1764)	II	LC	WV	I	BC
		Temminck's Stint	*Calidris temminckii* (Leisler, 1812)	II	LC	WV	I	BC
		Common Greenshank	*Tringa nebularia* (Gunnerus, 1767)	I	LC	WV	I	BC
		Wood Sandpiper	*Tringa glareola* (Linnaeus, 1758)	II	LC	WV	I	BC, FL
		Whimbrel	*Numenius phaeopus* (Linnaeus, 1758)	II	LC	WV	I	BC

Orders	Families	Common name	Scientific name	WPA Schedule	IUCN Red List status	Migratory status	Feeding guild	Major habitats
	Stercorariidae	Parasitic Jaeger	*Stercorarius parasiticus* (Linnaeus, 1758)	II	LC	WV	C	BC
Ciconiiformes	Ciconiidae	Asian Openbill	*Anastomus oscitan* (Boddaert, 1783)	II	LC	R	C	BC, FL
		Painted Stork	*Mycteria leucocephala (Pennant, 1769)*	II	LC	R	C	BC, FL
Gruiformes	Rallidae	White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant, 1769)	II	LC	R	O	BW
Pelicaniformes	Ardeidae	Eastern Cattle Egret	*Bubulcus coromandus* (Boddaert, 1783)	II	LC	R	C	BC, FL
		Great Egret	*Ardea alba* (Linnaeus, 1758)	II	LC	R	C	BC, FL, MG
		Medium Egret	*Ardea intermedia* (Wagler, 1829)	II	LC	R	C	BC, FL, MG
		Grey Heron	*Ardea cinerea (Linnaeus, 1758)*	II	LC	R	C	BW, FL
		Purple Heron	*Ardea purpurea* (Linnaeus, 1766)	II	LC	R	C	BW, FL
		Indian Pond Heron	*Ardeola grayii* (Sykes, 1832)	II	LC	R	C	BW, FL
		Little Egret	*Egretta garzetta* (Linnaeus, 1766)	II	LC	R	C	BC, FL, MG
		Western Reef Heron	*Egretta gularis* (Bosc, 1792)	II	LC	R	C	BC, FL, MG
		Black-crowned Night Heron	*Nycticorax nycticorax (Linnaeus, 1758)*	II	LC	R	C	BW, FL
	Threskiornithidae	Black-headed Ibis	*Threskiornis melanocephalus (*Latham, 1790)	II	LC	R	I	BW, FL
		Eurasian Spoonbill	*Platalea leucorodia* (Linnaeus, 1758)	I	LC	R	I	BW, FL
		Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	II	LC	R	I	BW, FL
Procellariiformes	Oceanitidae	Wilson's Storm Petrel	*Oceanites oceanicus* (Kuhl, 1820)	II	LC	WV	P	BC
Suliformes	Anhingidae	Oriental Darter	*Anhinga melanogaster* (Pennant, 1769)	II	NT	R	P	BW, FL
	Phalacrocoracidae	Indian Cormorant	*Phalacrocorax fuscicollis* (Stephens, 1826)	II	LC	R	P	BW, MG
		Little Cormorant	*Microcarbo niger* (Vieillot, 1817)	II	LC	R	P	BW, MG
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	II	LC	R	O	BW, MG
Anseriformes	Anatidae	Lesser Whistling Duck	*Dendrocygna javanica* (Horsfield, 1821)	II	LC	R	O	BW, MG

WPA status: I—Schedule I | II—Schedule II. IUCN Red List status: LC—Least Concern | VU—Vulnerable | NT—Near Threatened. Migration status: WV—Winter visitor | R—Resident. Feeding guild: C—Carnivore | I—Insectivore | O—Omnivore | P—Piscivore | F—Frugivore | N—Nectarivore. Habitats: BW—Backwater | BC—Beach | MG—Mangrove | FL—Farmlands.

November), Lesser Black-backed Gull *Larus fuscus* (n = 56 in January), Greater Crested Tern *Thalasseus bergii* and Brown-headed Gull *Chroicocephalus brunnicephalus* (n = 34 each in March and February, respectively), and Tibetan Sand Plover *Anarhynchus atrifrons* (n = 30 in December) (Image 5).

The Multiple correspondence analysis (MCA) showed clear habitat-associated assemblages of bird species across the study area (Image 6). The first two dimensions (dim) explained 38.7% of the total variance (dim.1: 22.14%, eigenvalue 0.4059; dim.2: 16.55%, eigenvalue 0.3034), indicating that these axes captured the most significant patterns in species-habitat relationships (Table 2). Although subsequent dimensions each explained smaller proportions of variance, their contribution declined gradually, and interpretation was therefore focused on the first two axes for visualization. Species characteristic of beaches and sandbars, such as terns, plovers, and jaegers, clustered distinctly with the beach vector. While other species like Gulls, Tibetan Sand Plover, few species of terns like Common Tern *Sterna hirundo*, Little Tern *Sternula albifrons*, and Greater Crested Tern show overlapping habitat preferences of beaches, backwater, and mangroves. Backwater habitats

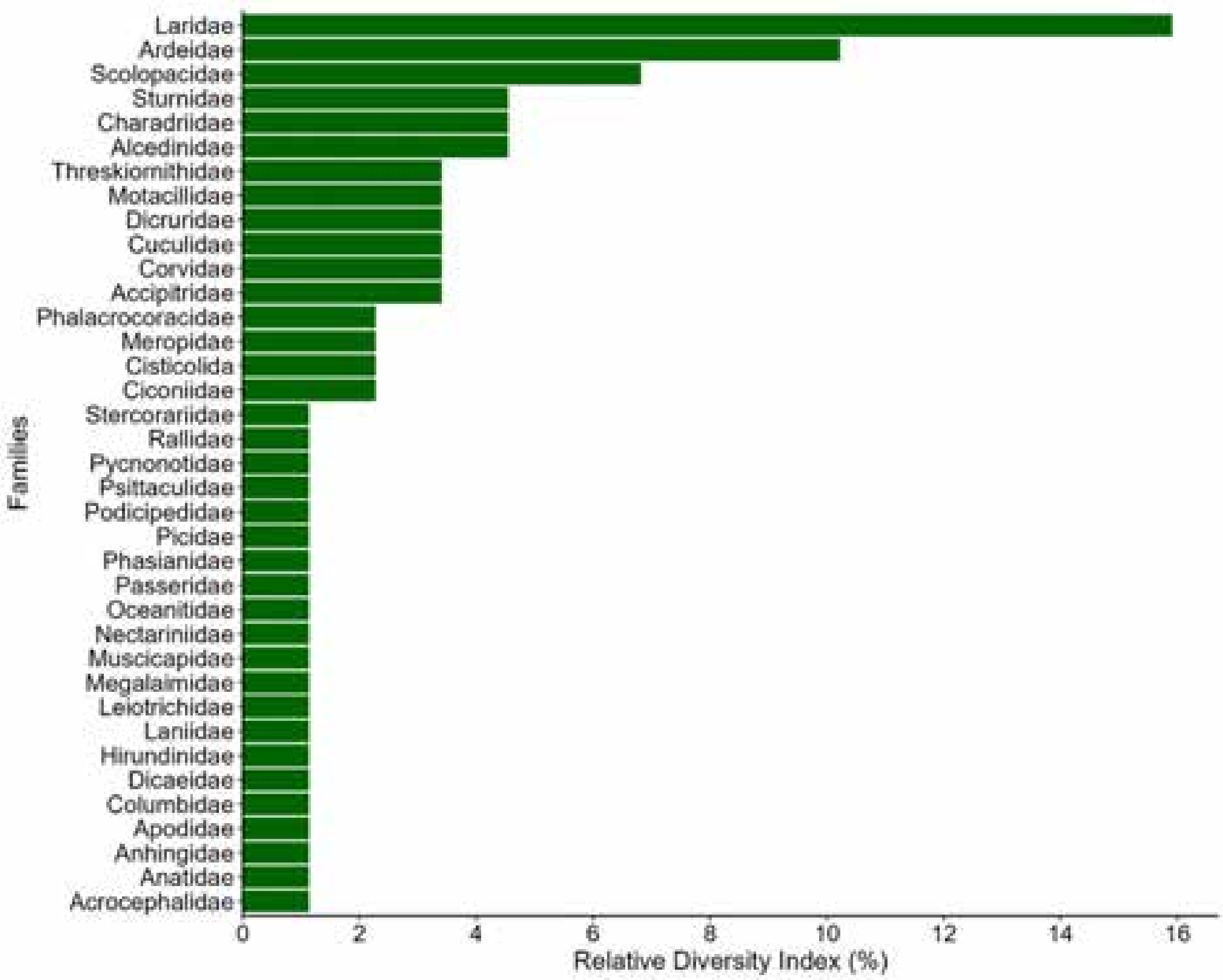

Image 3. Relative diversity index (%) of various families of avifauna recorded in Poovar.

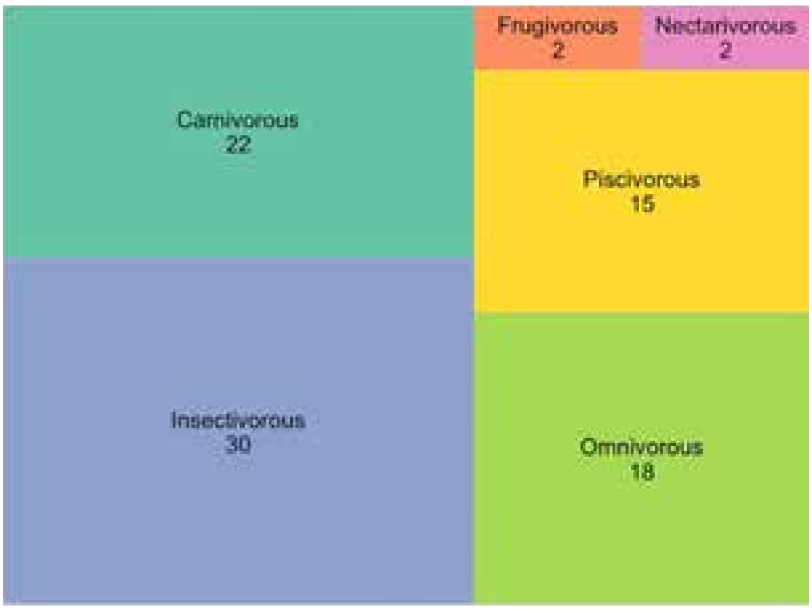

Image 4. Feeding guild composition of the avifauna in Poovar.

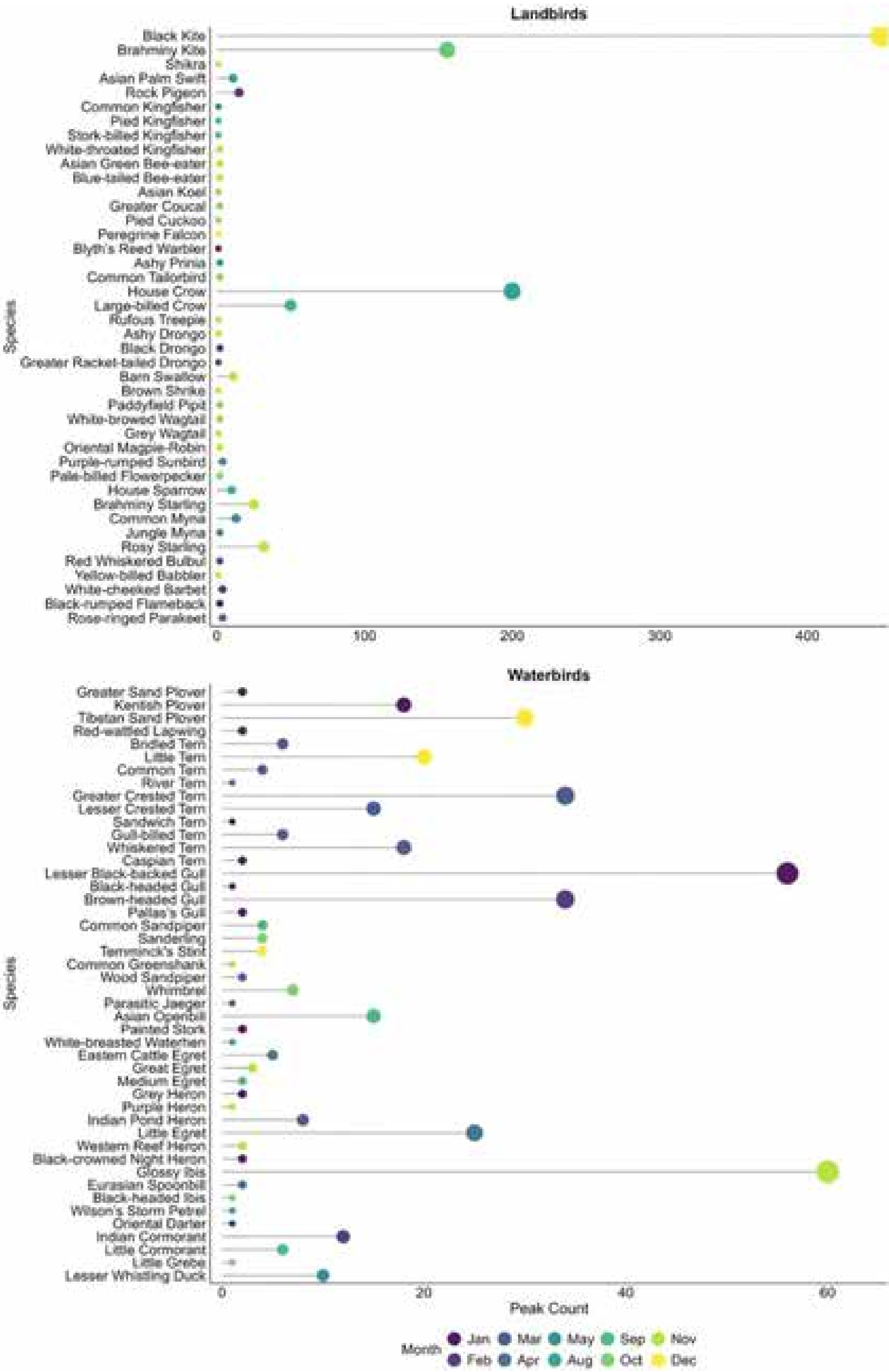

Image 5. Peak counts (one time) and the respective months of record of landbirds and waterbirds in Poovar.

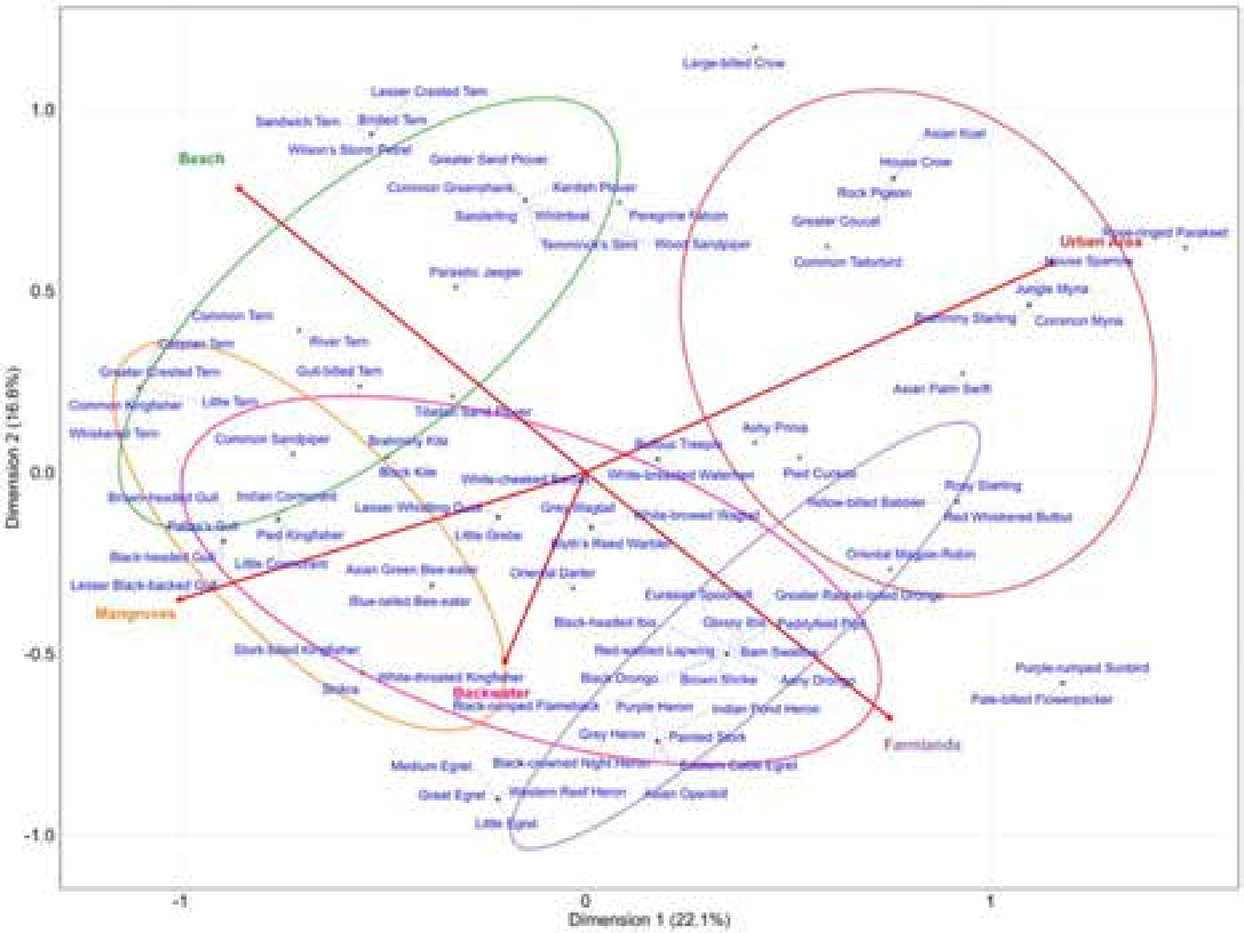

Image 6. Multiple correspondence analysis of the waterbirds and landbird species with diverse habitats in Poovar.

Table 2. Eigenvalues and percent variance explained by each multiple correspondence analysis dimension.

Dimensions	Eigenvalue	Variance percent
Dim.1	0.4059	22.14
Dim.2	0.3034	16.55
Dim.3	0.2198	11.99
Dim.4	0.1719	9.37
Dim.5	0.1711	9.33
Dim.6	0.1666	9.09
Dim.7	0.1411	7.69
Dim.8	0.1067	5.82
Dim.9	0.0581	3.17
Dim.10	0.0484	2.64
Dim.11	0.0397	2.16

showed a mixed assemblage of herons, egrets, storks, and ibises, with the majority of them overlapping with farmland habitats. Specific habitats, such as agricultural lands, were found to support the highest species richness of the insectivorous birds, whereas the wetland habitats were strongly associated with birds in the piscivorous and carnivorous guild (Panda et al. 2021). Agricultural fields supporting wetland birds are well documented in recent studies (Byju et al. 2024c).

Urban habitats or the human settlement areas formed a discrete group in Poovar, primarliy occupied by Passeriformes such as mynas, sparrows, coucal, koel, Common Tailor-bird *Orthotomus sutorius*, and pigeons. Very few landbird species, like Oriental Magpie Robin *Copsychus saularis*, Red-whiskered Bulbul *Pycnonotus jocosus,* among others, showed overlapping habitat preferences with both urban areas and farmlands. The size of each ellipse in the MCA plot represents the dispersion of species within that habitat category; larger ellipses indicate greater variability in species composition, just like composition, particularly in the backwater habitat (Image 7). In the MCA biplot, habitats represented by longer vectors, such as beach and urban areas, show species assemblages that are more distinct from the overall community, whereas shorter vectors indicate less exclusive species associations and greater compositional overlap, as observed for backwater and mangrove habitats. Along dimension 1, beach and mangrove habitats are positioned on the negative axis, while urban and farmland habitats occur on the positive axis, reflecting contrasting assemblages. Backwater habitat occupies an intermediate position and overlap with other habitats, highlighting their transitional species composition.

Diversity, abundance, and distribution of waterbirds are determined by the distinctive characteristics of habitats and factors such as food availability, vegetation characteristics, water availability, water quality, among others (Ma et al. 2010). Waterbirds comprised the majority of the avifaunam community in Poovar, with the order Charadriiformes being the dominant order. This aligned with the trend in other coastal ecosystems (Byju et al. 2025e), where species of Charadriidae and Laridae were the most abundant because of suitable feeding and roosting grounds, especially in heterogeneous habitats like estuaries, backwater, mangroves, and sandy beaches (Manikannan et al. 2012; Byju et al. 2024b). Such habitat mosaics offer diverse foraging substrates and water regimes, enabling partitioning of resources between different bird groups. Some bird species are associated with more than one habitat (Lorenzón et al. 2016). The occurrence of the same species in multiple habitat types indicates that the ecological and resource requirements of those species are fulfilled in both environments (Sharma et al. 2024). Similar patterns have been recorded in the Ashtamudi and Vembanad estuarine complexes of Kerala (Narayanan et al. 2011) and Perungulam wetland in Tamil Nadu (Mathibalan et al. 2026), where structurally complex wetlands supported higher bird diversities.

CONCLUSION

By sustaining diverse avian assemblages and facilitating breeding and seasonal occupancy, Poovar functions as a key node within the broader wetland network used by resident and migratory birds.

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ARTICLE

Abyssinian Blue-winged Goose *Cyanochen cyanoptera* Rüppell, 1845 population size, distribution, and habitat association in the central-south highlands of Ethiopia

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Abstract: The endemic and threatened Abyssinian Blue-winged Goose *Cyanochen cyanoptera* is restricted to the Ethiopian highlands, yet its population ecology and habitat use remain limited. This study assessed population size, spatial and temporal distribution, and habitat utilization across wetlands in the central-south highlands of Ethiopia over three consecutive years (2015–2018). Population counts were conducted using the total count method, and data were analysed in Jamovi (v2.5.6) and R (v4.5.1). Mean population counts varied significantly across months, with peak abundance in August (3,136 ± 105 individuals) and the lowest in May (420 ± 24 individuals). Generalized linear mixed models indicated that habitat type and season significantly influenced abundance, while random effects of sites (ICC = 0.682) and month (ICC = 0.141) accounted for substantial unexplained variation. Model-adjusted estimates showed significantly lower abundance in farmland habitats (39.9 geese, 95% CI: 19.3, 82.1) compared with shoreline (63.4 geese, 95% CI: 30.7, 131, ratio = 0.63, $z = -5.37$, $p < 0.001$) and grassland (69.8 geese, 95% CI: 33.9, 143.7, ratio = 0.57, $z = -6.95$, $p < 0.001$), with no significant difference between the latter two (ratio = 0.91, $z = -1.09$, $p = 0.52$). Habitat use showed strong seasonal variation ($p < 0.001$), with increased reliance on farmland during the dry season and preference for shoreline and grassland habitats during the wet season, reflecting seasonal plasticity. Although the overall population appears to be stable, its distribution is highly dynamic and driven by resource availability and specific habitat preferences. Increasing conversion of wetlands and communal grazing lands into agricultural fields has reduced core habitats, altering traditional land-use systems and intensifying human–geese interactions. These findings underscore the importance of wetland size, habitat quality, and socio-ecological drivers in shaping the distribution of *C. cyanoptera.* The long-term persistence of this range-restricted species will depend on protecting key wetlands and promoting sustainable land-use practices that balance conservation with local livelihoods.

Keywords: Agricultural expansion, endemic species, generalized linear mixed models, habitat selection, population status, seasonal distribution**.**

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Author contributions: Solomon Mengistu: Conceptualization, Methodology, Formal analysis, investigation, Data Curation, Writing-Orginal Draft, Writing - Review & Editing, Visualization. Afework Bekele: Conceptualization, Methodology, Validation, Resource, Writing-review & Editing, Supervision, project administration, Funding Acquisition.

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INTRODUCTION

Ethiopia comprises nearly 70% of the afro-tropical landmass above 2,000 m elevation, with intensive areas exceeding 3,000 m (Yalden 1983). These highlands, bisected by the Great Rift Valley, host isolated mountain systems rich in endemic flora and fauna (Hillman 1993; Tedla 1995; Dixon et al. 2021). Owing to its topographic diversity, Ethiopia forms part of two global biodiversity hotspots–the Eastern Afromontane and the Horn of Africa–supporting unique high-altitude ecosystems and specialized wildlife (Ebi 2014). Altitudinal gradients strongly influence species distributions, particularly among waterfowl adapted to alpine wetlands and grasslands.

Ethiopia comprises over 880 bird species, including several endemic and range-restricted taxa (Ash & Atkins 2009; Desalegn 2023). The Abyssinian Blue-winged Goose *Cyanochen cyanoptera*, Rüppell 1845, is Ethiopia's only endemic goose and is restricted to highland ecosystems ranging 1,800–4,500 m (Urban & Brown 1971; Ash & Atkins 2009; McCracken et al. 2009). The species occupies Afro-alpine grasslands, marshes, streams, and freshwater wetlands, where it primarily feeds on short grasses and sedges (Brown et al. 1982; Scott & Rose 1996). Although historically described as locally common in parts of the Ethiopian highlands (Urban & Brown 1971; Brown et al. 1982). Its distribution remains closely associated with high-altitude wetlands and adjacent grasslands.

Wetlands globally have experienced rapid decline due to land-use change, agricultural expansion, and urbanization (Mammides 2020; Cao et al. 2023; Fluet-Chouinard et al. 2023), leading to steeper population declines in wetland species compared to their terrestrial counterparts (Cao et al. 2023). Similar pressures affect Ethiopian wetlands, many of which occur within Important Bird and Biodiversity Areas (IBAs) and are increasingly degraded by cultivation, livestock grazing, and settlement expansion (Williams et al. 2004). Habitat loss and fragmentation reduce the availability of suitable breeding and feeding sites, posing significant threats to wetland-dependent species (Byju et al. 2025a). In the Ethiopian highlands, continued conversion of wetlands to farmland and expansion of eucalyptus plantations have further intensified habitat degradation.

Species with restricted distribution, such as *C. cyanoptera*, are particularly vulnerable to habitat changes because their survival depends on limited and specialized environments. Increasing human population pressure and agricultural expansion have altered many of these landscapes, and current information on population size, distribution patterns, and habitat associations remains limited. Despite its ecological significance and restricted range, *C. cyanoptera* remains poorly studied compared to other African waterfowl. Reliable and updated data on its population status and habitat use are essential for conservation planning, particularly in regions experiencing rapid environmental changes. Therefore, the present study aimed to determine the population size, distribution, and habitat use of *C. cyanoptera* in the central-south highlands of Ethiopia. The study also identifies key congregation sites and provides baseline ecological information to support effective conservation planning and management of this endemic species.

MATERIALS AND METHODS

Study Area

The study was conducted in the central-south highlands of Ethiopia within the Gurage Zone of the central Ethiopia region (7.667°–8.500° N, 37.500°–38.667° E) (Image 1). Its elevations range 1,000–3,719 m, with Mount Zebidar (Gurage Mountain) forming the highest peak. It lies along the western margin of the Great Rift Valley and forms part of an important watershed draining into the Awash, Rift Valley, Bilate and Omo-Gibe basins (Sahle et al. 2019). Gurage Zone is among the most densely populated areas in Ethiopia, with population densities exceeding 450 persons per km² (Sahle & Yeshitela 2018), resulting in increasing pressure on natural habitats.

Site Selection

Field surveys were conducted at two major wetland systems: Bojuabar wetlands in Ezha Woreda and Arekit Valley wetlands in Gumar Woreda (Image 1). Bojuabar wetlands consist of three small highland lakes–Bojuabar, Bojuabar-Akilil, and Elas-Eyesus, located along the Zebidar Mountain chain. These wetlands, associated with open grasslands, are under pressure from the expansion of agricultural lands and eucalyptus plantations, but remain important feeding, breeding, roosting, and molting habitats of *C. cyanoptera*.

Bojuabar Lake is located 200 km southwest of Addis Ababa and 28 km from Butajira, with coordinates of 8.050–8.267°N latitude and 37.833–38.200°E longitude. It is a larger lake with a surface area of 9.8 ha, located about 1 km south of Bojuabar town. The larger part (75%) is covered by Eucalyptus *Eucalyptus globulus* forest, yet

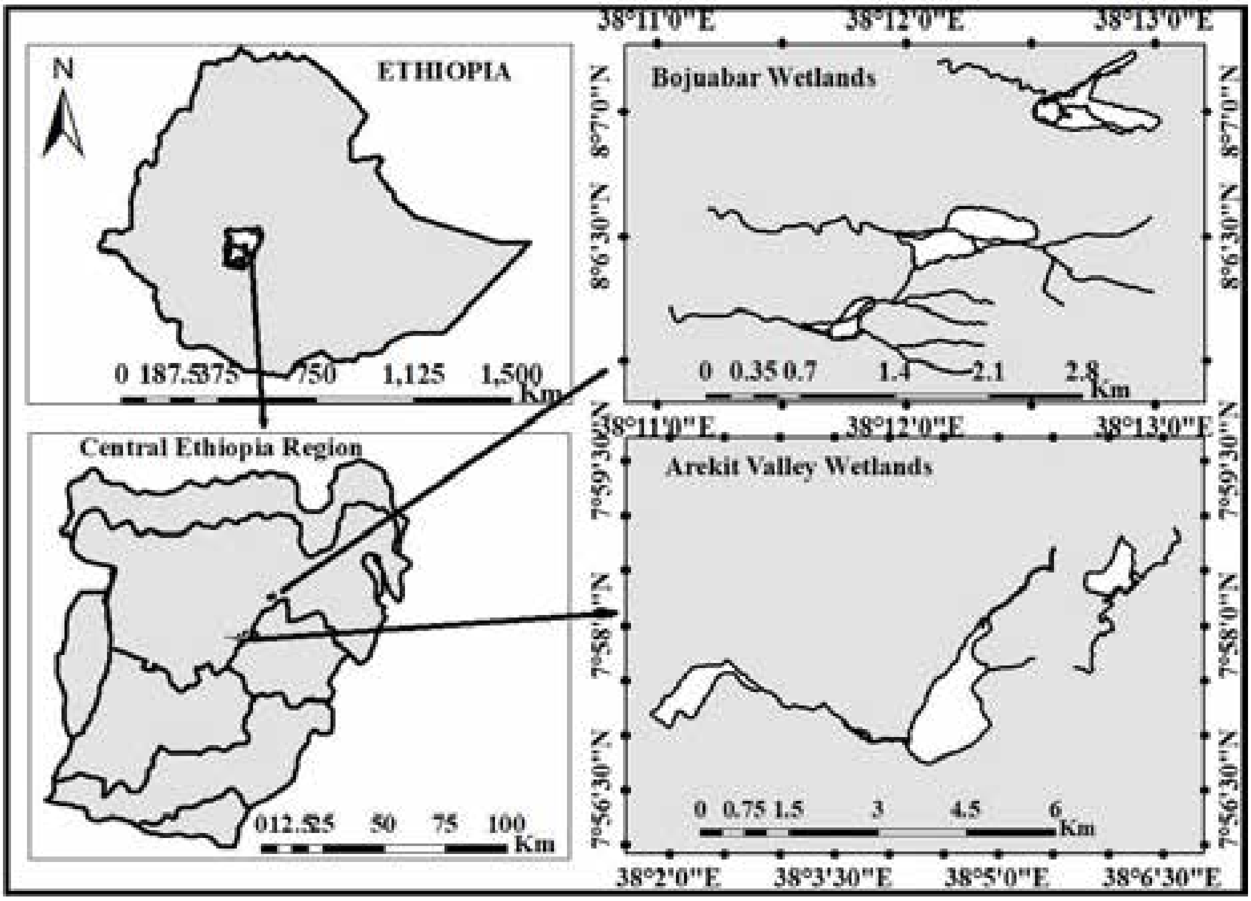

Image 1. The study area.

it remains a critical feeding, roosting, and molting habitat of Abyssinian Blue-winged Geese and a small population of Egyptian Geese *Alopochen aegyptiaca*. The area is also a wintering habitat for Palearctic birds.

Bojuabar-Akilil Lake is a small lake adjacent to Bojuabar town on the northern side. This lake is also used by Abyssinian Blue-winged Geese for feeding, roosting, breeding, and molting. It has a surface area of about 3.4 ha.

Elas-Eyesus Lake is the smallest lake situated about 0.5 km south of Bojuabar Lake. It is used as a breeding site for Abyssinian Blue-winged Geese and a pair of Egyptian Geese. It has a surface area of about 2.8 ha.

Weira River originates from the Zebidar Mountain range and flows west through the southern edge of Gumer Woreda, joining the Bilate River, which flows southwards to Lake Abaya. It possesses scattered forest dominated by Eucalyptus trees and patchy open grassland along its course. Most of the flat grasslands have been converted to farmland, leaving only swampy and hilly areas. Weira River is also an important breeding habitat for birds, particularly during the short rainy season.

Arekit Valley Wetlands consist of Arekit Lake and Zizencho Wetland. Lake Arekit is a shallow (2.5–3.2 m depth), rain-fed freshwater lake located at an elevation of 2,820–2,950 m, with a surface area of about 136 ha (Yirga et al. 2023). It is situated along the Addis Ababa-Wolkite-Hosanna road, about 55 km north of Hosanna and 228 km from Addis Ababa, with coordinates of 7.9500°–7.9667° N and 38.0750°–38.0833° E (Yirga et al. 2023). The lake has relatively important phytoplankton diversity (i.e., 34 taxa) and 56 bird species (Belete et al. 2022; Enawgaw & Wagaw 2023). It is a critical habitat for the *C. cyanoptera* as breeding, feeding, roosting, and molting habitats. Arekit Lake is under threat from the expansion and intensification of agriculture and urbanization. The Zizencho wetland is located 4 km north of lake Arekit along its outlet. It has small swampy grasslands associated with three temporary ponds at the eastern and western parts of Zizencho town. It is used as a feeding and breeding habitat for a small population of *C. cyanoptera*. This wetland is also threatened by agricultural expansion and settlement development.

Climate

The study area experiences marked climatic variation influenced by elevation, with a gradient ranging 1,000–3,638 m (Zerga et al. 2023). The mean annual rainfall and temperature were 916 mm and 16.6 °C at Arekit, and 1,153 mm and 17.3 °C at Bojuabar, respectively (Nmsa 2019).

Study design and population data

Population surveys of the *C. cyanoptera* were conducted over 36 months from November 2015 to October 2018. Surveys were repeated annually following similar seasonal time periods. The year was divided into three ecologically relevant seasons: dry season (November–February), short rainy season (March–May), and wet season (June–October), based on the amount of rainfall, vegetation phenology, and the distribution pattern of the species. Dry season is characterized by low humidity, diminished vegetation growth, and receding water level. The dry season spans two calendar years and is expressed using a split-year format (e.g., 2015/16).

The short rainy season is marked by intermittent rainfall and emergent vegetation growth, which triggers the breeding season of *C. cyanoptera.* The wet season is characterized by heavy and continuous rain with abundant vegetation growth and resources. This season is known for the congregation of *C. cyanoptera* for molting in large Lakes associated with grazing lands.

Habitats within each study site were classified into three major categories based on landscape features and observed habitat use: open water and shoreline, grassland, and farmland. Open water and Shoreline habitats (for simplicity, Shoreline habitats) included open water with emergent vegetation and adjacent zones within 10–25 m from lake margins, which provide critical feeding, nesting, roosting, escaping refuge sites, and resting areas for *C. cyanoptera*.

Grassland habitats consisted of open areas with natural or semi-natural grazing lands dominated by short grasses. These habitats have progressively declined due to conversion to farmland and urbanization activities. Farmland habitats included fallow, ploughed, and actively cultivated fields frequently utilized by *C. cyanoptera.*

The population size of the *C. cyanoptera* was estimated using the total count method from 51 fixed vantage points systematically selected to provide maximum visibility across wetlands and surrounding habitats. These observation points were established based on landscape features and vegetation cover, with distances of 300–500 m between consecutive points depending on habitat visibility. Surveys were conducted during peak activity periods (0600–1000 h and 1400–1800 h) using 10 x 42 binoculars. Individual birds in small flocks were counted directly, while larger flocks were estimated in groups of 10 or 100 individuals to maintain accuracy and efficiency. Each site was surveyed twice daily for three consecutive days each month by a team consisting of the researcher and two trained assistants. Daily mean counts were calculated for each habitat type.

Data Analyses

The population count data were organized in Excel by year, month, season, site, and habitat type. Data were exported as comma-separated values (CSV) files for analysis. Statistical analyses were conducted using Jamovi v2.3.28 and R v4.5.1. Descriptive statistics were used to summarize temporal and spatial variation in population counts across sites, seasons, and habitat types. Data normality was assessed using a Shapiro-Wilk or Kolmogorov-Smirnov test. Pairwise comparisons were conducted using the Type II Wald test, followed by Tukey's HSD post-hoc test for significant effects. Generalized linear mixed models (GLMMs) were employed to examine variation in population counts across sites, habitats, seasons, years, and months. Count data were analyzed using Negative Binomial error distribution to account for overdispersion and zero-inflation (Bolker et al. 2009). Random effects were included to account for temporal and spatial variation, with site and month treated as random factors. Models were fitted using the glmmTMB package in R. Model diagnostics were performed using DHARMa package to evaluate residual patterns and model fit. Statistical significance was tested using Type II Wald chi-square tests, and post-hoc comparisons were conducted using estimated marginal means (EMMs) with Tukey adjustment.

RESULTS

Population Size of Abyssinian Blue-winged Goose

The study revealed that the population size of *C. cyanoptera* varied across survey months and years. The highest mean population counts (Mean ± SD) were recorded in August 2018 (3,215 ± 61.27 individuals), followed by August 2017 (3,049 ± 54.31 individuals) (Image 2). The lowest count was recorded in May 2016 (251 ± 20.22 individuals). The overall monthly population trends, irrespective of year and site, showed the highest mean population size (Mean ± SD) in August (3,136.17

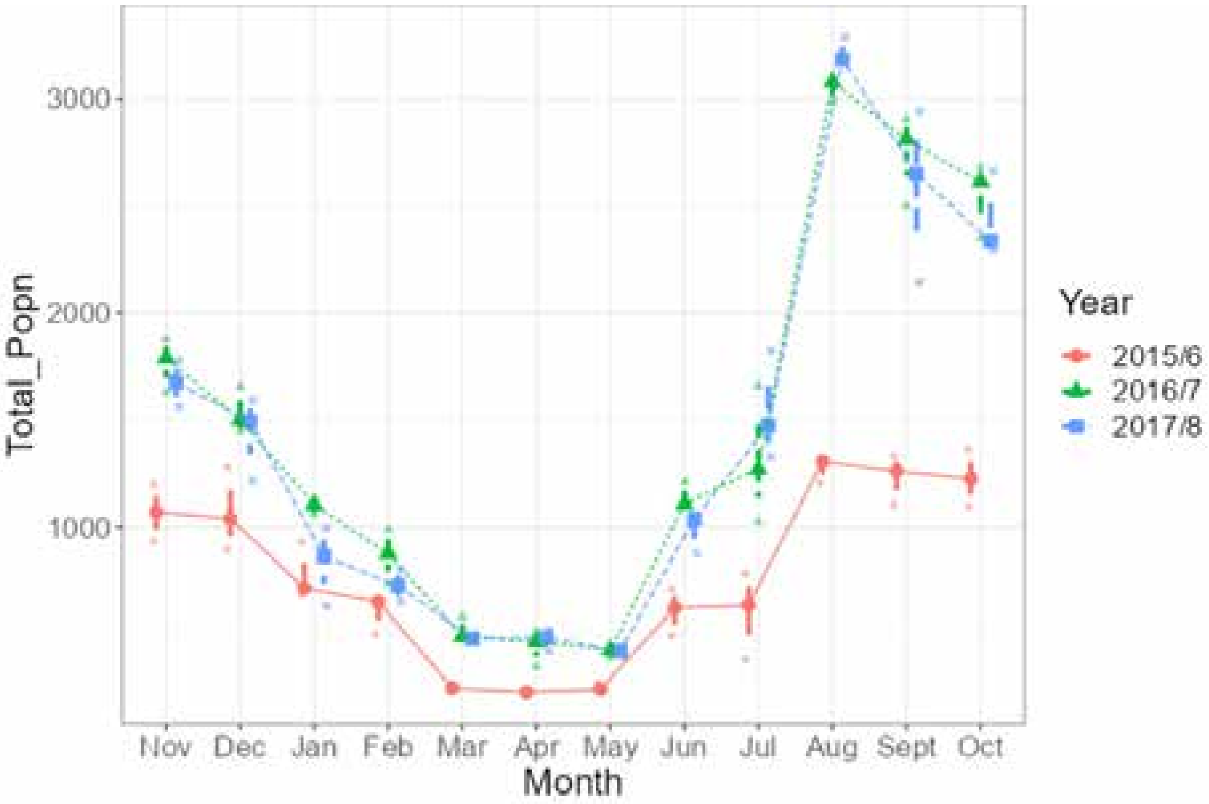

Image 2. The overall mean total population counts across the months and years in the central-south highlands of Ethiopia from 2015–2018.

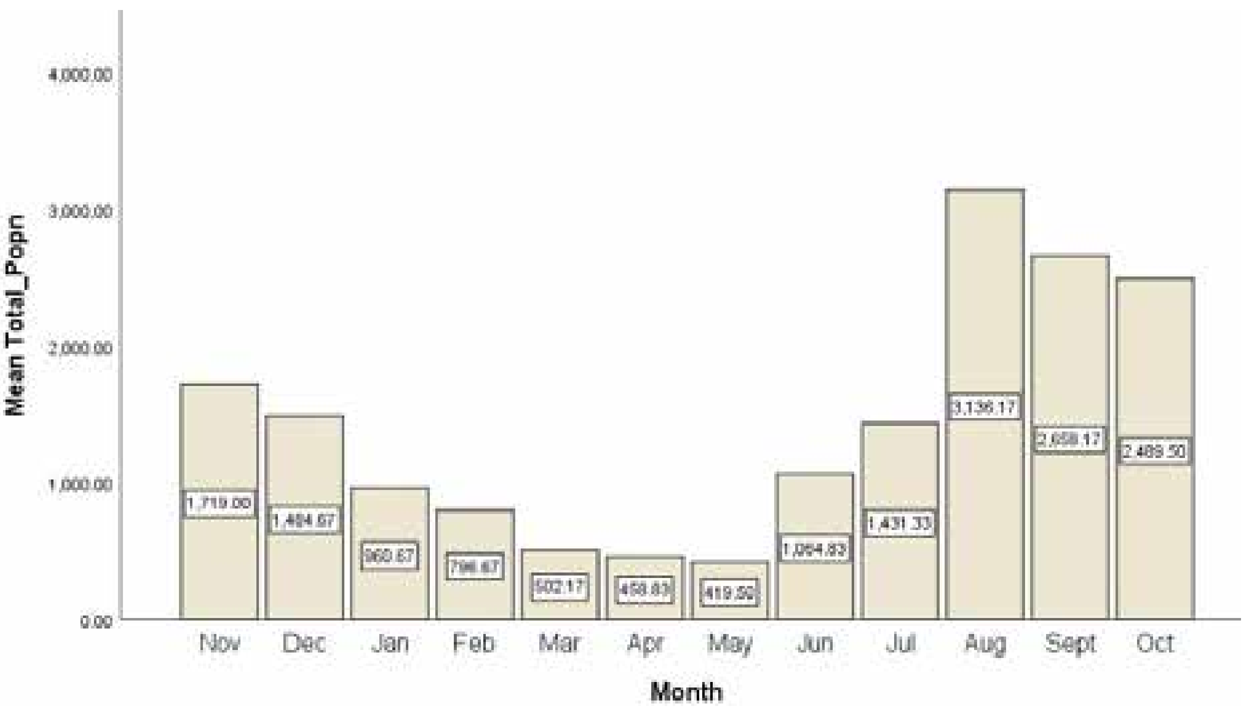

Image 3. The overall mean total population counts across the months in the central-south highlands of Ethiopia from 2015–2018.

± 104.50 individuals) and the lowest in May (419.50 ± 23.65 individuals) (Image 3). Population counts gradually declined from August to May and increased from June to August.

A GLMM with negative binomial distribution was fitted to assess the effect of year, habitat, and season on abundance, with random intercepts included for site and month. The GLMM revealed that the overall effect of year on abundance was insignificant (Type II Wald $\chi^2 = 1.52$, df = 2, p = 0.467). Compared to the baseline year (2015/2016), the yearly coefficients were not statistically significant (2016/2017: $\beta = -0.128$, p = 0.236; 2017/2018: $\beta = -0.124$, p = 0.253). Mean population counts across the habitats, seasons, and years were the highest in farmland during the dry season, whereas during the wet season, both shoreline and grassland habitats supported the highest mean population counts across the study years (Image 4).

The GLMM indicated significant effects of habitat (Type II Wald $\chi^2 = 55.06$, df = 2, p < 0.001) and seasonal effect (Type II Wald $\chi^2 = 19.54$, df = 2, p < 0.001) on spatial and temporal distribution and abundance of the *C. cyanoptera*. Model-adjusted estimated marginal means (EMMs) of abundance were the highest in the grassland (69.8 geese, 95% CI: 33.9–143.7) and shoreline habitats (63.4 geese, 95% CI: 30.7–131) and the lowest in farmland habitat (39.9 geese, 95% CI: 19.3–82.1). Post-hoc Tukey tests showed that abundance in farmland habitats was significantly lower than in both shoreline (ratio = 0.63, z = -5.37, p < 0.001) and grassland habitats (ratio = 0.57, z = -6.95, p < 0.001). But there was no significant difference in abundance between shoreline and grassland habitats (ratio = 0.91, z = -1.09, p = 0.52).

Model-adjusted estimated marginal means (EMMs) indicated that abundance during short-rainy season (33.9 geese, 95% CI: 15.9–72.4) was significantly lower than during both the wet season (76.3 geese, 95% CI: 36.3–160.5; ratio = 0.45, p < 0.001) and dry season (68.1 geese, 95% CI: 32.4–143.2; ratio = 0.50, p < 0.001). No significant difference in abundance was detected between the dry and wet seasons (ratio = 0.89, p = 0.799).

GLMM indicated that the random effect of site (ICC = 0.682) and month (ICC = 0.141) accounted for 68.2% and 14.1% of the variance, respectively. A Welch's ANOVA confirmed significant variation in abundance across sites ($F_{Welch(4,186.4)} =$ 94.49, p < 0.001); with large effect size ($\dot{\eta}^2_p$ = 0.67; 95% CI: 0.61–1.00) (Image 5). Post-hoc Pairwise Comparisons using the Adjusted-Game Howell test indicated significant differences (p < 0.001) between most sites, except between Arekit Lake and Bojuabar Lake ($P_{(Holm\text{-}adj)}$ = 0.12), and between Zizencho wetland and Elas-Eyesus Lake ($P_{(Holm\text{-}adj.)}$ = 0.21) (Image 5).

Welch's ANOVA test also confirmed significant variation in abundance across seasons ($F_{Welch(2,\ 193.3)} =$ 53.00, p < 0.001, $\dot{\eta}^2_p$ = 0.35; 95% CI: 0.26–1.00) (Image 6). The wet season had 1.4× marginally higher abundance than the dry season (p = 0.02) and 3.7× significantly higher abundance than the short-rainy season (p < 0.001). The dry season likewise had 2.64x significantly higher abundance than the short-rainy season (p < 0.001) (Image 6). The relative use of different habitat types was assessed based on the number of individuals recorded in each habitat (Image 7). Habitat use varied significantly across seasons (t = -12.5, df = 966, p < 0.000). During the dry season, farmland (38.30%) and shoreline (36%) habitats were preferred by the highest proportions of individuals, with the least records in grassland habitats (26%). During the short-rainy season, grassland (43.00%) and Shoreline (31.51%) habitats were preferentially utilized by *C. cyanoptera*, while farmland habitats (25.46%) were the least utilized. During the wet season, shoreline (51.36%) and grasslands (35.83%) habitats were preferred by the highest proportions of the individuals, while only 12.82% of the *C. cyanoptera* individuals utilized farmland habitats (Image 7).

The habitat utilization varied significantly across the months (p < 0.000). Utilization of shoreline habitat reached its peak in August (61.51%) and declined to its lowest level in May (31.49%) (Image 8). Grassland habitat utilization was highest in May (46.25%), following the light rainfall in February, and lowest in December (22.79%). Farmland habitat utilization was lowest in August (9.00%) and increased progressively to reach its peak in December (42.25%) (Image 8). Habitat utilization varied significantly across study sites (p < 0.000). Shoreline habitats were utilized the most at Bojuabar Lake (45.60%), followed by Arekit Lake (39.48) and the lowest at Bojuabar-Akilil Lake (Image 9). In contrast, farmland habitat utilization was highest at Elas-Eyesus Lake (29.61%), followed by Arekit Lake (27.77%) and Bojuabar-Akilil Lake (23.22%) and the lowest at Bojuabar Lake (17.72%). At Zizencho wetland, grassland habitat accounted for 81% of habitat use, while farmland accounted for 19.00%. The highest grassland utilization was recorded at Zizencho wetland (81%), followed by Bojuabar-Akilil Lake (44.26%) and the lowest at Arekit Lake (32.75%) (Image 9).

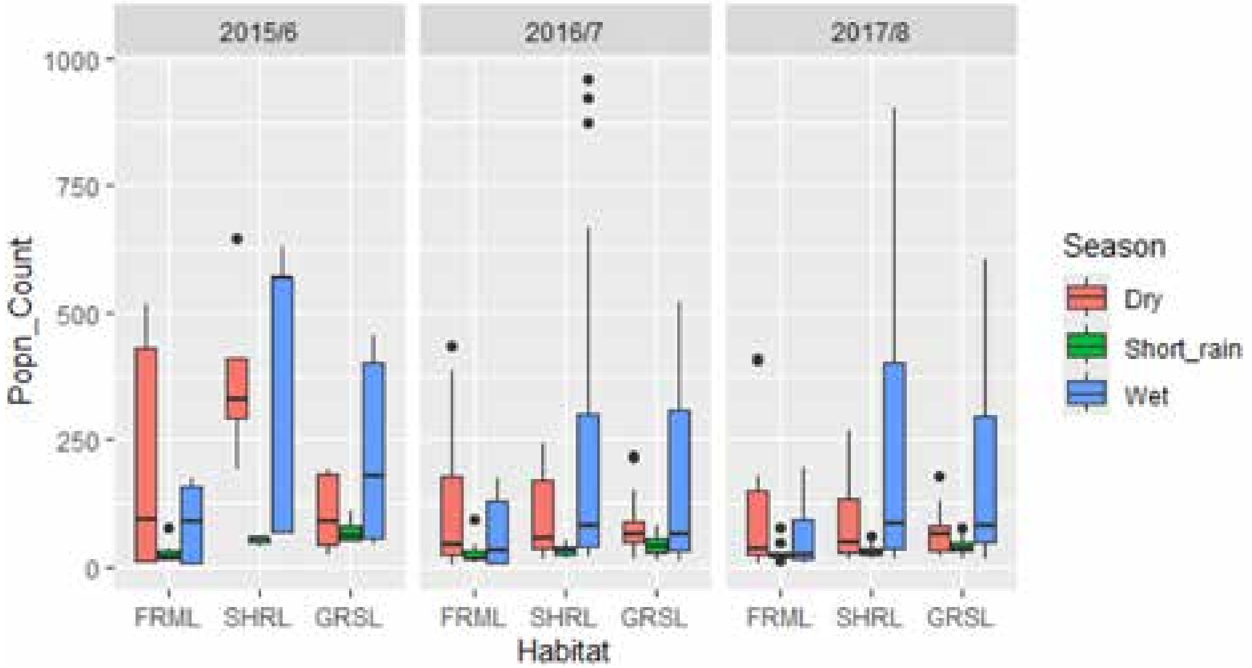

Image 4. The mean population counts across habitat, season, and year in the central-south highlands of Ethiopia from 2015–2018.

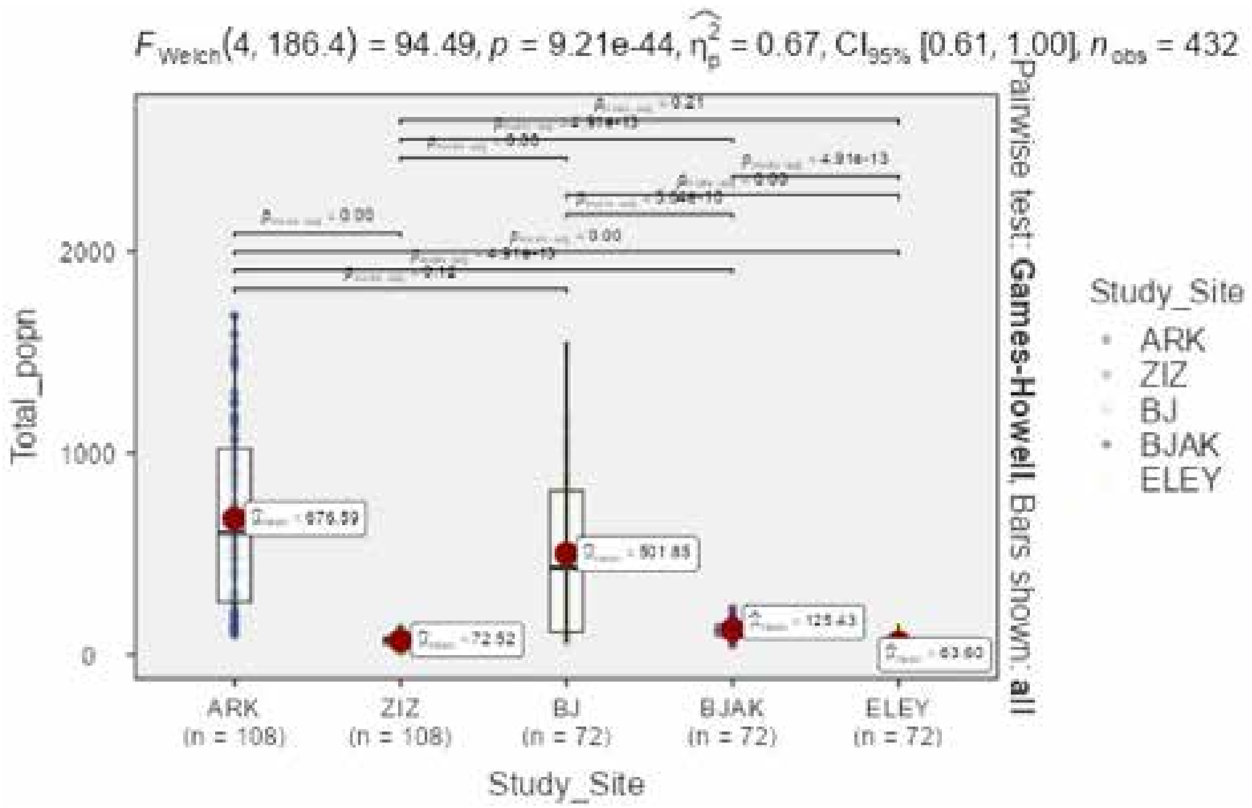

Image 5. Post-hoc pairwise comparison (Adjusted Game Howell test) between sites in the central-south highlands of Ethiopia from 2015–2018.

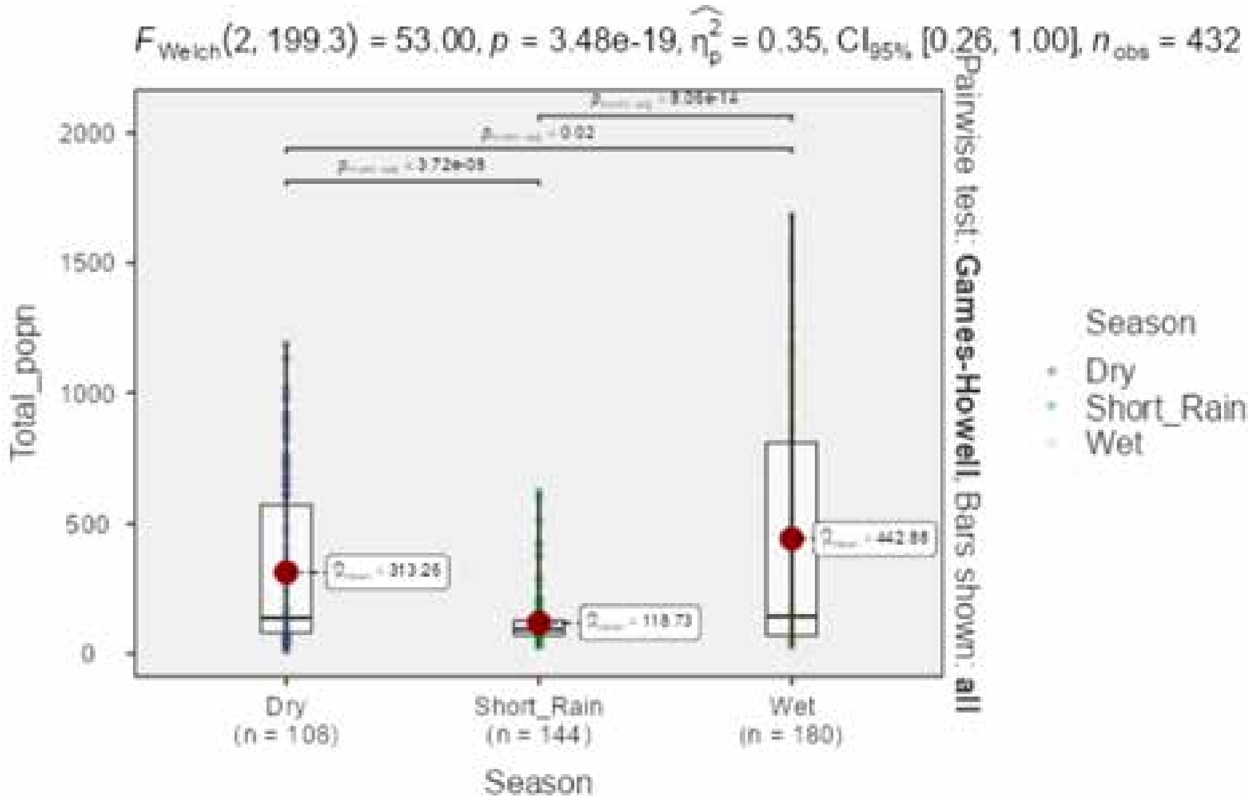

Image 6. Post-hoc pairwise comparison (Adjusted Game Howell test) between seasons in the central-south highlands of Ethiopia from 2015–2018.

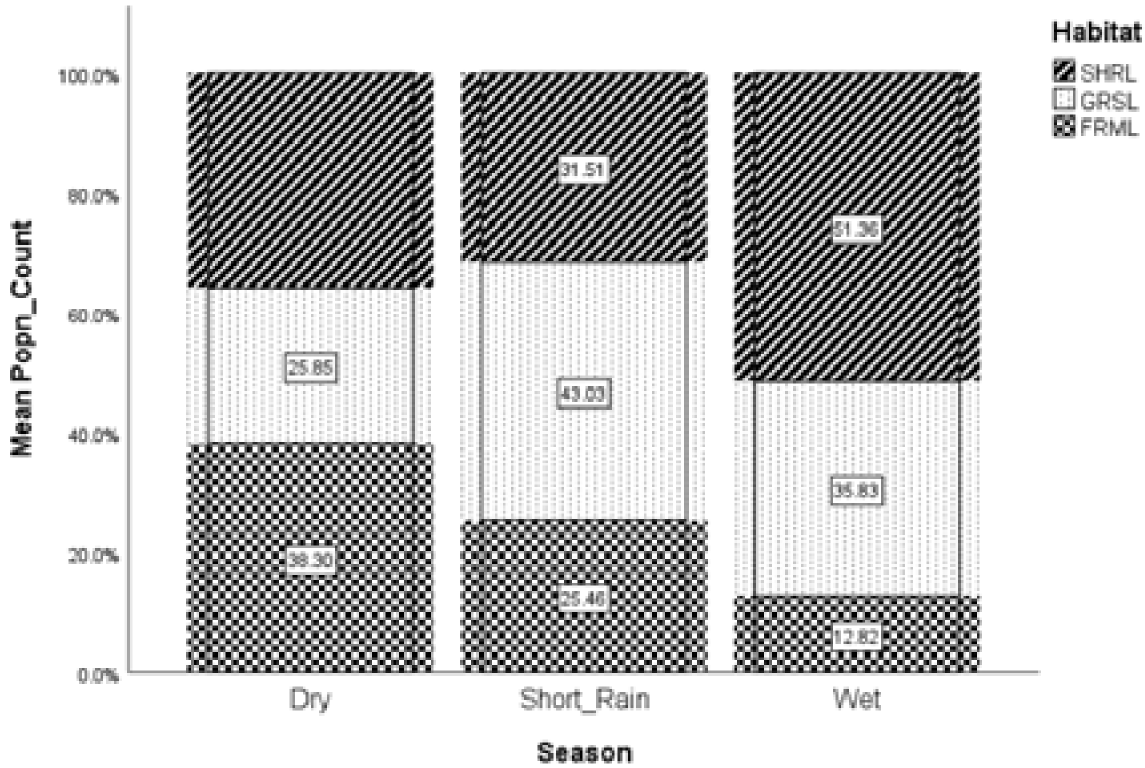

Image 7. Percentage of habitat utilization by *Cyanochen cyanoptera* in the central-south highlands of Ethiopia across the three habitat types from 2015–2018.

DISCUSSION

The present study identified for the first time Arekit Lake and Bojuabar Lake in the central-south highlands of Ethiopia as critically important habitats for the threatened Abyssinian Blue-winged Goose. These two lakes supported higher population sizes than other surveyed sites, particularly during the long rainy season (June–August), with peak abundance recorded in August. This period coincided with increased availability of natural food resources, including grasses and herbaceous vegetation.

The large and permanent open-water areas of Arekit and Bojuabar lakes likely provide refuge from predators and anthropogenic threats, particularly during the flightless molting periods. Wetlands that support large congregations during molting are considered essential habitats for waterfowl conservation. The annual molting congregations recorded at Arekit and Bojuabar lakes represented more than 20% of the global population estimates of *C. cyanoptera* (5,000–15,000 individuals) reported by previous studies (Brown et al. 1982; Callaghan & Green 1993; Scott & Rose 1996), highlighting the conservation significance of these wetlands and their suitability as IBAs. In contrast, smaller wetlands such as Bojuabar_Akilil Lake, Elas-Eyesus Lake, and the temporary ponds within Zizencho wetland supported comparatively lower population sizes, likely due to their limited open-water extent and reduced refuge opportunities during molting.

Seasonal variation in abundance and habitat utilization was likely influenced by changes in forage availability, molting requirements, and breeding dispersal. Population counts of the *C. cyanoptera* declined from September to May following the molting period, which may be related to seasonal changes in vegetation quality, as forage palatability typically decreases with plant maturation (Van Der Wal et al. 2000). Similar post-molting habitat shifts have been reported in other goose species (Madsen & Mortensen 1987). During the dry season, *C. cyanoptera* increasingly utilized farmland habitats, particularly post-harvest fields containing cereal seeds, weeds, and crop residues that provide alternative food resources when natural forage becomes less nutritious. The increased use of agricultural habitats during the period of declining forage quality is

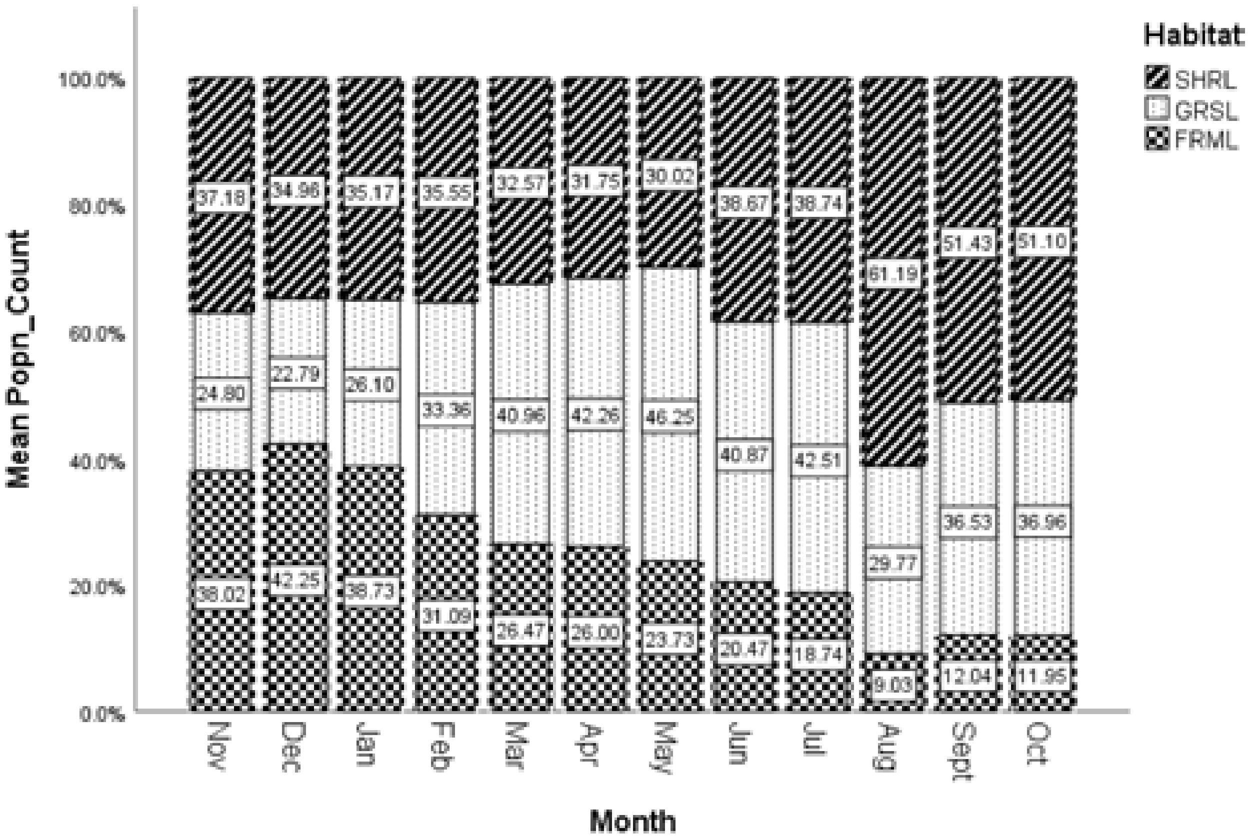

Image 8. Percentage of habitat utilization by *Cyanochen cyanoptera* in the central-south highlands of Ethiopia across the months from 2015–2018.

consistent with observations reported for Canada Geese *Branta canadensis*, Greylag Geese *Anser anser*, Greater White-fronted Geese *Anser albifrons*, and Egyptian Goose *Alopochen aegyptiaca* (Mangnall & Crowe 2002; Ely & Raveling 2011; Askren 2021; Zhang et al. 2023).

The significantly lower abundance recorded during the short-rainy season was likely associated with breeding dispersal. Unlike colonial breeding waterfowl, *C. cyanoptera* breed in dispersed pairs and are scattered across streams, riverbanks, seasonal wetlands, and other breeding habitats during this period. Light rainfall occurring toward the end of February triggered the re-growth of perennial grasses and germination of cereal residues and weeds, creating more spatially dispersed feeding opportunities. Consequently, birds became less concentrated around wetlands. Similar patterns of breeding dispersal linked to food availability were reported for Egyptian Goose in South Africa (Mangnall & Crowe 2002).

Habitat utilization patterns demonstrated clear seasonal shifts, with the highest densities recorded in core areas of optimal habitat (Gerhardy et al. 2025). Shoreline and grassland habitats supported the highest abundance of *C. cyanoptera* during the wet season, whereas farmland habitats became increasingly important during the dry season. The comparable abundance recorded between shoreline and grassland habitats suggests that both habitats appeared to provide feeding and refuge opportunities for *C. cyanoptera*. A marked decline in grassland areas was observed due to conversion to agricultural land. At Arekit Lake, communal grazing lands have been converted to farmlands and urban settlements, resulting in a reduction of core habitats used by *C. cyanoptera*. Agricultural expansion and urbanization therefore, represent major anthropogenic threats contributing to habitat loss in the central-south highlands of Ethiopia. During the wet season and molting period, birds remained closely associated with shoreline habitats near permanent open-water where graminoids and herbaceous vegetation were abundant, and disturbance was relatively low. Geese typically prefer habitats with abundant food resources and access to water for predator avoidance (Hughes et al. 1994). Habitat selection is also influenced by behavioral factors such as flocking benefits and individual fitness (Aplin et al. 2014).

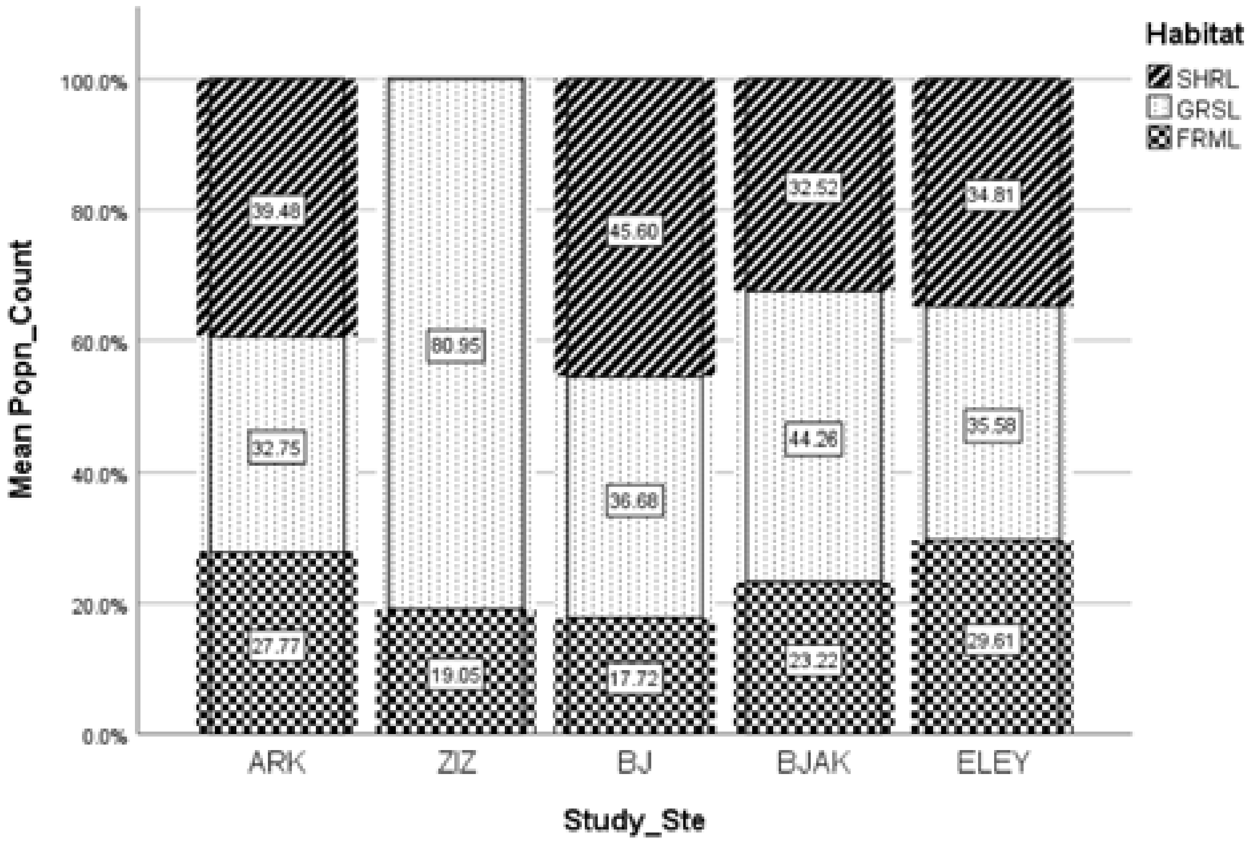

Image 9. Percent of habitat utilization of the bird in the central-south highlands of Ethiopia across the study site from 2015–2018.

Shoreline habitat utilization peaked during August when birds were concentrated around permanent wetlands during molting. Grassland habitat utilization increased toward May following light rainfall and regeneration of fresh vegetation. These findings indicate that habitat use by *C. cyanoptera* changed seasonally in response to resource availability. Most geese are grazing herbivores that specialized in short, high-quality grass swards characterized by low fibre content and high digestibility (Fox et al. 2017). Similarly, *C. cyanoptera* primarily foraged on grasses and herbs in grassland and shoreline habitats during the wet season but shifted seasonally to farmlands and fallow fields during the dry season as natural forage quality declined. Increased utilization of agricultural habitats during periods of reduced natural forage availability has also been reported in other goose species (Fox & Abraham 2017).

The spatial variation in habitat use among study sites further reflected differences in habitat structure and wetland characteristics. Shoreline habitats were most intensively utilized at Bojuabar and Arekit lakes, which contain relatively larger permanent open-water areas and extensive shoreline vegetation. In contrast, grassland habitats dominated habitat use at Zizencho wetland, where temporary ponds and surrounding grasslands formed the principal habitat matrix. Farmland utilization was relatively higher at Elas-Eyesus Lake and Arekit, possibly reflecting greater agricultural encroachment and proximity of cultivated fields to wetlands. The high variance explained by site-level random effects in the GLMM supports the importance of local habitat conditions in determining abundance and habitat selection. Agricultural expansion into wetland margins and socio-economic pressures represent major anthropogenic threats contributing to habitat loss and degradation of wetlands in the central-south highlands of Ethiopia. Shoreline and grassland habitats around Arekit Lake have increasingly been converted into agricultural fields and human settlements, resulting in a reduction of important molting and feeding habitats used by *C. cyanoptera*. Similar but less extensive habitat conversion was also observed around Bojuabar Lake. Field observations and information obtained from local communities indicated that portions of communal grazing lands surrounding wetlands have recently been converted into agricultural lands managed by investors and organized youth groups, often with limited environmental safeguards (Belete et al. 2022). These land-use changes appear linked to broader development initiatives aimed at increasing agricultural productivity and employment opportunities. Such land-use changes have accelerated the loss of shoreline and grassland habitats that historically supported both wetland biodiversity and traditional community-based livelihood systems that developed for millennia. Traditionally, wetlands in the region functioned as communal grazing lands and sources of essential natural resources for local communities (Dixon et al. 2021). Indigenous land-use systems such as controlled grazing, seasonal land rotation, and fallowing historically contributed to the maintenance of wetland integrity while simultaneously supporting local livelihoods. Farmers in the central-south highlands of Ethiopia commonly leave farmland fallow for one or two years to restore soil fertility and support livestock grazing (Tolessa et al. 2016). Such fallow lands currently provide important alternative feeding habitats for *C. cyanoptera* after the molting season and may partially compensate for the loss of natural grassland habitats. However, continued conversion of shoreline and grassland habitats into agricultural fields has progressively reduced natural feeding grounds, increasing the species' dependence on cultivated lands and potentially increasing localized human-goose conflicts.

Historically, *C. cyanoptera* was not considered a major agricultural pest because farmlands were located away from molting wetlands such as Arekit and Bojuabar lakes. The species primarily utilized short-grazed grasslands around lakes and rarely used tall hay grasslands, except during nesting. This behavior may partly explain the relatively tolerant attitudes of local communities toward *C. cyanoptera* compared with other goose species such as A. *aegyptiaca* which nest on the top of traditional huts and are highly mobile and frequently forage in farmlands away from wetlands. Nevertheless, continued loss of natural habitats may increasingly force *C. cyanoptera* into cultivated areas, potentially intensifying future human-wildlife conflicts.

The interaction between local livelihood needs, agricultural development priorities, and ecological sustainability highlights the complex socio-ecological drivers underlying wetland degradation in Ethiopia. Similar wetland degradation associated with unregulated agricultural expansion has been reported elsewhere (Yu & Wu 2018; Desta et al. 2022; Byju et al. 2025b). Integrating indigenous resource-management practices such as controlled grazing and crop rotation into contemporary land-use planning may enhance long-term wetland sustainability while supporting conservation of important habitats for *C. cyanoptera*.

CONCLUSION

This study identified Arekit Lake and Bojuabar Lake as critically important molting, roosting, and feeding habitats for the threatened Abyssinian Blue-winged Goose in the central-south highlands of Ethiopia. Seasonal variation in abundance and habitat use was strongly associated with availability, molting requirement, and breeding dispersal. During the wet season, geese congregated in shoreline and grassland habitats around permanent lakes where food resources and refuge conditions were favorable. Following the molting period, birds dispersed into adjacent agricultural landscapes, utilizing fallow fields and crop residues during the dry season–a behavioral adaptation observed in other waterfowl species globally. The lower abundance observed during the short rainy season was associated with dispersal of breeding pairs to scattered breeding habitats and seasonal water bodies.

The study further demonstrated that local habitat characteristics strongly influenced abundance and habitat selection. Permanent wetlands with extensive open-water areas and shoreline vegetation supported larger molting congregations than smaller or temporary wetlands. Shoreline and grassland habitats functioned as complementary feeding and refuge areas, while farmlands provided important alternative feeding habitats during periods of reduced natural forage availability.

Agricultural expansion, urbanization, and conversion of communal grazing lands into cultivated fields were identified as major threats contributing to habitat degradation and loss of important molting and feeding habitats. Continued reduction of natural habitats may increase the dependence of *C. cyanoptera* on agricultural landscapes and intensify future human-wildlife conflicts. Protection of key wetlands such as Arekit and Bojuabar lakes, together with sustainable land-use planning that incorporates ecological safeguards and indigenous resource-management practices, is therefore essential for long-term conservation of the species. The long-term persistence of this range-restricted species will depend on protecting key wetlands such as Arekit Lake and Bojuabar Lake, together with promoting sustainable land-use practices that balance conservation with local livelihoods.

Future studies incorporating telemetry and broader landscape-level monitoring are recommended to improve understanding of movement patterns, breeding distribution, habitat connectivity, and seasonal dispersal of *C. cyanoptera*. Such information will be important for developing effective long-term conservation strategies for this range-restricted and threatened Ethiopian endemic goose species.

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ARTICLE

Foraging postures and techniques used by the White-bellied Heron *Ardea insignis* Hume, 1878 (Aves: Pelecaniformes: Ardeidae) in Namdapha Tiger Reserve, India

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Abstract: The White-bellied Heron *Ardea insignis* occurs in Bhutan, India, and Myanmar. Bhutan supports the majority of the known global population (approximately 30 individuals), followed by India (around 10 individuals), while only a few individuals occur in Myanmar. The population continues to decline across its range, posing a serious threat to the species' survival. This heron is unique in preferring fast-flowing freshwater rivers, yet its foraging behaviour remains poorly understood. As a fish-eating bird, a continuous supply of freshwater fish is essential for its survival and reproduction. From 2013 to 2017, its foraging behaviour was studied in Namdapha Tiger Reserve, the only site in India where most individuals are found. The aim was to understand how this visual predator forages in fast-flowing rivers, where strong currents make prey detection and capture difficult. It was found that the heron employs a variety of postures and techniques to cope with these conditions. Using continuous focal sampling, individuals were observed and documented their body postures and prey capture methods through photography. Over approximately 850 h of observation, the herons were seen feeding exclusively on fish. Their foraging behaviour was strongly influenced by water current, requiring specific techniques to maximise prey capture. The birds displayed distinctive movement patterns and postures to avoid detection by prey and to handle captured fish effectively. Some postures were associated with unsuccessful capture attempts. This study highlights previously undocumented feeding behaviours, which are important for developing conservation strategies aimed at protecting the species and its specialised habitat.

Keywords: Arunachal Pradesh, body postures, foraging technique, freshwater rivers, northeastern India, prey handling.

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Author details: Dr. Himadri Sekhar Mondal completed his PhD on the behavioural studies of Critically Endangered White-bellied Heron *Ardea insignis* from the Pondicherry University in 2019. He has joined BNHS as scientist on 2018 and has worked on different projects since then. He is currently working on the bird disease surveillance project in Sikkim Himalaya. Dr. Gopinathan Maheswaran is currently working as a senior scientist with Zoological Survey of India and his research interests include behavioural studies on the long-legged wading birds besides forest bird community studies in various protected areas in India.

Author contribution: HSM involved in data collection, analyses, conceptualization and writing of this article. GM helped in writing of this article and also accrued the fund for this study.

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INTRODUCTION

Long-legged wading birds employ a wide range of foraging techniques, which can be categorised based on posture, behaviour, and physical adaptations used to capture prey (Kushlan 1978; Maheswaran & Rahmani 2002). The choice of technique varies among species and even among individuals. Birds often select behaviours that maximise foraging efficiency (Maheswaran & Rahmani 2002; Aarif et al. 2025). According to Stephens & Krebs (1986), behavioural choices are often influenced by capture success rate or time between captures rather than net energy gain. In the case of the White-bellied Heron (WBH hereafter), despite using suitable postures and techniques, the fast-flowing rivers of Namdapha Tiger Reserve (Namdapha TR) reduce capture efficiency, allowing fish to escape easily. The average capture rate is only 0.47 fish per hour, meaning more than two hours may pass between successful attempts. This low success rate is partially offset by the consumption of larger fish (greater than 18 cm), which provide higher energy returns (Mondal & Maheswaran 2021). The species is extremely shy and avoids human presence, leading to its confinement in remote river systems. This behaviour contributes to its low population size. Given these challenges, understanding how WBH adapts different foraging strategies was a key objective of this study.

The WBH is classified as 'Critically Endangered' and is distributed across the eastern Himalayan foothills in Bhutan and northeastern India, extending to northern Myanmar (Maheswaran et al. 2021b). In India, Arunachal Pradesh is a stronghold, with nesting sites recorded mainly in Namdapha Tiger Reserve and nearby forest areas (Mondal & Maheswaran 2014, 2025). Currently, the reserve has around 4–5 individuals which is roughly 8% of the known global population (c. 60 individuals). Most previous studies have focused on population status, nesting, and conservation. However, except our previous study (Mondal & Maheswaran 2021) that determined the effects of water depth and directional orientation of herons especially while foraging 'upstream' or 'downstream' in the unique habitat of fast-flowing freshwater rivers, no other study has discussed postures and techniques used by this rare heron to capture and consume its prey in the fast-flowing rivers. As a solitary, visually hunting piscivore dependent on river systems, its survival depends heavily on habitat quality. This study is the first to document the diverse foraging behaviours of this species in fast-flowing freshwater rivers in northeastern India, providing insights essential for its conservation. Detailed quantitative analyses of the frequency of such behaviours, success versus failure rates, time spent in shallow water, and preferred fish size classes are not presented here, as these aspects were addressed by Mondal & Maheswaran (2021).

MATERIALS AND METHODS

Study area

The study was conducted in Namdapha Tiger Reserve (27.508–27.661 °N to 96.251–96.976 °E) in Changlang District, Arunachal Pradesh, India. The Reserve covers 1,985 km² and borders Myanmar. Major rivers include the Noa-Dehing, Namdapha, and Deban Nallah, along with numerous streams. Fieldwork was carried out during winter months (November 2013 to January 2017). Observations were not conducted during the monsoon due to flooding. Approximately 1,400 h of field observation were completed, including 858.45 h focused on foraging behaviour.

Behavioral observations

Continuous focal sampling method was used (Altman 1974; Martin & Bateson 2007). Observations were conducted daily from 0530 h to 1730 h (IST). Data collection began when a heron was located and ended when it left the site or was disturbed. Observations were made using a pair of Nikon 8 x 40 binoculars and a Nikon PROSTAFF 5 Fieldscope 82-A from distances of at least 200 m. Temporary hides were constructed using natural materials at known foraging sites within Noa-Dehing and Namdapha Rivers, two of the major river systems of Namdapha. Photographs were taken using a D70S DSLR camera (with 150–500 mm Sigma lens). Multiple observation sites were selected at least 1 km apart. Recorded behaviours were compared with existing literature on long-legged wading bird foraging (Meyerriecks 1960; Kushlan 1976, 2011; Rodgers 1983; Kelly et al. 2003; Kushlan & Hancock 2005; Maheswaran & Rahmani 2008).

RESULTS

General observations

Over 850 h of observation, various postures and behaviours employed by WBH while foraging were documented in fast-flowing rivers within Namdapha TR, namely Noa-Dehing and Namdapha. The species was found to feed exclusively on live fish. Most observations were recorded on clear, sunny days. Although herons were occasionally observed foraging during rainy conditions in winter and at the onset of the monsoon from late March, no alternative strategies were documented to compensate for reduced visibility in murkier water.

Foraging behaviours

1. Motion-based strategies

Stand and wait: Remaining motionless for long periods (3–4 hours or even longer) waiting for its prey (Images 1–3). In total, herons were observed spending 821.71 h (Table 2).

Scan and walk: Moving carefully to inspect potential prey areas (Image 4). Herons were seen using this mode of foraging strategy for 36.74 h (Table 2).

Walk slowly: Stalking prey with controlled movement.

Walk-stand-wait: Alternating between walking and pausing.

Walk quickly: Active searching, sometimes disturbing prey.

Crouch and chase: Rapid pursuit with submerged head and neck (Image 5).

Hopping: Short flights to new feeding locations that are at short distances (Image 6).

2. Water current-based strategies

Upstream: Monitoring incoming fish; includes foot-stirring to flush prey (Image 7), and herons were seen spending 403.97 h facing upstream (Table 2).

Foot stirring and balancing: The WBH has well-built long legs (tarsus: 176–216 mm) that enable heron to withstand the high-water current, particularly when standing amidst the fast-flowing rivers. Furthermore, WBH deploys a unique foraging technique while foraging facing 'upstream'. The WBH stands on one foot while using the other foot to slowly stir the water forward (against the current) and backwards. This behavior appears to help the bird disturb fish that are hiding beneath boulders, making them easier to catch. At the same time, this technique allows the heron to maintain its balance in fast-flowing river water.

Downstream: Waiting for fish carried by the current (Image 8) while facing downstream. Herons were seen spending 454.48 h this way (Table 2).

Body postures

Crouched: Positioning the body parallel to water for stealth (Image 1).

Upright: To have enhanced scanning ability (Image 2).

Erect: Alert posture for maximum visibility of the targeted patch (Image 3).

Head postures and movements

Peering over: This posture reduced glare to improve vision under daylight conditions (Image 9).

Facing down: Used while preparing to strike (Image 10).

Movements include neck craning (Image 9), head tilting (Image 11), swaying, and bobbing (Image 12) to improve prey detection.

Prey capture techniques

Bill stab: Rapid strike using neck movement (Image 13).

Bill lunge: Forward thrust using body momentum (Image 14).

Prey handling (Bill capture)

Grasp capture: Grasping the fish firmly (Image 15) between the bills.

Impale capture: Used sharp bills to pierce the fish (Image 16).

Fish are swallowed head-first. The heron may toss the fish to reposition it and often moves to shore before consuming it to reduce escape risk (Image 17a–d).

Other behaviours

Bill wiping: Cleaning the bill after feeding (Image 18).

Bill opening: Observed after failed attempts; such function amongst WBHs is unclear (Image 19).

Prey dropping: Rejecting dead or unsuitable fish.

Pirating: Rare attempts by other bird species to steal prey (Image 20).

Detailed definitions of different postures and behaviour of WBH observed in Namdapha TR, and similar such postures observed among other long-legged wading birds by others are given in Table 1.

DISCUSSION

Majority of the behavioural postures exhibited by the WBHs in Namdapha TR have also have been observed and documented in other waterbird species around the world (Table 1). Herons in general exhibited a wide range of foraging postures, which they selectively employ to capture prey (Kushlan 2011). Whereas, in Namdapha TR, the WHBs are primarily found in open riverbeds, foraging in fast-flowing freshwater rivers (Mondal & Maheswaran 2021). The postures and behaviours exhibited by herons are closely interrelated and are influenced by the success or failure of foraging attempts (Image 21). As a solitary

Image 1–6. White-bellied Heron *Ardea insignis* Hume, 1878: 1—'stand and wait' for the prey in 'crouched' posture in 2015 | 2—'stand and wait' for the prey in 'upright posture' in 2015 | 3—'stand and wait' for the prey in 'erect posture' in 2015 | 4—'scan and walk' while searching the prey in river water in 2015 | 5—'crouch and chase' the prey in river water in 2015 | 6—'hopping' to change its foraging location in 2015. © 1,2,3,4&6—Himadri Sekhar Mondal; 5—G. Maheswaran.

forager, the WBH requires considerable time and focus to capture prey in relatively undisturbed and profitable areas, often returning to the same sites daily. The 'standing' posture allows the bird to remain motionless while waiting for prey to become visible in the water. According to Kushlan & Hancock (2005), successful foraging in this posture demands skill and experience, as the bird must avoid detection while maintaining stillness in flowing water. Disturbance from intruders can disrupt both prey availability and the bird's concentration. Thus, adopting an upright or alert posture serves as an effective strategy for both prey detection and territorial vigilance.

WBH primarily defends its foraging habitat against

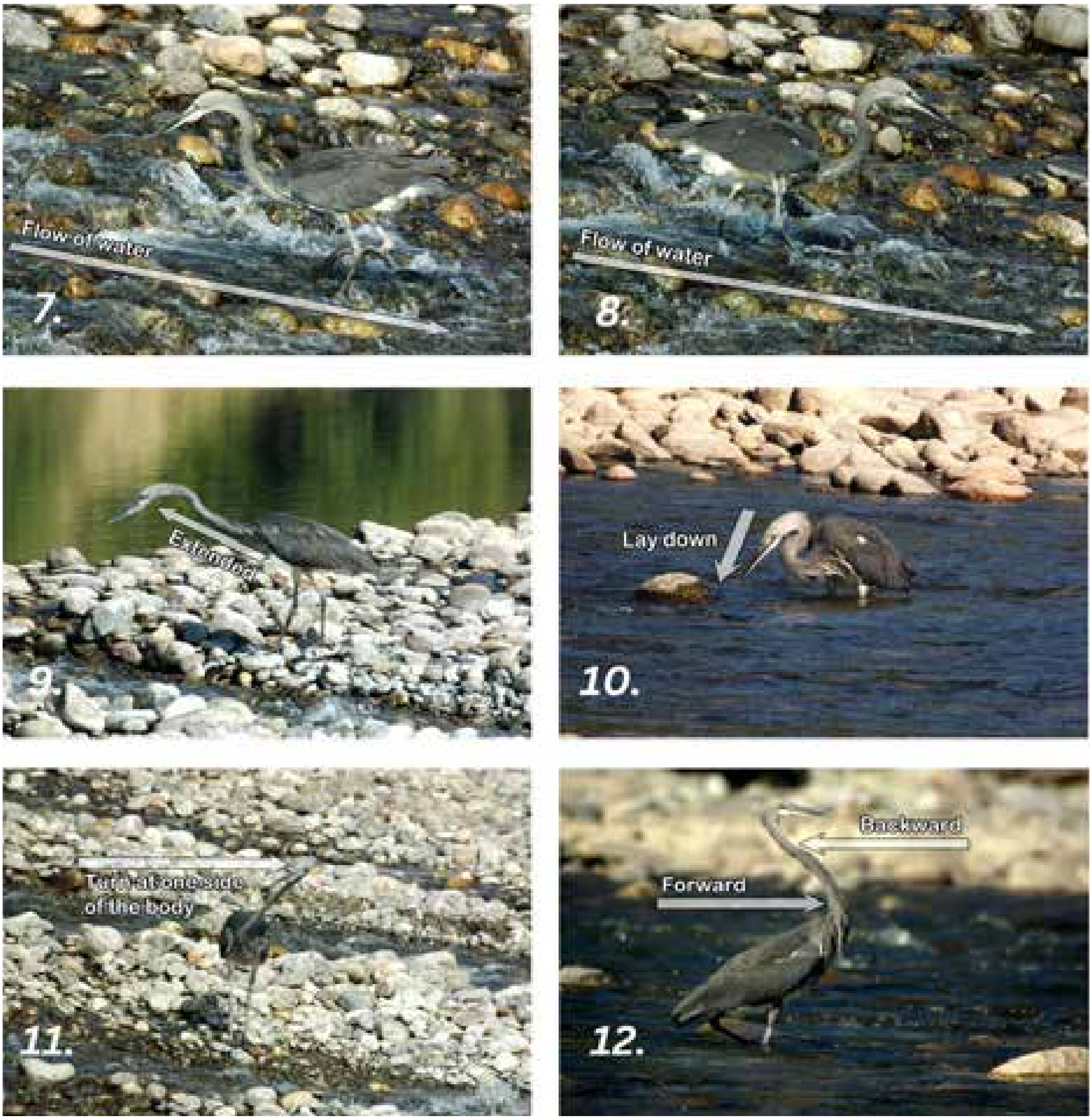

Image 7–12. White-bellied Heron: 7—Searching its prey while 'facing upstream' in 2014 (Mondal & Maheswaran 2021) | 8—searching its prey while its 'facing downstream' in 2014 (Mondal & Maheswaran 2021) | 9—searching its prey in 'peering over' head posture. Also, searching its prey while stretching out its head and neck together (neck craning) in 2015 | 10—Searching its prey in 'facing down' head posture in 2016 | 11—searching its prey while turning its head and neck together at one side of the body (head tilting) in 2015 | 12—'Head bobbing' while walking in 2016. © Himadri Sekhar Mondal,

solitary or paired piscivorous birds such as the Black Stork *Ciconia nigra*, Crested Kingfisher *Megaceryle lugubris*, and other WBHs, while interactions with flock-foraging species like the Great Cormorant *Phalacrocorax carbo* are rare. The presence of other waterbirds may prompt this solitary species to seek alternative microhabitats for feeding as observed in the case of Black-necked Storks (Maheswaran & Rahmani 2001). WBH demonstrates behavioral flexibility by selecting appropriate feeding postures based on environmental conditions. This adaptability is particularly important given its low capture efficiency (35.95%) and capture rate (0.47 fish/hr) (Mondal & Maheswaran 2021). Rather than relying on a single strategy, WBH combines multiple postures and behaviours to enhance foraging success. When foraging while facing upstream, WBH

Table 1. Definition of different postures and behaviour of White-bellied Heron observed in Namdapha Tiger Reserve.

Name of the posture/ behaviour	Definition	References
Stand and wait	Heron stands motionless waiting for its prey to approach.	Meyerriecks 1960; Kushlan 1976
Scan and walk	Herons moving carefully to inspect potential prey areas	This study
Walk slowly	Stalking prey with controlled movement of less than 60 steps per minute	Rodgers 1983; Kushlan & Hancock 2005
Walk-stand-wait	Walking is used extensively by the foraging herons as they often merge walking slowly and standing together by making attempts alternatively to catch their prey	Kushlan 1976, 2011
Walk quickly	Herons walk quickly stirring water and searching for fishes	Kushlan 2011
Crouch and chase	While standing in water waiting for fish, the heron plunges its bills in water in pursuit of fleeing fish; while doing so, heron moves in crouched posture submerging entire bill and neck in water. We have rarely seen heron catching fish employing this strategy	This study
Facing Upstream	The heron positions itself along the river with its head facing upstream, allowing it to monitor the movement of fish carried by the current	Mondal & Maheswaran 2021
Foot stirring and balancing	The heron stands on one leg while slowly moving the other backward and forward, in the direction of the current. This behaviour appears to help disturb fish hidden beneath boulders, while allowing the bird to maintain balance in the fast-flowing river.	This study
Facing Downstream	The heron occasionally positions itself facing downstream, with its tail oriented toward the oncoming current.	Mondal & Maheswaran 2021
Hopping	While foraging, the heron makes short, hopping flights from one feeding site to another	Kushlan 2011
Crouched posture	The heron bends its legs and retracts its head to keep its body parallel to the surface beneath it	Kushlan 2011
Upright posture	The heron stands upright and extends its head so that the neck angles away from its vertically aligned body	Kushlan 2011
Erect posture	The heron holds its head and neck elevated—up to 90° from the horizontal—while keeping the bill level or slightly pointed upward	Kushlan 2011
Peering over	The heron extends its neck and tilts its head to obtain a binocular view of potential prey	Kushlan 2011
Facing down	The heron lowers its bill, head, and neck to probe for or pick up its prey	Kushlan 2011
Neck craning	Heron stretch out its neck and head together in order to search for its prey	Kushlan 2011
Head tilting	The heron turns its head and neck to one side while keeping the rest of its body stationary	Kushlan 2011
Head swaying	The heron moves its head and neck to scan the surroundings for prey	Kushlan 2011
Head bobbing	It is a sinuous forward-and-backward movement of the head and neck	Kushlan 2011
Bill stab	It is a downward or lateral strike involving a rapid, directed movement of the heron's head and neck while the body remains stationary	Kushlan 2011
Bill lunge	The heron lunges its body forward while keeping its feet in place	Kushlan 2011
Grasp capture	In this bill-capture technique, prey are seized in a manner similar to a tweezer-like grip	Kushlan 2011
Impale capture	In this capture technique, the heron pierces the fish with its bill while striking at it	Kushlan 2011
Prey handling	The time taken by the bird between capturing and swallowing its prey	Maheswaran & Rahmani 2008
Bill wiping	The heron typically wipes its bill against a boulder or other available nearby structure	Kushlan 2011
Bill opening	The heron opens its bill and holds it open for a few seconds while scanning the river water	This study
Prey dropping	The heron releases the captured prey instead of consuming it	Kelly et al. 2003
Pirating	This involves stealing food from other birds	Kushlan 2011

often adopts an erect or upright posture to detect fish moving with the current. It frequently employs 'walking' and 'hopping' behaviours to pursue prey that escape initial strikes. In contrast, when facing downstream, prey detection occurs only after water passes the bird, making 'crouched' and 'stand-and-wait' postures more effective.

WBH uses an upright posture while walking slowly in a crouched posture when rapidly pursuing prey (crouch and chase). 'Head swaying' is commonly observed during stationary foraging (stand and wait), while 'head bobbing' is more frequent during active searching (scan and walk). Some behavioural patterns observed during the study—such as 'crouch and chase,' 'upstream,' 'downstream,' and 'bill opening'—are newly documented for this species. The primary function of this diverse behavioural repertoire is to maximize prey capture. In Namdapha TR, WBH was observed feeding exclusively on live fish. An unusual observation occurred on 10 December 2015, when a WBH picked up and then dropped a fish, likely dead and lodged among river boulders. Although the bird initially pursued the dropped fish, it subsequently

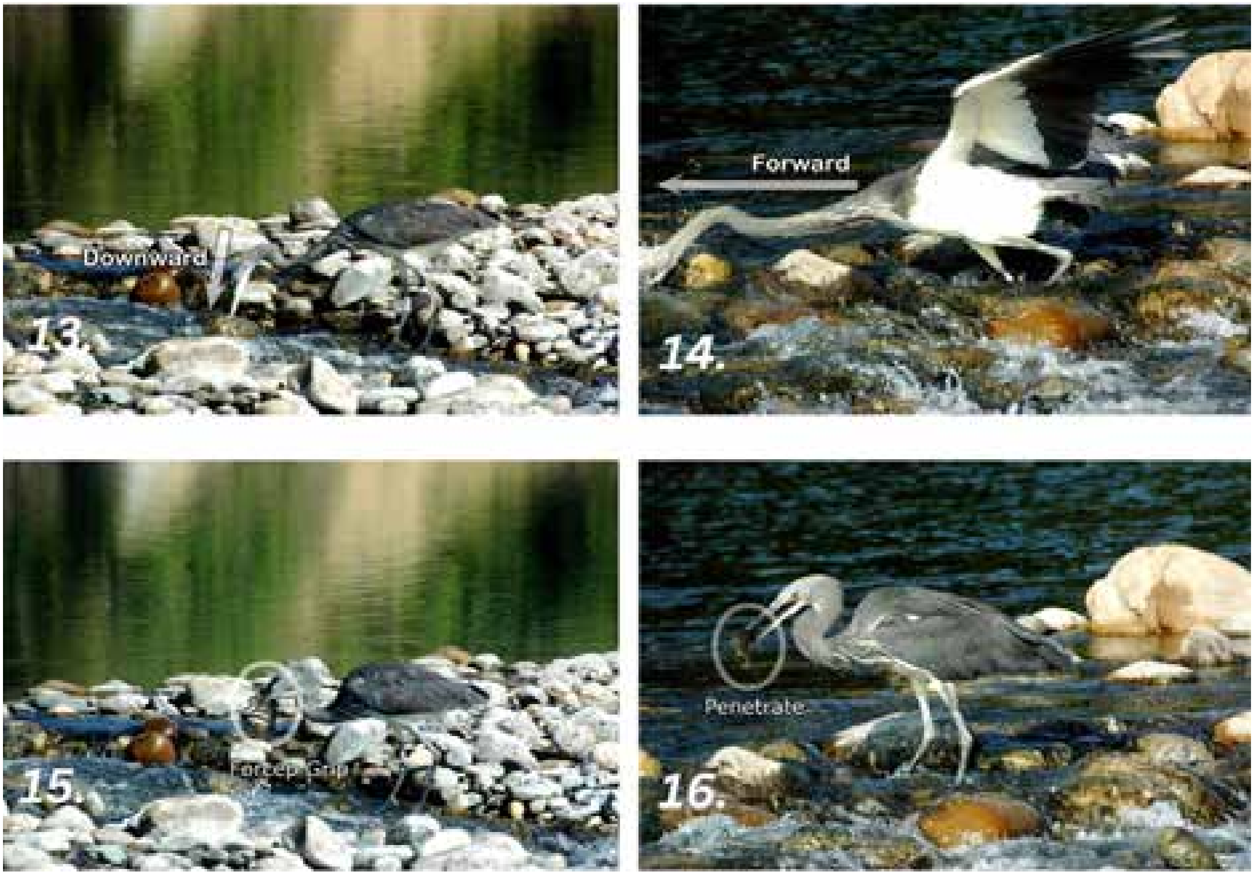

Image 13–16. White-bellied Heron: 13—'Bill stab' to capture its prey in 2015 | 14—'bill lunge' to capture its prey in 2015 | 15—'grasp capture' the prey in 2015 | 16—'Impale capture' the prey in 2015. © Himadri Sekhar Mondal,

ignored it, suggesting possible recognition and rejection of non-viable prey. Dead fish are occasionally found floating due to poisoning or illegal fishing practices such as dynamite use. Maintaining a healthy river ecosystem within Namdapha TR (Maheswaran et al. 2021a) is therefore critical to sustaining fish populations that support piscivorous birds, including the WBH.

The WBH exhibits remarkable behavioural adaptations that enable it to survive in challenging environments. Its survival is closely tied to the protection of its habitat, particularly the maintenance of healthy river ecosystems and stable fish populations. This study offers important insights into the species' foraging behaviour, providing a valuable foundation for future conservation efforts. Any alteration in river systems—whether due to prolonged dry seasons or human activities such debris dumping and road expansion can significantly disrupt the heron's habitat. Furthermore, illegal fishing pressure and stinkbug collection (Maheswaran & Das 2025) inside Namdapha over the years may force herons to abandon their current stronghold and move to less suitable alternative sites. Recently, two herons were seen in Lohit River in Walong further north of Namdapha (Reddy et al. 2021) clearly supporting the fact that individuals do disperse in search of alternative sites. Such dispersal may result from offspring seeking new territories away from their natal areas, or from shifts in habitat characteristics and disturbances as discussed above. The precise causes—and the origins of these individuals—remain unclear. Furthermore, no detailed observations have ever been made on these individuals' foraging behaviour to elucidate what Lohit River offers herons in terms of prey.

Table 2. Summary of the observation on the foraging behaviour of White-bellied Heron in Namdapha Tiger Reserve.

Particulars	Hours
Total time herons observed foraging	858.45
Time spent observed on motion-based foraging strategies - Stand and wait - Scan and walk	 821.71 36.74
Time spent observed on water current-based foraging strategies - Upstream - Downstream	 403.97 454.48

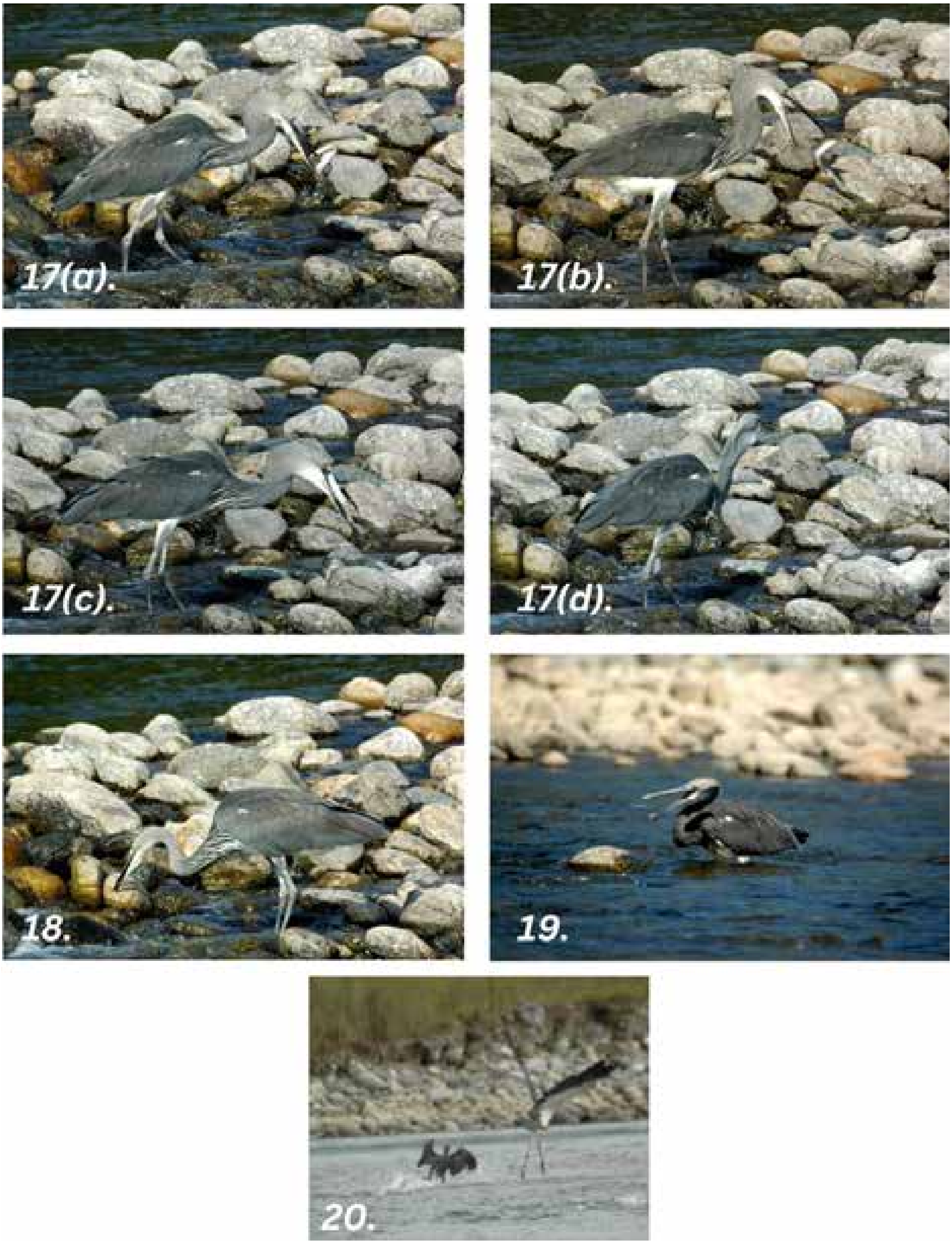

Image 17—20. White-bellied Heron: 17(a–d)—sequential steps of 'prey handling' in 2015 | 18—'bill wiping' after swallowing a fish in 2015 | 19—'bill opening' behaviour in 2016 | 20—a Great Cormorant chased the WBH, as it was trying to steal ('pirating') the fish captured in 2014. © Himadri Sekhar Mondal.

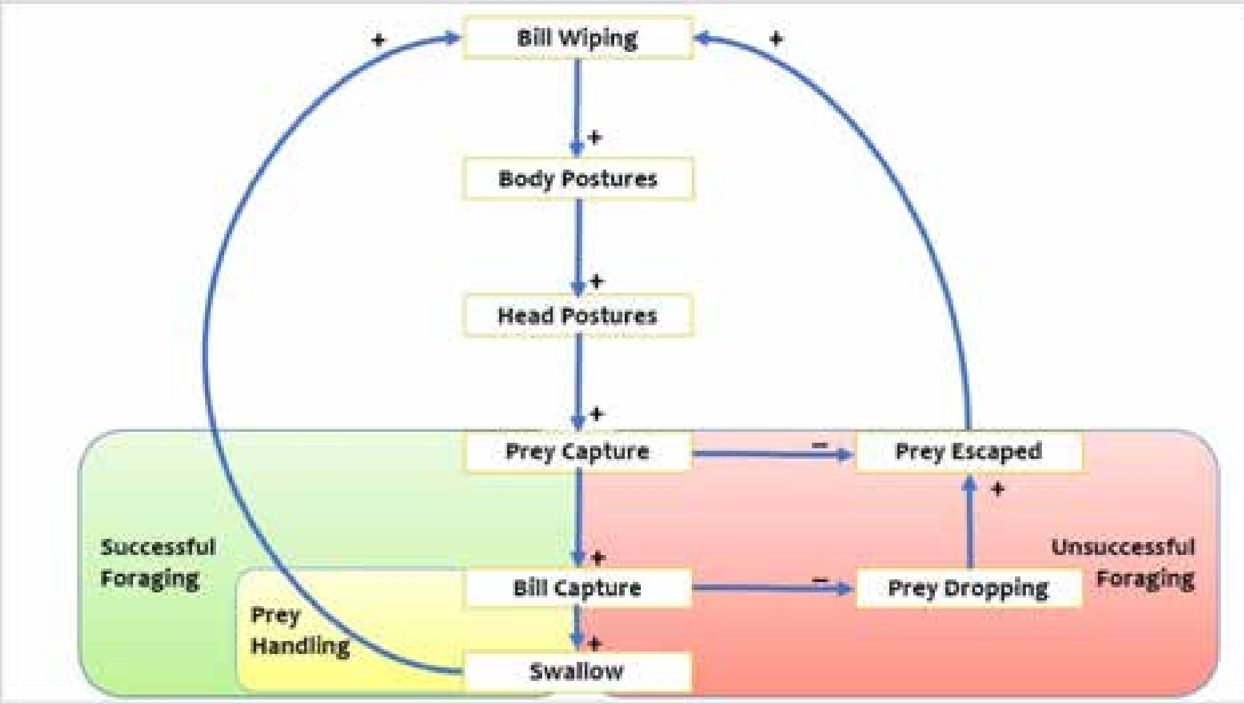

Image 21. The causal loop diagram of the White-bellied Heron foraging: WBH monitor its prey by standing or walking while keeping its body at a particular posture ('body posture'). By 'head posture' it monitored the prey in the river water. Then it attempted to catch the prey through 'prey capture'. If the prey escaped from its attempt, then this attempt resulted into an unsuccessful foraging event. The WBH can hold the fish in its bill through different 'bill capture' postures. Time between successful capture and swallow is known as 'prey handling' time and under such circumstances, the entire event resulted into a successful foraging event. Sometimes the fish might drop from the bill of WBH (during the prey handling) and escaped, resulted into an unsuccessful foraging attempt. Under both of these circumstances of success or failure, the WBH wipe its bill and stand or walk in a or a combination of different body postures.

Long-term observations in Namdapha indicate a growing concern: declining rainfall patterns over the years have led to significant alterations in riverine habitats, including the expansion of grasslands along the Noa-Dehing River. These environmental changes appear to have facilitated a rapid increase in feral buffalo populations maintained by local tribes, thereby exerting additional pressure on the ecosystem and potentially disrupting its balance.

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সাদা পেটের বক (Ardea insignis) ভুটান, ভারত এবং মায়ানমারে পাওয়া যায়। এই প্রজাতির বকের জনসংখ্যার অধিকাংশই (প্রায় ত্রিশটি) ভুটানে আছে। এরপরে ভারতে প্রায় দশটি এবং মায়ানমারে খুব অল্পসংখ্যক এই পাখি পাওয়া যায়। তবে এই বকের ভৌগলিক বাসস্থান জুড়ে এদের সংখ্যা ক্রমশ হ্রাস পাচ্ছে, যা এই প্রজাতির অস্তিত্বের জন্য বেশ আশঙ্কাজনক। এই বকের একটি বিশেষ বৈশিষ্ট্য হল, এরা দ্রুত স্রোতযুক্ত স্বাদু-জলের নদীকে তাদের খাদ্য সংগ্রহের উপযুক্ত স্থান হিসাবে পছন্দ করে। তবুও এই পাখিটির খাদ্য সংগ্রহ সংক্রান্ত এই বিশেষ আচরণটির (foraging behaviour) ব্যাপারে এখনও পর্যন্ত খুব কম তথ্যই উপলব্ধ আছে। তাই এই মৎস্যভুক পাখিটির জীবনধারণ এবং সফল প্রজননের জন্য এই স্বাদু-জলের নদীগুলিতে মাছের ধারাবাহিক উপস্থিতি অত্যন্ত গুরুত্বপূর্ণ। ২০১৩ থেকে ২০১৭ সাল পর্যন্ত আমরা ভারতবর্ষের নামদাফা টাইগার রিজার্ভে এই পাখিটির খাদ্য সংগ্রহ সংক্রান্ত আচরণ নিয়ে একটি গবেষণা করেছিলাম। ভারতবর্ষের এই স্থানে এই প্রজাতির বকের সংখ্যা এখনও পর্যন্ত সর্বাধিক। আমাদের এই গবেষণার মূল উদ্দেশ্য ছিল, সঠিকভাবে বুঝতে চেষ্টা করা যে কিভাবে এই দৃষ্টি-নির্ভর শিকারি পাখিটি দ্রুত-স্রোতযুক্ত নদীতে টিকে থেকে তাদের খাদ্য সংগ্রহ করে। কারণ প্রবল স্রোতের কারণে এই নদীতে শিকার শনাক্ত করা এবং তাদের ধরার কাজ অত্যন্ত কঠিন। গবেষণায় দেখা যায়, এই বকটি এমন কঠিন পরিবেশে শিকার ধরার জন্য বিভিন্ন রকমের দেহভঙ্গি ও কৌশল ব্যবহার করে। ধারাবাহিক ফোকাল স্যাম্পলিং (continuous focal sampling) পদ্ধতিতে আমরা এই পাখিদের পর্যবেক্ষণ করে আলোকচিত্রের মাধ্যমে তাদের দেহভঙ্গি এবং শিকার ধরার কৌশল নথিভুক্ত করেছি। প্রায় ৮৫০ ঘণ্টার পর্যবেক্ষণে দেখা যায়, এই বক শুধুমাত্র মাছ খায়। নদীর স্রোতের গতি তাদের খাদ্য সংগ্রহের এই আচরণকে বিশেষভাবে প্রভাবিত করে। ফলে শিকারের সফলতা বৃদ্ধির জন্য তাদেরকে বিশেষ কৌশল অবলম্বন করতে হয়। শিকার যাতে সহজে তাদের উপস্থিতি টের না পায় এবং যে মাছ তারা ইতিমধ্যে ধরেছে, সেটা যাতে দক্ষতার সাথে সামলানো যায়, তাই তারা বিশেষ ও স্বতন্ত্র চলন পদ্ধতি এবং দেহভঙ্গি ব্যবহার করে। এখানে উল্লেখিত কিছু দেহভঙ্গি তারা শুধুমাত্র নিজেদের শিকার ধরার ব্যর্থ প্রয়াসের পরেই ব্যবহার করে। এই গবেষণায় বকদের খাদ্য সংগ্রহের বেশকিছু আচরণ প্রথমবারের জন্য নথিভুক্ত করে হয়েছে। এই সমস্ত নথিবদ্ধ আচরণবিধি এই বিরল প্রজাতির বক এবং তাদের এই বিশেষ বাসস্থান সংরক্ষণের ক্ষেত্রে গুরুত্বপূর্ণ ভূমিকা পালন করবে বলে ধারণা করা হয়।

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ARTICLE

Breeding ecology and nest-site characteristics of the Black-necked Stork *Ephippiorhynchus asiaticus* in Khijadiya Bird Sanctuary, a Ramsar Wetland of Gujarat, India

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Abstract: This study assessed the population status, nesting ecology, breeding phenology, and reproductive performance of the Black-necked Stork *Ephippiorhynchus asiaticus* in Khijadiya Bird Sanctuary, a Ramsar Site (No. 2492) located along the Gulf of Kachchh, India. Field surveys were conducted from July 2024 to March 2025 using stratified point counts (n = 48 points), nest monitoring, and systematic behavioural observations. All nests were constructed on *Neltuma juliflora* (syn. *Prosopis juliflora*) at heights of 3–4.5 m. Active nesting extended from early October (nest building) to late December (fledging). The mean nest attendance per visit was 62 ± 18 minutes (n = 89 visits), and partner replacement during foraging occurred in 94% of departures, indicating strong biparental coordination. Each nest produced two fledglings. Nesting sites were associated with shallow semi-perennial water (0.3–0.7 m), emergent vegetation, elevated micro-topography, and low disturbance levels. The sanctuary supported 21–23 individuals during the peak season, including breeders, non-breeders, and juveniles.

Keywords: Biparental care, breeding phenology, fledging success, nest fidelity, nesting habitat, parental investment, post-fledging care, reproductive success, waterbird conservation, wetland ecology.

સારાંશ: આ અભ્યાસમાં ભારતના કચ્છના અખાતના કિનારે આવેલ અને રામસર સ્થળ (ક્રમાંક ૨૪૯૨) તરીકે માન્યતા પ્રાપ્ત ખિજડિયા પક્ષી અભયારણ્યમાં કાળી ડોક ઢોંક (બ્લેક-નેક્ડ સ્ટોર્ક, *Ephippiorhynchus asiaticus*)ની સંખ્યાની સ્થિતિ, માળા બાંધવાની પારિસ્થિતિક વિજ્ઞાન, પ્રજનન પ્રવૃત્તિનો સમયગાળો તથા પ્રજનન સફળતાનું મૂલ્યાંકન કરવામાં આવ્યું હતું. જુલાઈ ૨૦૨૪ થી માર્ચ ૨૦૨૫ દરમિયાન ક્ષેત્ર સર્વેક્ષણ હાથ ધરવામાં આવ્યું હતું જેમાં પોઈન્ટ કાઉન્ટ પદ્ધતિ (કુલ ૪૮ પોઈન્ટ) દ્વારા માળાઓનું નિયમિત નિરીક્ષણ તથા વર્તણુકના અવલોકનો લેવામાં આવ્યા હતા. તમામ માળાઓ ગાંડા બાવળ (*Neltuma juliflora*; સમાનાર્થી: *Prosopis juliflora*) વૃક્ષ પર ૩-૪.૫ મીટરની ઊંચાઈએ બનાવવામાં આવ્યા હતા. પ્રજનન પ્રવૃત્તિઓનો સમયગાળો ઓક્ટોબરની શરૂઆતમાં માળા નિર્માણથી શરૂ થઈ ડિસેમ્બરના અંતમાં બચ્ચાં ઉડવા સક્ષમ બને ત્યાં સુધી રહ્યો હતો. દરેક અવલોકન દરમિયાન માળા પર પુખ્ત પક્ષીઓની સરેરાશ હાજરી ૬૨ ± ૧૮ મિનિટ (કુલ ૮૯ મુલાકાતો) નોંધાઈ હતી. ખોરાકની શોધ દરમિયાન ૯૪% કિસ્સાઓમાં એક પક્ષી માળામાંથી નીકળ્યા પછી તેના સાથી પક્ષીએ માળાની જવાબદારી સંભાળી હતી, જે બંને માતા-પિતાની મજબૂત સંકલિત સંભાળ દર્શાવે છે. દરેક માળામાંથી બે બચ્ચાં સફળતાપૂર્વક ઉડવા સક્ષમ બન્યાં હતાં. માળા બાંધવાના સ્થળો છીછરા પાણીવાળા (૦.૩ - ૦.૭ મી.), બહારઉગી આવેલી જળવનસ્પતિ, ઊંચાઈ ધરાવતા સૂક્ષ્મ ભૂઆકાર તથા ઓછા માનવીય ખલેલવાળા વિસ્તારોમાં બનેલા હતા. પ્રજનનના મુખ્ય સમય દરમિયાન અભયારણ્યમાં પ્રજનન કરતા પુખ્ત પક્ષીઓ, અપ્રજનન પક્ષીઓ તથા કિશોર પક્ષીઓ સહિત કુલ ૨૧-૨૩ કાળી ડોક ઢોંક (બ્લેક-નેક્ડ સ્ટોર્ક) નોંધાયા હતા.

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INTRODUCTION

Wetlands designated under national and international conservation frameworks receive formal protection; however, continuous ecological monitoring is essential to detect hydrological changes, salinity fluctuations, invasive species expansion, anthropogenic disturbances, and shifts in vegetation structure and waterbird communities (Ramsar Convention Secretariat 2016; Byju et al. 2026). Monitoring programmes often emphasize migratory birds, yet the assessment of the breeding ecology of resident waterbird species is equally important. Breeding performance may reflect habitat quality, resource availability, and disturbance intensity, thereby, serving as a reliable indicator of wetland ecosystem condition (Green & Elmberg 2014; Byju et al. 2025).

The Black-necked Stork *Ephippiorhynchus asiaticus* is a large wetland-dependent bird distributed across southern and southeastern Asia and parts of Australasia (Ali & Ripley 1983; Hancock et al. 1992; Maheswaran & Rahmani 2002; Nawab & Srivastava 2009; Grimmett et al. 2011; Pathak et al. 2013; BirdLife International 2025). Although it is globally categorized as 'Least Concern' (BirdLife International 2025), the species occurs at low densities in India and exhibits scattered breeding populations (Rahmani 1989; Barman & Talukdar 1996; Sundar & Kaur 2001; Sundar 2003, 2004, 2005). It typically nests on tall trees in proximity to wetlands and demonstrates strong nest-site fidelity (Ali & Ripley 1983; Ishtiaq 1998; Sundar 2003; Ishtiaq et al. 2004; Maheswaran & Rahmani 2006).

Research on this species in India has largely focused on regions such as Keoladeo National Park in Rajasthan, Dudhwa National Park, and the Etawah–Mainpuri landscape of Uttar Pradesh (Ishtiaq 1998; Maheswaran 1998; Maheswaran & Rahmani 2002, 2006; Sundar 2003). Earlier surveys documented its limited distribution, with Rahmani (1989) reporting 141 sightings from 11 states and Sundar & Kaur (2001) recording 30 individuals across five states during field surveys conducted in 1998–1999.

In Gujarat, Khijadiya Bird Sanctuary, a protected wetland and a Ramsar site, together with its surrounding landscape, has consistently been identified as an important habitat for the species in the Saurashtra region, supporting breeding activity (Pandey & Teli 2005; Pathak et al. 2013; Gujarat Forest Department 2022). Regional assessments have also reported scattered occurrences across wetlands in the state, although confirmed breeding sites remain limited. This highlights the ecological significance of wetlands such as Khijadiya in sustaining local populations (Sundar 2003; Pathak et al. 2013; Gujarat Forest Department 2022).

While records of occurrence and occasional nesting observations are available from different parts of Gujarat, comprehensive information on breeding phenology, nest-site attributes, and reproductive success within this wetland remains limited. Considering the ecological importance of the habitat and the species' low-density breeding strategy, site-specific empirical evidence is necessary to support long-term monitoring and conservation planning. A systematic evaluation of breeding ecology in Khijadiya, therefore, contributes to effective local management and enhances broader understanding of the reproductive ecology of large wetland-dependent storks. The present study provides updated information on nesting ecology and reproductive performance of the Black-necked Stork in Khijadiya Bird Sanctuary and highlights habitat characteristics associated with successful nesting.

Study Area

Khijadiya Bird Sanctuary (6.05 km²) is located approximately 12 km north-east of Jamnagar along the southern coast of the Gulf of Kachchh, Gujarat, between 22.5167° & 22.5833° N and 70.1167° & 70.2500° E (Image 1). According to the biogeographic classification of Rodgers and Panwar (1988), the sanctuary falls within the semi-arid zone (Zone 4), specifically the Gujarat–Rajputana province (4B). The wetland complex comprises shallow freshwater impoundments on the eastern side and tidally influenced brackish to saline habitats on the western side, creating a distinct ecotonal transition between inland freshwater systems and marine-influenced environments (Gujarat Forest Department 2022). The elevation ranges approximately 5–10 m. The climate is semi-arid, with an average annual rainfall of 550–600 mm, most of which is received during the south-west monsoon period from June to September (IMD 2020).

Vegetation patterns reflect the prevailing salinity gradient across the area. Saline areas support mangrove patches dominated by *Avicennia marina*, whereas freshwater zones sustain emergent macrophytes such as *Typha* spp. and *Phragmites karka*. The terrestrial fringes are mainly covered by thorn scrub vegetation dominated by *Neltuma juliflora* (syn. *Prosopis juliflora*) and *Acacia* spp. (Pandey & Teli 2005). The coexistence of dual hydrological regimes and habitat heterogeneity enhances primary productivity and increases trophic complexity, supporting fish, crustaceans, and macroinvertebrates that form the food base for

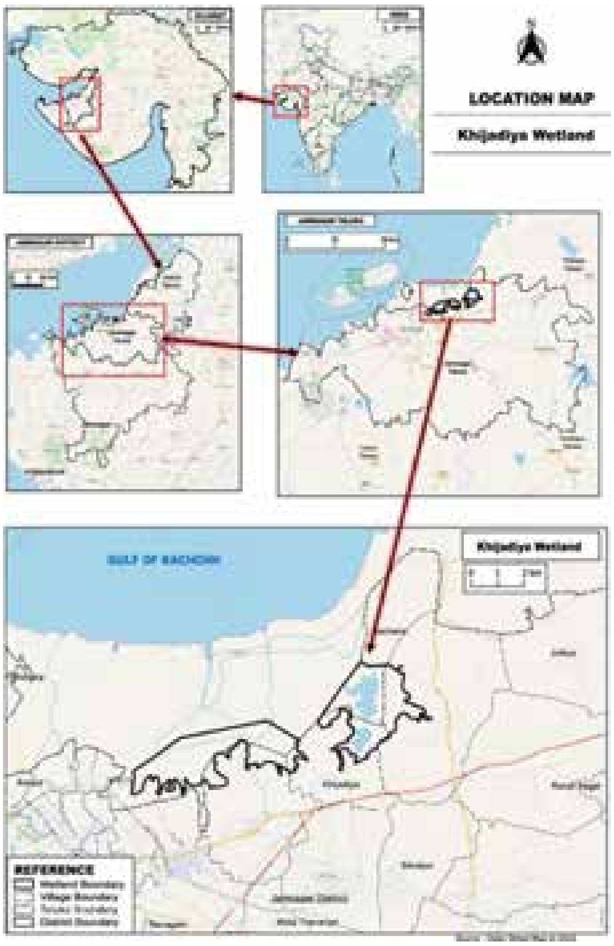

Image 1. Study area - Khijadiya Bird Sanctuary.

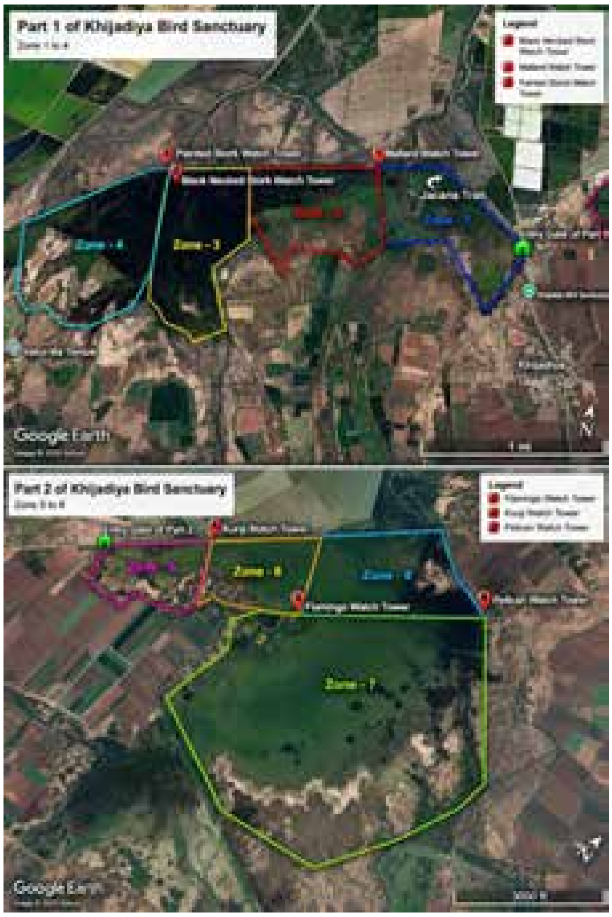

Image 2. Zone map - Khijadiya Bird Sanctuary.

diverse resident and migratory waterbird assemblages (Pandey & Teli 2005; Pathak et al. 2013; Gujarat Forest Department 2022).

Khijadiya Bird Sanctuary lies along the Central Asian Flyway, reinforcing its ecological importance as a staging, wintering, and breeding site for waterbirds (CMS 2014). For administrative management and ecological monitoring, the sanctuary is further divided into defined management zones (Image 2).

METHODS

Field surveys focusing on breeding ecology were conducted from July 2024 to March 2025, covering the monsoon, post-monsoon, and winter seasons. The overall field effort comprised approximately 95–120 field days. Abundance estimation was carried out using a stratified fixed point-count design (Bibby et al. 2000). A total of 48 georeferenced sampling points were established across eight management zones, maintaining a minimum spacing of 300 m to minimize spatial overlap and double counting. Counts were conducted simultaneously across survey sites within fixed time periods, with at least three observers independently surveying each survey site to minimize the possibility of double-counting individuals.

Each point was surveyed for 20–30 minutes per visit, resulting in approximately 230 survey sessions. During each survey, individuals were recorded along with group size, age class (where identifiable), behavioural observations, and associated habitat characteristics. Nest searches were conducted between October 2024 and February 2025. Confirmed nests were monitored from a distance of at least 50 m using binoculars (Nikon 10 x 50) and spotting scopes (16–48 x / 20–60 x), following standardized nest-monitoring protocols (Postupalsky 1974). Data collected from nests included nesting substrate, nest height, clutch outcome, chick survival, and patterns of adult attendance.

Behavioural observations were recorded using focal and scan sampling methods (Altmann 1974), generating approximately 320 hours of observation data. Nest attendance duration, foraging bout length, and partner exchange frequency were quantified to construct activity budgets. Habitat assessments were conducted within a 100–150-m radius around each nest site, recording parameters such as water depth, hydroperiod, vegetation composition, canopy cover, substrate elevation, and indicators of anthropogenic disturbance.

RESULTS AND DISCUSSION

Abundance of BNS in Khijadiya

The abundance of the Black-necked Stork in Khijadiya Bird Sanctuary showed moderate seasonal variation during the study period (Table 1). Four active nests, each occupied by a breeding pair, confirmed the presence of eight breeding adults. Post-hatching monitoring recorded two chicks per nest, resulting in eight juveniles. In addition, five non-breeding adults were regularly observed across the wetland. Together, these breeding adults, juveniles, and non-breeding adults accounted for a peak seasonal population of 21 individuals. Occasional sightings of an additional 3–5 individuals outside the regularly monitored breeding and foraging areas were considered intermittent observations, likely representing transient or dispersing birds, and were therefore excluded from the confirmed peak population estimate.

Previous observations from Gujarat indicate that the Black-necked Stork generally occurs at low densities, with most records documenting solitary individuals or breeding pairs across wetlands and surrounding landscapes (Pandey & Teli 2005; Pathak et al. 2013). The observed range of 13 regularly occurring individuals, increasing to a seasonal peak of 21 with the inclusion of juveniles and transient birds, reflects the species' characteristic low-density and territorial distribution pattern. Earlier studies have similarly reported that the species maintains large home ranges and widely spaced breeding territories associated with extensive wetland systems (Ali & Ripley 1983; Sundar 2005, 2006; Maheswaran & Rahmani 2006). The presence of four breeding pairs, along with additional non-breeding individuals, suggests that the sanctuary supported breeding activities and served as an important foraging and refuge area during the study period.

Nesting Sites and Habitat Features

Four active nests of Black-necked Stork were recorded across spatially separated management zones of Khijadiya Bird Sanctuary, reflecting the species' territorial nesting behaviour. The distribution of nests did not show clustering, which is consistent with the large breeding territories reported for this species in wetland and agricultural landscapes (Rahmani 1989; Sundar 2003; Maheswaran & Rahmani 2006).

Table 1. Summary of species abundance.

Details of birds	No. of individuals
Breeding Adults (4 pairs)	8
Juveniles (2 per nest × 4 nests)	8
Non-breeding adults (regularly seen)	5
Additional intermittent individuals	3
Total during peak season	**21**

All nests were constructed on *N. juliflora* at heights ranging 3–4.5 m and consisted of large stick platforms with shallow central depressions. Although the species commonly nests on tall native trees such as *Acacia nilotica*, *Ficus* spp., *Bombax ceiba*, *Dalbergia sissoo*, and *Ficus religiosa* (Ishtiaq 1998; Sundar 2003, 2006; Pathak et al. 2013), the present observations demonstrate adaptive use of structurally suitable invasive tree species where native nesting substrates are limited. Elevated nest placement likely reduces the risk of terrestrial predation and provides safe flight access for this large-bodied stork.

Nests were located along shallow wetland margins characterized by heterogeneous vegetation and a mosaic of open water patches. Within a 100–150-m radius around the nests, water depth ranged 0.3–0.7 m, supporting abundant prey resources such as fish, amphibians, crustaceans, and aquatic invertebrates (Gawlik 2002). The vegetation structure was diverse, with *N. juliflora* contributing approximately 35–48 % canopy cover, interspersed with emergent macrophytes including *Typha angustifolia*, *Phragmites karka*, and *Cyperus* spp., along with scattered *A. nilotica* and *Salvadora persica* on slightly elevated patches. Such shallow and structurally complex wetlands are considered suitable breeding habitats for the species because they enhance prey availability and foraging efficiency (Maheswaran & Rahmani 2002; Sundar 2005). However, because habitat availability across the sanctuary was not quantitatively compared, these observations should be interpreted as habitat associations rather than evidence of habitat selection.

Nest trees were situated on raised mounds approximately 0.5–1.2 m above the surrounding wetland

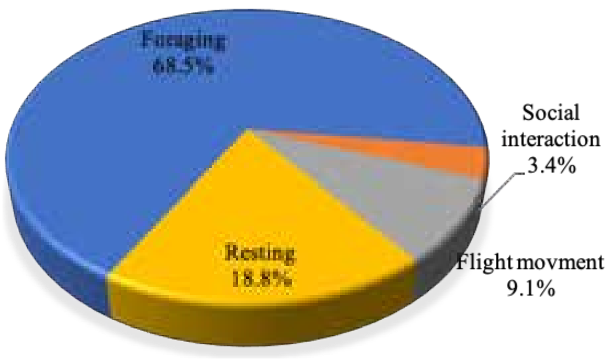

Image 3. Activity budget of Black-necked Stork (April–July).

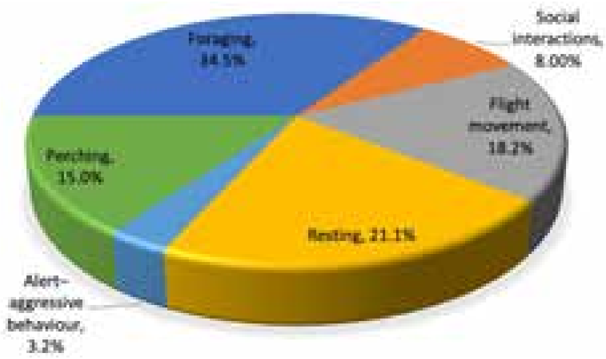

Image 4. Activity budget of Black-necked Stork (early August and late September).

surface, with mudflats and foraging pools located within 0.3–0.5 km, facilitating repeated provisioning during incubation and chick-rearing stages. Low anthropogenic disturbance within restricted-access compartments further supported nesting success, consistent with the documented sensitivity of the species to human activity near breeding sites (Rahmani 1989; Sundar 2004). Zones 1, 3, & 4 (Part 1) and Zone 6 (Part 2) recorded nests; and these locations were characterised by wetland–woodland interfaces and habitat condition. These habitat features were consistently associated with occupied nesting sites during the study period. The presence of these habitat features around nest trees in the Khijadiya Wetland Complex likely contributed to the successful breeding observed during the study period.

Breeding Phenology and Nesting Dynamics

The pre-breeding activities and breeding of the Black-necked Stork in the Khijadiya Wetland Complex extended from early August to late December, with clear behavioural transitions marking successive phases. From April to July, the activity budget was dominated by foraging (68.5%), followed by resting (18.8%) and flight (9.1%), whereas social interaction remained minimal (3.4%) (Image 3). The predominance of feeding behaviour during this period suggests routine habitat use primarily for energy acquisition and maintenance, with no observable signs of territoriality or reproductive activity. Behaviour during this phase was largely individualistic and focused on sustenance.

A distinct behavioural shift was observed during early August to late September. Foraging activity declined to 34.5%, while resting (21.1%) and flight activity (18.2%) increased. Perching behaviour rose to 15.0%, social interactions increased to 8.0%, and alert–aggressive behaviour emerged (3.2%), although no courtship displays were recorded (Image 4). This transition may be associated with territorial establishment and pair coordination prior to active breeding. The increase in perching and vigilance behaviour suggests territory surveillance and activities associated with nesting, whereas heightened social and aggressive interactions indicate pair bonding and territorial defence. Overall, the comparison of activity budgets suggests a marked shift in behavioural patterns prior to nesting.

Active nesting occurred from early October to late December. Nest construction was recorded between 3 and 17 October, followed by nest maintenance from 19 to 22 October. Egg hatching took place between 23 and 30 October, and intensive parental care continued from 4 November to 26 December (Image 5). A total of 89 nesting visits were recorded across the four active nests, with an occupancy rate of 92.60%. The maximum continuous adult presence at nests was 5.3 hours, and the mean duration per visit was 62 ± 18 minutes (n = 89).

Egg laying predominantly occurred during September and October, consistent with previous studies from India that associate breeding onset with post-monsoon hydrological conditions and improved prey availability (Sundar 2003). The period from October to December, therefore, represented the core reproductive phase in the study area. Biparental care was consistently observed during incubation and chick-rearing, confirming the importance of coordinated parental investment during this phase.

The post-nesting phase began in late December after all four monitored nests became inactive following successful fledging. By early January, adult pairs were observed foraging alongside juveniles across the wetland. Six juveniles were recorded accompanying adults, maintaining a distance of approximately 6–18 m during foraging activities. A total of 37 independent juvenile foraging attempts and 22 begging events, followed by adult food provisioning were documented,

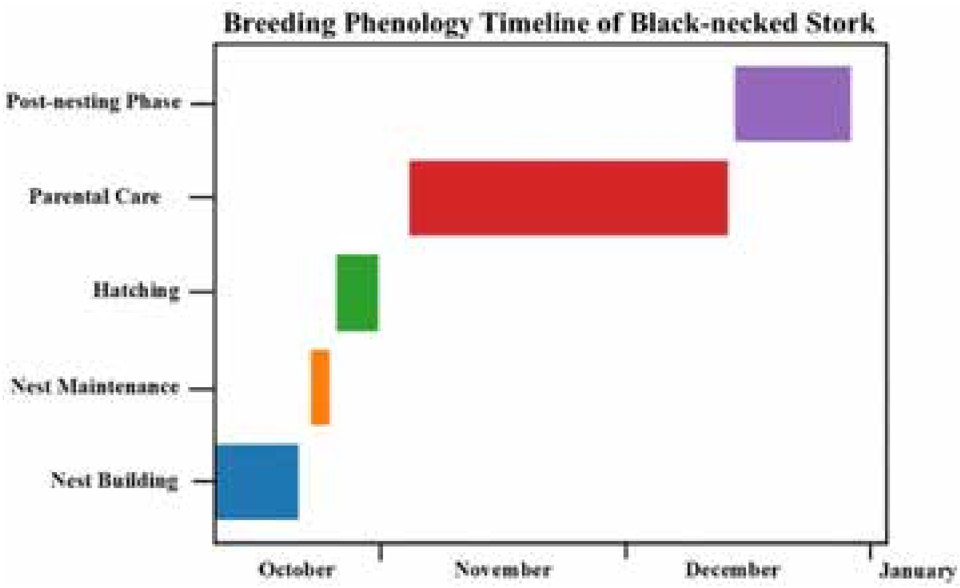

Image 5. Breeding phenology timeline of Black-necked Stork.

indicating partial dependence during the post-fledging stage. Although the monitored nests were inactive by late December, local observations suggest that nesting activity in the broader Khijadiya landscape may extend into January, reflecting spatial and temporal variation in breeding completion.

Breeding phenology observed in the present study follows a seasonal progression beginning with behavioural transitions during August–September and culminating in active nesting from October to December. Similar breeding patterns have been reported from semi-arid regions of India, where nesting typically begins after the monsoon when wetlands are replenished, and prey resources increase (Sundar 2005; Maheswaran & Rahmani 2006). Pre-breeding behavioural changes, including increased perching, heightened alertness, and enhanced pair interactions, suggest behaviours consistent with territorial establishment and pair coordination before nest construction, a pattern commonly documented for large stork species (Hancock et al. 1992). However, these behavioural functions were inferred from field observations and were not directly tested in the present study.

Reproductive Performance and Breeding Success

Post-hatching monitoring confirmed that all four nests saw the emergence of two chicks each, while three had early emergence, and one followed later. The number of chicks remained stable through late December, and by 20–21 December, individuals had reached near pre-fledgling size, suggesting healthy growth and high early survival. No instances of predation, chick mortality, or nest abandonment were recorded during the monitoring period. All four nests successfully produced fledglings, resulting in eight juveniles from four breeding pairs and yielding a 100% fledgling success rate (Table 2).

Table 2. Summary of breeding parameters and reproductive success of the Black-necked Stork.

Parameter	Value	Notes
Total active nests	4	All nests were monitored throughout the season
Total breeding pairs	4 pairs (8 adults)	A total of 13 individuals were observed, but only 4 pairs nested
Successful nesting attempts	4	No nest failure recorded
Failed nesting attempts	0	No predation, abandonment, or damage
Total fledglings	8 juveniles	2 fledglings per nest
Fledging success	2 fledglings per nest	Successful breeding outcomes were observed during the study period
Evidence of predation	None observed	

The recorded clutch size was two eggs per nest, which is slightly lower than previously reported clutch sizes of 3–4 eggs for the species, where typically 1–3 chicks fledge per successful nest (Ishtiaq 1998; Maheswaran 1998; Sundar 2003). Rare cases of higher fledging output, including four fledglings from individual nests, have also been documented (Sundar et al. 2007). However, in most studies, two surviving chicks per successful nest represent the common reproductive output. The present findings, therefore, fall within the lower but ecologically consistent range of productivity reported for the species.

Compared with earlier studies from Uttar Pradesh, where breeding success showed considerable variation and many nests failed to produce fledglings (Sundar 2003), all monitored nests in Khijadiya successfully produced fledglings during the study period. The habitat characteristics associated with these occupied nests may have contributed to the observed breeding outcomes. Reproductive performance in the sanctuary aligns with evidence that breeding success in the Black-necked Stork is strongly influenced by stable hydrological conditions, adequate prey availability, and secure nesting substrates near wetlands (Sundar 2005; Maheswaran & Rahmani 2006). The semi-perennial wetland regime and relatively low disturbance levels were characteristics of the areas surrounding occupied nests and may have contributed to sustained parental investment throughout incubation and chick-rearing.

Post-fledging observations further confirmed prolonged parental care, with juveniles accompanying adults and displaying begging behaviour prior to independent dispersal. Such extended dependency and gradual attainment of independence are characteristic of large stork species and reflect adaptive strategies that enhance juvenile survival during early life stages.

CONCLUSION

The findings suggest that Black-necked Storks utilized Khijadiya Bird Sanctuary for breeding and foraging during the study period and provided baseline information on nesting ecology and breeding performance within the wetland complex. Occupied nests were associated with shallow wetlands, structurally suitable nesting trees, and relatively low anthropogenic disturbance. These habitat characteristics coincided with successful breeding during the study period. Similar observations have been reported in earlier ecological studies, which emphasize the role of protected wetland complexes in sustaining viable breeding populations of the species. Although the study provides valuable insights into the breeding ecology of the Black-necked Stork in Khijadiya Bird Sanctuary, the findings are based on observations from a limited number of nests during a single breeding season. Consequently, the results should be interpreted as indicative rather than definitive, and long-term monitoring across multiple breeding seasons will be necessary to evaluate interannual variation in nesting ecology, habitat use, and reproductive performance. Continued protection of wetland hydrology, conservation of existing nesting trees, and effective regulation of human activities within the sanctuary will be essential to ensure the long-term persistence and conservation of this species in the region.

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ARTICLE

An updated checklist and new records of butterfly species in Kedarnath Musk Deer Sanctuary (western Himalaya), Uttarakhand, India

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Abstract: This study presents an updated checklist of butterflies of Kedarnath Musk Deer Sanctuary (KMDS), located in the Garhwal Himalaya of Uttarakhand, India, based on systematic field surveys conducted across multiple elevations and habitats. A total of 300 butterfly species belonging to six families and 19 subfamilies were recorded from the Sanctuary. The present work documents 153 species newly recorded from KMDS, substantially expanding the previously known butterfly fauna of the area. Species records were verified through photographic documentation and standard taxonomic literature, and only diagnostically confirmed records were included in the checklist. The updated inventory highlights the sanctuary as an important repository of butterfly diversity in the western Himalaya and provides a reliable baseline for future faunistic, taxonomic, and biodiversity assessments.

Keywords: Butterfly diversity, distribution extension, elevational gradient, insect conservation, insect fauna, Lepidoptera, new records, Papilionoidea, photographic documentation, Protected area.

सारांश: यह अध्ययन उत्तराखण्ड के गढ़वाल हिमालय में स्थित केदारनाथ कस्तूरी मृग अभयारण्य (KMDS) की तितलियों की एक अद्यतन सूची प्रस्तुत करता है, जो विभिन्न ऊँचाई वाले क्षेत्रों एवं आवासों में किए गए व्यवस्थित क्षेत्रीय सर्वेक्षणों पर आधारित है। इस अध्ययन में अभयारण्य से छह कुलों (Families) एवं 19 उपकुलों (Subfamilies) से संबंधित कुल 300 तितली प्रजातियाँ अभिलिखित की गईं। इनमें से 153 प्रजातियाँ पहली बार केदारनाथ कस्तूरी मृग अभयारण्य से दर्ज की गई हैं, जिससे इस क्षेत्र की पूर्व ज्ञात तितली विविधता में उल्लेखनीय वृद्धि हुई है। सभी प्रजातियों की पहचान फोटोग्राफिक अभिलेखों तथा मानक वर्गिकी साहित्य के आधार पर सत्यापित की गई तथा केवल पुष्ट पहचान वाली प्रजातियों को ही सूची में सम्मिलित किया गया। यह अद्यतन सूची अभयारण्य को पश्चिमी हिमालय में तितली विविधता के एक महत्वपूर्ण केंद्र के रूप में स्थापित करती है तथा भविष्य में जीवसूची (faunistic), वर्गिकी (taxonomic) एवं जैव विविधता संबंधी अध्ययनों के लिए एक विश्वसनीय आधारभूत संदर्भ प्रदान करती है।

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Author contributions: AK planned the work, designed the study. PK, GL, and PA conducted robust fieldwork in the Kedarnath Musk Deer Sanctuary. RL identifies the study and helps with the analysis and designing the graph.

INTRODUCTION

Butterfly diversity in the Himalayan region is strongly influenced by steep elevation gradients, rugged terrain, climatic heterogeneity, and habitat mosaics (Acharya & Vijayan 2015). These micro and macrohabitat components make it one of the most important regions for Lepidoptera diversity in India (Devi et al. 2023; Dewan et al. 2024). Variations in temperature, rainfall, and vegetation structure along elevation gradients play a key role in shaping species richness and distribution patterns, with many species showing narrow habitat and altitudinal preferences (Parmesan 2003; Hill et al. 2021). Uttarakhand, particularly the Garhwal Himalaya, supports high butterfly diversity, yet faunistic documentation remains uneven across protected areas (Sondhi & Kunte 2018). Kedarnath Musk Deer Sanctuary (KMDS) represents a large, ecologically diverse landscape within the western Himalaya, yet information on its butterfly fauna is limited and outdated (Singh 2009). This highlights the need for a focused, up-to-date checklist to accurately document butterfly diversity within the sanctuary.

Over 500 butterfly species have been documented in Uttarakhand (Sondhi & Kunte 2018), with around 407 reported specifically from the Garhwal region (Singh et al. 2016). This landscape provides nutrient-rich habitats that support the region's flourishing butterfly fauna. KMDS, an essential protected area in the Garhwal region of the western Himalaya, is renowned for its diverse habitats and rich biodiversity component. It is an important protected zone dedicated to the conservation of the endangered Musk Deer *Moschus chrysogaster* encompasses a diverse array of ecosystems, such as alpine meadows, temperate forests, and subalpine scrublands (Champion & Seth 1968), each creating distinct microhabitats that sustain a rich array of fauna, including numerous butterfly species. The region's moderate temperatures and well-distributed rainfall support an abundance of nectar-rich flowers and host plants, which are critical for butterfly survival and reproduction. During summer, the soil remains moist from melting snow, promoting the growth of algae, mosses, and lichens, which in turn support a thriving butterfly population. The forest floor, valley gorges, and tree canopies often showcase a vibrant kaleidoscope of butterflies (Lochan et al. 2022). Understanding the diversity of butterfly species is crucial for maintaining the health and balance of any ecosystem. This knowledge allows us to predict habitat preferences and comprehend their roles within trophic levels. Despite its ecological significance, butterfly diversity in KMDS faces several threats, including habitat degradation and heavy tourism, which severely impact butterfly populations (Sharma et al. 2019; Lochan et al. 2022). Moreover, the use of pesticides and insecticides poses a direct threat to butterflies, disrupting their food chains and reproductive cycles (Ara & Haque 2021; Kubelková 2024; Wani & Shah 2024). An earlier study at KMDS recorded 147 butterfly species (Singh 2009). Considering the altitude-dependent variations in topography and the diverse habitats at different elevations, this number may be underestimated. Given this gap, a thorough investigation is essential to accurately determine the total number of butterfly species in the sanctuary. By synthesising existing knowledge and contributing new insights, this paper aims to foster a deeper understanding of the diversity of butterflies and their environment in KMDS.

Study area

The current study was conducted in the KMDS, located in the western Himalaya at an elevational range of 800–5,960 m, between 30.7352° N and 79.0662° E (Image 1). Spanning 975 km^2, this landscape falls under the western Himalayan region and is classified under IUCN Management Category IV (Managed Nature Reserve) in the Biogeographical Province 2.38.12. It is part of the western Himalaya Endemic Bird Area, recognised as an Important Bird Area (IBA Code IN-UT-07) (Stattersfield 1998; Vázquez 1998). The area generally consists of dense forests, largely dominated by *Quercus leucotrichophora*, *Q. semecarpifolia*, and *Rhododendron* spp. with a deep understory of *Rosa brunonii*, *Berberis asiatica*, and *Carissa carandas*. The diverse habitats and climatic conditions provide a suitable environment for a wide range of butterfly species. Around 29 study sites were selected across different parts of the sanctuary, followed by direct sampling (Table 1).

METHODS

Butterfly surveys were conducted over a period of three years, from March 2021–August 2024, across KMDS. The sanctuary was divided into equal-sized grid cells, from which 29 grids were selected to represent the full elevation range of the area (~800–5,960 m). Each selected grid was surveyed multiple times during favourable weather conditions during the peak butterfly activity period. Surveys were carried out using visual encounter and transect-based walks. Due to rugged terrain and variable habitat structure, variable-length

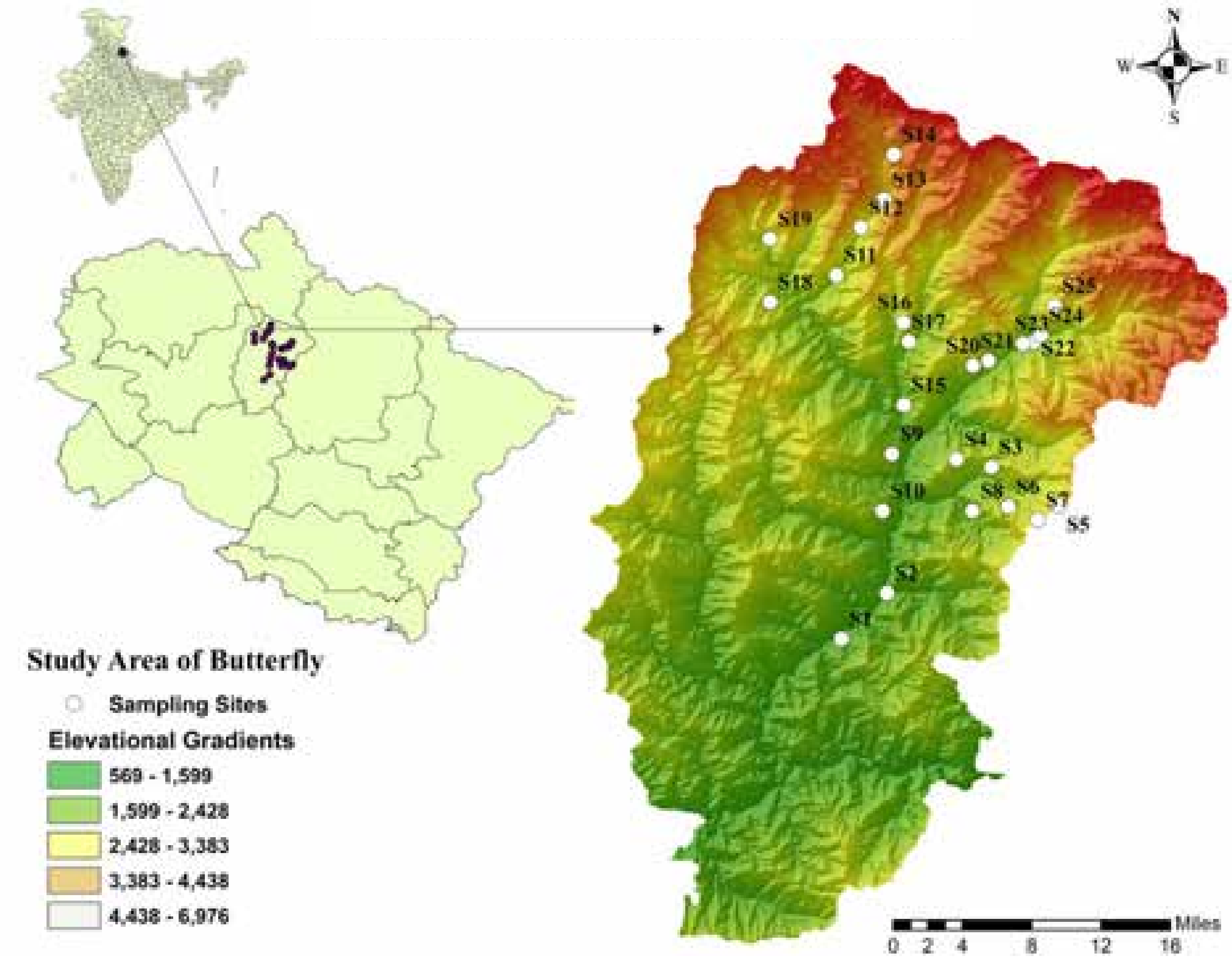

Image 1. Study area (Kedarnath Musk Deer Sanctuary) depicting the location of all sampling sites for the present study.

transects (0.5–2 km) were employed instead of fixed-width transects. Transects were walked across major habitat types, including forested areas, grasslands, meadows, and riverine zones, to maximise species detection across elevation gradients. In total, surveys comprised approximately 14 field days per month. All records were based on non-invasive photographic documentation; no specimens were collected. Butterflies were photographed using Nikon Coolpix P900, P610, and D7500 cameras, and locations were recorded using a Garmin eTrex 20 GPS unit. Species identification was performed using standard field guides and taxonomic literature (Kehimkar 2008, 2016; Sondhi & Kunte 2018). For rare or taxonomically challenging species, diagnostic morphological characters visible in photographs, particularly wing patterns and underside markings, were carefully compared with published descriptions and reference images. Only records supported by clear diagnostic photographic evidence were treated as confirmed and included in the checklist; uncertain records were excluded from confirmed results.

RESULTS

Seventeen years since the last study in this landscape, comprehensive research on butterfly diversity was deemed necessary. The present survey indicates the number of butterfly species may have been underestimated in previous studies. Through detailed observations conducted over three consecutive years, around 300 butterfly species were recorded (Table 2, Image 2), compared with the previously documented 147 (Singh 2009). This update includes 153 additional species, some of which are either new to the region or exceedingly rare. Among the newly recorded species some of the rare butterflies are *Melanitis zitenius*, *Aeromachus stigmata*, *Hasora taminatus*, *Catapaecilma major*, *Miletus chinensis*, *Belenois aurota*, *Hestina persimilis*, *Pelopidas conjuncta*, *Ionolyce helicon*, *Heliophorus oda*, *Heliophorus indicus* (Fruhstorfer), *Heliophorus epicles* (Godart), *Heliophorus brahma* (Moore), *Heliophorus moorei coruscans*, *Heliophorus moorei tytleri*, *Iraota timoleon* (Stoll), *Sinthusa chandrana*, *Tarucus venosus*, *Chliaria othona*, *Catochrysops panormus*, *Everes huegelii huegelii* (Gistel), *Spindasis vulcanus*, *Spindasis elima*, *Aricia agestis nazira*, *Neope pulaha*, *Melanitis phedima bela*.

Most significant records from the KMDS region

1. Great Evening Brown *Melanitis zitenius* Herbst, 1796. *M. zitenius,* with its known distribution extending eastwards from Kumaon to Sikkim, was previously reported in Uttarakhand by Uniyal et al. (2013). Subsequent literature has called for validation, given the absence of specimens or photographic evidence to support this claim (Singh et al. 2016). This species is legally protected in India under Schedule II of the Wildlife (Protection) Act, 1972. A photographic record of a single individual on 12 December 2016 at an elevation of approximately 1,680 m on a forest floor in the sanctuary marks the first confirmed photographic record for Uttarakhand and the first confirmed record from KMDS. To the best of current knowledge, this species has not been previously reported from KMDS (Singh 2009). This species is considered very rare in the state (Image 3).

2. Veined Scrub Hopper *Aeromachus stigmata,* a small butterfly, has been documented in Assam and Arunachal Pradesh in the northeastern Himalayas, with an altitude range of up to 1,700 m (Kehimkar 2016). According to the existing literature, there is no prior record of this species in the KMDS. On 12 August 2021, this species was observed near an oak forest with Lantana-dominated bushes close to a water stream at an elevation of 1,800 m. This marks yet another significant breakthrough in the sighting of this species within the KMDS (Image 3).

3. White-banded Awl *Hasora taminatus* Hübner, 1818. *H. taminatus,* recognised by the distinct white band on the underside of its hindwing, is typically observed at lower elevations, with a distribution documented across the Western Ghats, Eastern Ghats, and parts of the northeastern states (Kehimkar 2016). Previous literature does not mention its presence in the western Himalayan region. This record is the first for this part of the Himalaya and Uttarakhand, including KMDS. A solitary specimen was photographed on 05 October 2019, at an elevation of 1,560 m near an oak-pine mixed forest (Image 3).

4. The Common Tinsel *Catapaecilma major*. *C. major,* is primarily found in the southeastern and northeastern regions of India, thriving in dense forests and open hilly jungles. It is quite rare in Uttarakhand, with just one photographic record from the Kumaon region (Kumar et al. 2019). There have been no prior records of this species in the Garhwal region (Singh et al. 2016). The first instance of *C. major* in Garhwal was documented on 23 July 2018, at an altitude of 870 m near lantana shrubs. This represents the first confirmed record of this species in KMDS (Image 3).

5. Common Brownie *Miletus chinensis*. *M. chinensis*, a rare butterfly species previously unrecorded in the Garhwal Himalaya region (Singh et al. 2016), was observed on 08 August 2020, at an elevation of 2500 m in a habitat primarily dominated by Oak and interspersed with *Drepanostachyum* spp. This marks the first confirmed record of this species in the sanctuary (Image 3).

6. Pioneer *Belenois aurota*. *Belenois aurota* (Pioneer) is a widespread and highly migratory pierid butterfly commonly occurring in open habitats, forest edges, and valleys across the Himalaya. The species has been previously reported from several localities in Uttarakhand, including forest, Dehradun Valley & Shiwaliks; Shikhar Falls, Sahastradhara, Maldeota, Mussoorie, confirming its regional presence (Singh et al. 2016). The present observation from KMDS adds an important locality record within this high-altitude protected area.

7. Siren *Hestina persimilis* Westwood, 1851. Thriving in forested regions, this rare butterfly is usually observed in the Himalaya at elevations ranging 750–1,460 m, though it may occasionally ascend to higher altitudes. On 13 September 2021, this elusive species was documented at an elevation of 800 m, within a habitat dominated by Lantana bushes (Image 3). Notably, earlier records did not document this species within the sanctuary (Singh 2009).

8. Conjoined Swift *Pelopidas conjuncta* Herrich-Schäffer, 1869. An uncommon species, *P. conjuncta* is considered locally rare in Uttarakhand (Singh et al. 2016). It prefers forested and woodland habitats, with its range extending up to 2,000 m in the Himalaya. Photographed at an elevation of 1,870 m in an oak-mix forest on 05 March 2021, this species has now been added to the butterfly fauna of the sanctuary (Image 3).

9. Pointed Lineblue *Ionolyce helicon*. The Pointed Lineblue, *Ionolyce helicon*, is a characteristic montane lycaenid of the Himalayan region, often encountered in

Table 1. Sampling sites, altitude, coordinates and habitat type.

Site	ID	Elevation (m)	Habitat types
Agastyamuni	S1	895	Oak pine mixed forest with cropland
Chandrapuri	S2	990	Hill stream with oak, pine, and mixed forest
Sari	S3	2242	Oak mixed forest
Deoriyatal	S4	2417	Oak mixed forest
Tungnath	S5	3436	Oak-Blue Pine-Rhododendron mixed forest
Duggalbitta	S6	2488	Blue pine, oak mixed forest
Baniyakund	S7	2805	Oak mixed with Blue Pine
Makkumath	S8	1800	Oak-Rhododendron mixed forest
Guptkashi	S9	2189	Pine mixed forest
Nagjagayi	S10	1800	Pine mixed forest
Gourikund	S11	2324	Pine-Oak mixed forest
Bheembali	S12	2829	Oak with grassland
Lincholi	S13	3493	Oak with blue pine and grassland
Kedarnath	S14	5960	Grassland with flowering plant
Kalimath	S15	1792	Oak-pine mixed forest
Chaumasi	S16	2691	Oak-Deodar mixed forest
Chilode	S17	1870	Oak-Pine mixed forest
Triyuginarayan	S18	1895	Oak-Pine mixed forest
Tausi	S19	2495	Oak-Blue Pine-Deodar mixed forest
Ranshi	S20	2478	Oak- Blue Pine mixed forest
Gondar	S21	2500	Oak mixed with Ringal bamboo forest
Khdara	S22	2127	Oak mixed with Ringal bamboo forest
Bantoli	S23	2800	Oak mixed with Ringal bamboo forest
Nanu	S24	2300	Oak mixed with Ringal bamboo forest
Madmaheswar	S25	3500	Oak-Deodar-Blue Pine mixed forest
Uchola	S26	2000	Oak-Bamboo-Deodar mixed forest
Chopta	S27	1800	Pine-dominated landscape
Malkhi	S28	2300	Oak-Pine mixed forest
Kartikswami	S29	2069	Oak pine Mixed Forest

sheltered forest clearings and along shrub-dominated trails. Unlike the more widespread lowland lineblues, this species shows a stronger association with mid- to high-elevation habitats, making it a notable component of alpine-temperate transition zones. Its occurrence in the KMDS highlights the ecological importance of this protected area in sustaining specialized Himalayan butterfly fauna.

10. Eastern Blue Sapphire *Heliophorus oda* Hewitson, 1865. *H. oda* is a rare butterfly species in India, primarily found from Himachal Pradesh to Sikkim, including Nepal and Bhutan, at elevations of 2,000–3,500 m (Kehimkar 2016). Previous surveys in the sanctuary did not report its presence (Singh 2009). A single male was documented outside the sanctuary near Mussoorie, with a possible distribution range of 1,500–3,000m in Uttarakhand (Singh et al. 2016). In our observation, *H. oda* was observed in 07 October 2022 in an oak-dominated forest at 1,800 m near Makkumath, KMDS (Image 3).

11. Indian Purple Sapphire *Heliophorus indicus* Fruhstorfer. The Indian Purple Sapphire, *Heliophorus indicus*, is a localized Himalayan butterfly largely restricted to cool temperate forests and higher montane landscapes. It is usually observed in sunny openings, where males display rapid fluttering flight and frequently settle on low herbs or damp patches. Due to its narrow elevation preference and comparatively scattered distribution, the presence of this sapphire in Kedarnath Musk Deer Sanctuary is significant, indicating the sanctuary's role as a refuge for specialized high-altitude lycaenid species.

12. Purple Sapphire *Heliophorus epicles* Godart, 1824. *H. epicles,* a locally rare species, had previously been reported in Uttarakhand. Prior studies, particularly in the sanctuary (Singh 2009) lacked clarity regarding the species' presence. In the current study, this species was photographed on 27 September 2020, at an elevation of 1,980 m in a mixed oak-rhododendron forest (Image 3).

13. Golden Sapphire *Heliophorus brahma* Moore, 1858. *H. brahma* is a small butterfly with a rare presence in Uttarakhand and scarce records in the western Himalayas. Previous studies have documented the species in various parts of Uttarakhand (Uniyal 2004; Kunte et al. 2019). Its presence is lacking in the earlier research (Singh 2009). *H. brahma* was recorded at an elevation of 2,130 m, in a moist habitat near a stream dominated by *Rosa brunonii* bushes. The butterfly was observed to be active throughout the day in May and June (Image 3).

14. **Azure Sapphire *Heliophorus moorei coruscans*.** The Azure Sapphire is a high-altitude Himalayan subspecies typically associated with temperate oak–rhododendron forests and alpine meadows during the summer flight season. It is most often encountered in sunlit forest openings and along moist hill paths, where individuals frequently feed on small-flowered herbs. Its documentation from KMDS reflects the sanctuary's rich montane butterfly assemblage and emphasizes the importance of conserving these fragile alpine–temperate

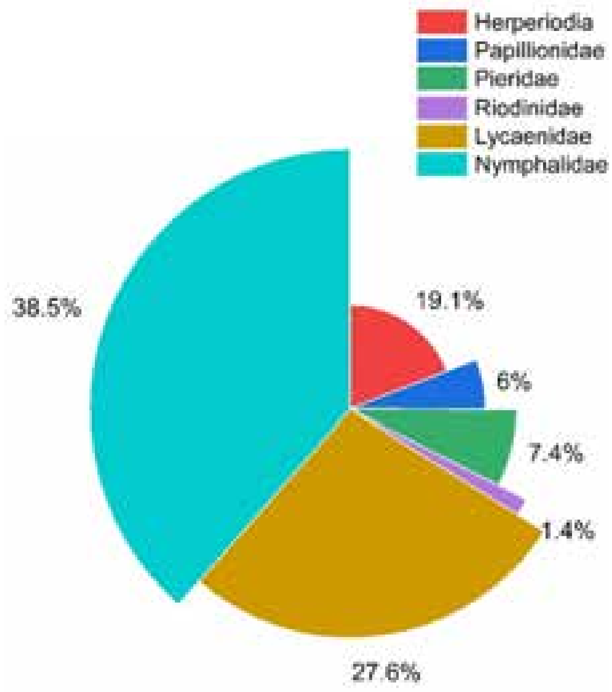

Image 2. Family composition of butterflies in Kedarnath Musk Deer Sanctuary.

ecotones that support such visually distinctive and habitat-sensitive lycaenids.

15. Silverstreak Blue *Iraota timoleon* Stoll, 1790. *I. timoleon*, an uncommon butterfly previously recorded only at lower elevations in Uttarakhand (Kunte et al. 2019), was not listed in earlier KMDS documentation (Singh 2009). Its presence is now confirmed with a sighting on 11 March 2018, at 1030 m in a shrubby habitat near an oak forest (Image 3).

16. **Broad Spark *Sinthusa chandrana*** is a forest-associated lycaenid typically encountered in shaded valleys and lower temperate zones of the Himalaya. Unlike the bright sapphires and lineblues that frequent open sunny patches, this species is more secretive and rarer in Uttarakhand (Singh et al. 2016), often remaining close to understory vegetation and appearing briefly along forest trails. Its occurrence in Kedarnath Musk Deer Sanctuary highlights the presence of intact woodland microhabitats that support less conspicuous but ecologically important members of the Himalayan butterfly community.

17. **Himalayan Pierrot *Tarucus venosus* Moore, 1882**. A common butterfly species typically found in the Himalayan foothills at elevations up to 1,200 m in Uttarakhand (Kunte et al. 2019). Observations and photographs of several individuals were recorded during our survey in the sanctuary. This species was notably more frequently observed in July, at elevations up to 2,100 m, primarily within oak-mixed forest habitats (Image 3).

18. Orchid Tit *Chliaria othona* is a characteristic Himalayan lycaenid strongly associated with moist temperate forests and shaded hill slopes. It is typically observed flying low near bushes or resting quietly beneath leaves, making it easy to overlook during rapid surveys. The species is common at low elevations in Uttarakhand, but no records have been reported from the Kedarnath Musk Deer Sanctuary (Singh 2009). The species is often linked with well-preserved forest habitats, and its record from KMDS supports the importance of this protected landscape in maintaining specialized butterfly fauna dependent on cool, undisturbed woodland conditions.

19. Silver Forget-me-not *Catochrysops panormus* is a widespread lycaenid butterfly typically found in open grassy patches, forest edges, and disturbed habitats where low herbaceous vegetation is abundant. This species typically prefers low elevation (Kehimkar 2016). This is the first record from KMDS and its presence reflects the mosaic of open and semi-open microhabitats within the sanctuary that support both generalist and montane butterfly assemblages.

20. Dusky Blue Cupid *Everes huegelii huegelii* is a characteristic Himalayan blue largely confined to montane and subalpine zones, where it inhabits open slopes, alpine meadows, and flower-rich clearings during the short summer season (Kehimkar 2016). The species is often observed nectaring on small herbs and is considered a typical representative of high-elevation lycaenid fauna. This is the first record from the KMDS.

21. Common Silverline *Spindasis vulcanus* is a conspicuous lycaenid typically associated with dry scrub, forest edges, and open hill slopes. Unlike many high-altitude sapphires restricted to cool-temperate forests, this species is more robust and often occurs in warmer, lower-montane habitats with scattered shrubs. Its records from the KMDS indicate heterogeneous edge habitats that support both open-country and forest-margin butterfly species.

22. Scarce Shot Silverline *Spindasis elima* is a Himalayan lycaenid typically encountered along wooded slopes, scrubby clearings, and montane forest margins. Compared to the more widespread *S. vulcanus*, this species is less frequently observed and shows a stronger association with intact mid-elevation habitats. This is the first documentation from KMDS.

23. Orange-bordered Argus *Aricia agestis nazira* is a high-altitude subspecies, usually associated with alpine meadows, rocky slopes, and herb-rich grasslands during the summer months. Its presence is often linked with cold-adapted montane ecosystems, where it flies close to the ground and frequently settles on low vegetation. The record of this argus from KMDS highlights the sanctuary's alpine butterfly diversity and the ecological value of its meadow habitats within the greater Himalayan landscape.

24. Veined Labyrinth *Neope pulaha* is a temperate forest butterfly commonly associated with shaded woodland trails, moist ravines, and dense understory vegetation in the Himalaya. Unlike open-habitat lycaenids, this species prefers low-light environments and is often observed resting on tree trunks or leaf litter, relying on its cryptic underside markings for concealment. It is uncommon in Uttarakhand (Singh et al. 2016), and its presence in the KMDS indicates the existence of well-preserved forest microhabitats that support satyrine butterflies adapted to cool, shaded montane ecosystems.

25. Dark Evening Brown *Melanitis phedima bela* is a shade-loving satyrine butterfly frequently active during late afternoon and dusk, unlike most daytime-flying Himalayan species. It is typically encountered at forest edges, in shaded clearings, and in moist valleys, where it rests quietly among leaf litter. The species is well known for its remarkable dry-season camouflage, mimicking dead leaves, which enhances survival in fluctuating Himalayan environments. This is the first record from KMDS.

26. Dark Himalayan Oakblue *Arhopala rama* is a forest-dependent Himalayan Oakblue closely associated with mature broadleaf temperate forests, particularly oak-dominated habitats. Species of *Arhopala* are often considered indicators of intact woodland ecosystems because they depend on specific host plants and shaded canopy environments. This species is not rare but vagrant, and is found mostly during the post-monsoonal season.

DISCUSSION

The earlier study, conducted over a decade ago, seems to have overlooked substantial portions of the butterfly fauna, likely due to a combination of fragmentary surveys and habitat variation within the sanctuary. The present study recorded 300 butterfly species, substantially exceeding the 147 species previously reported by Singh (2009), suggesting that earlier inventories may not have fully captured the butterfly diversity of KMDS. The additional 153 species, including several rare and uncommon species, highlight the need for more comprehensive, periodic biodiversity assessments in the ecologically rich Sanctuary. Underestimation of regional biodiversity, including butterflies, may significantly challenge the development of effective conservation planning and management strategies. Given that KMDS encompasses a broad elevation gradient of approximately 500–7,068 m above sea level, while the present surveys covered elevations of 800–5,960 m, the diversity of habitats within the sanctuary is likely to contribute substantially to regional butterfly diversity. The sanctuary encompasses subtropical forests at lower altitudes, temperate forests at mid-elevations, and alpine meadows at higher altitudes, each offering unique ecological niches for butterflies (Jaryan et al. 2013; Uniyal et al. 2013), but probably lacks adequate cover during the survey, particularly in the more inaccessible high-altitude regions.

The presence of newly recorded species in KMDS suggests that the Sanctuary provides critical habitat for both common and rare butterflies, contributing to regional and possibly national biodiversity conservation. The addition of these species in the current study, and their absence in earlier surveys, highlight the importance of long-term monitoring to account for seasonal and interannual variations in species presence and abundance. Furthermore, the addition of other rare and uncommon species like *Miletus chinensis*, *Belenois aurota, Hestina persimilis*, *Pelopidas conjuncta*, *Baoris farri*, *Arhopala centaurus*, *Horaga viola*, *Pedesta masuriensis*, *Ampittia subvittatus*, *Symbrenthia hypselis*, and *Limenitis trivena*, not only enriches the sanctuary's biodiversity inventory but also emphasizes the region's potential as a refuge for lesser-known, often overlooked species. The presence of such species aligns with studies conducted in other Himalayan regions, where highly localized or rare species have been found to persist in isolated pockets of suitable habitat (Dawar et al. 2022).

Additionally, this study aligns with research conducted in other parts of the Himalayas, where recent surveys have revealed previously unknown species, indicating that many regions may still harbour undiscovered biodiversity (Ghazoul 2006). For example, Sharma et al. (2019) documented several first-time records of butterfly species in neighbouring areas of Uttarakhand, suggesting that the Western Himalayas, despite being well-studied, continue to yield surprises regarding species diversity. This highlights the dynamic nature of biodiversity in mountainous regions, where microhabitats, climatic variations, and elevation play crucial roles in shaping species distributions (Mani

Table 2. Updated checklist of butterflies (Lepidoptera: Papilionoidea) recorded from Kedarnath Musk Deer Sanctuary, Uttarakhand, India.

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
A. Super family: Hesperioidea				
i. Family: Hesperiidae				
A. Sub-family: Coeliadinae				
1	*Bibasis sena*	Orange Tail Awl	Uncommon	Moist forest up to 1500
2	*Hosora chromus*	Common-banded Awl	Rare	Forest edges up to 2000
3	*Hasora taminatus* Hübner	White-banded Awl	Uncommon	Forest edges up to 2000
4	*Burara harisa* Moore	Orange Awlet	Uncommon	Forest edges up to 1500
5	*Berara oedipodea*	Branded Orange Awlet	Uncommon	Hill forests up to 1500
6	*Choaspes benjaminii*	Indian Awlking	Uncommon	Forests 300–2400
b. Sub-family: pyrginae				
7	*Celaenorrhinus leucocera*	Common Spotted Flat	Common	Forest up to 2500
8	*Celaenorrhinus munda* Moore	Himalayan Spotted Flat	Uncommon	Forest up to 2000
9	*Celaenorrhinus pero*	Mussorie Spotted Flat	Common	Hill forests 1500–2000
10	*Pseudocoladenia dan*	Fulvous Pied Flat	Common	Forest edges up to 2200
11	*Celaenorrhinus dhanada*	Himalayan Yellow Flat	Rare	Forest edges 300–1800
12	*Tagiades japetus* Stoll	Common Snow Flat	Uncommon	Forest up to 1000
13	*Tagiades menaka*	Spotted Snow Flat	Common	Hill forests 1500–2000
14	*Tagiades litigiosa* Möschler	Water Snow Flat	Common	Forest up to 2000
15	*Sarangesa dasahara* Moore	Common Small Flat	Common	Grassland and forest edges
16	*Caprona agama*	Spotted Angle	Uncommon	Grassland and forest edges
17	*Caprona ransonneti*	Golden Angle	Uncommon	Forest and forest edges
18	*Odontoptilum angulatum*	Chestnut Angle	Common	Forests up to 2400
19	*Spialia galba* Fabricus	Indian Skipper	Common	Grassland and forest 2500
c. Sub-family: Hesperiinae				
20	*Aeromachus dubius*	Dingy Scrub Hopper	Uncommon	Grassland up to 2000
21	*Aeromachus stigmata* Moore	Veined Scrub Hopper	Uncommon	Forest 1500–2100
22	*Aeromachus jhora* de Nicéville	Grey Scrub Hopper	Uncommon	Forest up to 1800
23	*Ochus subvittatus*	Tiger Hopper	Rare	Forest up to 1000
24	*Sovia grahami Evans*	Graham Ace	Rare	Forest up to 1500
25	*Pedesta masuriensis* Moore	Mussoorie Bush Bob	Rare	Hill forests 1500–2000
26	*Notocrypta feisthamalli alysos*	Spotted Demon	Common	Forest edges 300–2500
27	*Udaspes folus* Cramer	Grass Demon	Common	Grassland and forest 2500
28	*Taractrocera danna* Moore	Himalayan Grass Dart	Uncommon	Forest up to 1500–2200
29	*Potanthus dara*	Himalayan Dart	Uncommon	Forest up to 1700
30	*Ampittia dioscorides* Fabricius	Bush Hopper	Common	Forest up to 1000
31	*Suastus gremius* Fabricius	Indian Palm Bob	Common	Forest up to 1200
32	*Hyarotis adrastus praba* Moore	Tree Flitter	Common	Forest up to 1600
33	*Matapa aria* Moore	Common Red eye	Common	Forest up to 1000
34	*Eurionota torus*	Rounded Palm Red-eye	Rare	Forest up to 1500
35	*Taractrocera maevius*	Common Grass Dart	Common	Grassland and scrub 1600
36	*Oriens golo gola* Moore	Common Dartlet	Common	Forest low elevation
37	*Potanthus pseudomaesa pseudomaesa* Moore	Common Dart	Common	Hill forest up to 1200
38	*Telicota bambusae bambusae*	Dark Palm Dart	Common	Forest edges up to 1500
39	*Baoris farri* Moore	Paintbrush Swift	Rare	Forest up to 1100
40	*Gegenes nostrodamus*	Dingy Swift	Rare	Forest clearing at low elevation

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
41	*Parnara guttatus*	Straight Swift	Common	Forest up to 2400
42	*Parnara ganga*	Continental Swift	Common	Forest edges at low elevation
43	*Parnara guttatus*	Oriental Straight Swift	Common	Grassland and drier plains
44	*Borbo cinnara*	Rice Swift	Uncommon	Forest up to 1000
45	*Pseudoborbo bevani*	Bevan's Swift	Uncommon	Forest up to 2100
46	*Pelopidas subochracea*	Large branded swift	Uncommon	Forest up to 2400
47	*Pelopidas conjuncta*	Conjoined Swift	Rare	Forest edges up to 1200
48	*Polytremis discreta*	Himalayan Swift	Uncommon	Hill forest up to 3000
49	*Polytremis eltola*	Yellow spot swift	Common	Forest 300–3000
50	*Pelopidas mathias*	Small Branded Swift	Common	Grassland and scrub 2200
51	*Halpe homolea aucma* Swinhoe	Indian Ace	Uncommon	Forest low elevation
52	*Suastus gremius* Fabricius	Indian Palm Bob	Common	Forest up to 1000
53	*Matapa aria* Moore	Common Redeye	Common	Forest up to 1000
54	*Notocrypta curvifascia*	Restricted Demon	Common	Forest up to 400–1800
55	*Notocrypta feisthamelii*	Spotted Demon	Common	Forest up to 1000–2500
56	*Udaspes folus* Cramer	Grass Demon	Common	Forest up to 2200
B. Super family: Papilionoidea				
1. Family: Papillionidae				
A. Sub-family: Parnassiinae				
57	*Parnassius epaphus epaphus*	Common Red Apollo	Uncommon	Rocky hillsides 2000–5000
58	*Parnassius hardwickii*	Common Blue Apollo	Uncommon	Alpine meadow up to 5000
b. Sub-family: Papillioninae				
59	*Troides aeacus aeacus* Felder & Felder	Golden Birdwing	Common	Forest up to 2700
60	*Graphium eurous caschmirensis* Rothschild	Six-Bar Swordtail	common	Hill forest up to 2700
61	*Graphium cloanthus*	Glassy Bluebottle	common	Hill forest up to 2700
62	*Graphium sarpedon*	Common Bluebottle	common	Forest up to 2700
63	*Graphium doson*	Common Jay	common	Forest and garden 1200
64	*Byasa polyeuctes*	Common Wildmill	common	Forest up to 3500
65	*Byasa latreillei*	Rose Windmill	common	Hill forest up to 2700
66	*Byasa dasarada Ravana* Moore	Great windmill	Uncommon	Forest up to 3600
67	*Pachliopta aristolochiae*	Common Rose	Uncommon	Grassland up to 2400
68	*Atrophaneura aidoneus* Doubleday	Lesser Batwing	Uncommon	Forest up to 2600
69	*Papilio protenor* Cramer	Spangle	common	Forest up to 2600
70	*Papilio bianor polyctor* Boisduval	Common Peacock	common	Hill Forest up to 2500
71	*Papilio polytes*	Common Mormon	common	Grassland up to 1900
72	*Papilio machaon asiaticus* Ménétriés	Common Yellow Swallowtail	Uncommon	Meadows and scrub 4800
73	*Meandrusa lachinus lachinus* Fruhstorfer	Brown Gorgon	Uncommon	Hill forest up to 2600
74	*Papilio demoleus demoleus* Linnaeus	Lime Butterfly	common	Cropland and forest edges
2. Family: Pieridae				
A. Sub-family: Coliadinae				
75	*Eurema andersonii* Moore	One-spot Grass yellow	Uncommon	Forest up to 2200
76	*Eurema blanda silhetana* Wallace	Three-spot Grass yellow	Common	Forest up to 1700
77	*Eurema brigitta rubella* Wallace	Small Grass yellow	Common	Forest clearing up to 3660
78	*Eurema hecabe* Linnaeus	Common Grass yellow	Common	Forest up to 3000
79	*Eurema laeta*	Spotless Grass yellow	Common	Forest up to 2500
80	*Gonepteryx rhamni nepalensis* Doubleday	Common Brimstone	Very Common	Forest up to 2500

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
81	*Catopsilia pomona*	Common Emigrant	Common	Forest up to 2500
82	*Catopsilia pyranthe* Linnaeus	Mottled Emigrant	Common	Forest and habitation 3000
83	*Colias erate* Esper	Pale clouded Yellow	Uncommon	Open hillsides 3500
B. Sub-family: Pierinae				
84	*Pieris daplidice moorei* Röber	Bath White	Common	Meadow scrub 2700
85	*Pieris canidia indica*	Indian Cabbage White	Common	Forest and farmland 3500
86	*Pieris brassicae nepalensis* Doubleday	Large Cabbage White	Common	Meadow, scrub up to 4000
87	*Pieris rapae*	Small cabbage White	Common	Hill slopes up to 1800
88	*Pieris bryoniae*	Mountain Greenvein White	Uncommon	Hill forest 1200–3000
89	*Aporia leucodice soracta* Moore	Himalayan Blackvein	Common	Forest up to 3000
90	*Aporia agathon caphusa*	Great Black veined	Very Common	Hill forest up to 3050
91	*Delias eucharis* Drury	Common Jezebel	Very Common	Garden and forest low elevation
92	*Delias belladonna horsfieldii*	Hill Jezebel	Very Common	Forest up to 3000
93	*Cepora nerissa Phryne* Fabricius	Common Gull	Very Common	Grassland up to 2500
94	*Appias libythea* Fabricius	Striped Albatross	Rare	Forest edges up to 1000
95	*Leptosia nina* Fabricius	Psyche	Common	Forest up to 1900
96	*Belenois aurota* Fabricius	Pioneer	Common	Grassland and scrub 2800
3. Family: Riodinidae				
A. Sub-family: Riodininae				
97	*Abisara bifasciata*	Plum Judy	Common	Forest and garden 2000
98	*Abisara fylla*	Dark Judy	Common	Forest up to 2000
99	*Zemeros flegyas indicus*	Punchinello	Common	Forest 2300
100	*Dodona eugenes* Bates	Tailed Punch	Rare	Hill forest up to 3000
101	*Dodona durga* Kollar	Common Punch	Common	Hill forest up to 2500
4. Family: Lycaenidae				
A. Sub-family: Poritiinae				
102	*Poritia hewitsoni hewitsoni* Moore	Common Gem	Uncommon	Forest up to 1200
b. sub-family: Miletinae				
103	*Miletus chinensis assamensis*	Common Brownie	Rare	Hill forest up to 1500
C. Sub-family: Curetinae				
104	*Curetis acuta* Moore	Angled Sunbeam	Common	Forest up to 1700
105	*Curetis bulis* Westwood	Bright Sunbeam	Common	Forest up to 2100
D. Sub-family: Aphnaeinae				
106	*Spindasis nipalicus* Moore	Silver Grey Silverline	Uncommon	Hill forest up to 2500
107	*Spindasis vulcanus*	Common Silverline	Common	Plain and hills up to 2700
108	*Spindasis elima*	Scarce Shot Silverline	Uncommon	Hill forest up to 3000
109	*Spindasis lohita*	Long-banded Silverline	Common	Grassy open area
110	*Apharitis lilacinus*	Lilac Silverline	Rare	Forest up to 1600
E. Sub-family: Polyommatine				
111	*Everes argiades diporides* Chapman	Chapmans Cupid	Common	Forest up to 2600
112	*Chilades pandava pandava* Horsfield	Plain Cupid	Common	Forest edges up to 2400
113	*Chilades parrhasius parrhasius* Fabricius	Indian Cupid	Common	Grassland and forest 2000
114	*Chilades lajus lajus* Stoll	Lime Blue	Common	Grassland and forest 1900
115	*Anthene emolus*	Common Ciliated Blue	Common	Hill forest up to 1300
116	*Petrelaea dana*	Dingy Lineblue	Common	Forest low elevation
117	*Nacaduba kurava*	Transparent Six Lineblue	Uncommon	Hill forest 1000–2000
118	*Ionolyce helicon*	Pointed Line Blue	Uncommon	Forest up to 1000

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
119	*Everes (argiades) indica* Evans	Tailed Cupid	Uncommon	Hill forest 1400–3000
120	*Everes huegelii huegelii*	Dusky Blue Cupid	Uncommon	Hill forest 1400–2850
121	*Acytolepis puspa gisca* Fruhstorfer	Common hedge Blue	Common	Forest up to 3000
122	*Oreolyce vardhana vardhana* Moore	Dusky Hedge Blue	Uncommon	Forest 400–2500
123	*Udara dilecta dilecta* Moore	Pale Hedge Blue	common	Hill forest 500–3000
124	*Udara albocaerulea* Moore	Albocerulean	Rare	Hill forest below 1000
125	*Celastrina lavendularis limbata* Moore	Plain Hedge Blue	common	Forest 400-2500
126	*Celastrina gigas* Hemming	Silver Hedge Blue	Common	Forest clearing 2000–3000
127	*Celastrina huegelii huegelii* Moore	Large Hedge Blue	Common	Forest up to 3000
128	*Celatoxia marginata* de Nicéville	Margined Hedge Blue	Common	Hill Forest up to 3000
129	*Celastrina argiolus kollari* Linnaeus	Hill Hedge Blue	Uncommon	Meadow and forest 3000
130	*Zizeeria karsandra* Moore	Dark Grass Blue	common	Grassland and forest 2500
131	*Pseudozizeeria maha* Kollar	Pale Grass Blue	Common	Grassland and forest 2500
132	*Zizeeria oits oits* Fabricius	Lesser Grass Blue	Common	Grassland and forest 2500
133	*Lampides boeticus* Linnaeus	Pea Blue	common	Hills and plain up to 3000
134	*Leptotes plinius Plinius* Fabricius	Zebra Blue	Common	Grassland and forest 2100
135	*Euchrysops cnejus*	Gram Blue	Common	Grassland and forest edges
136	*Aricia agestis nazira*	Orange-bordered Argus	common	Forest edges 1800-3000
137	*Lycaena phlaeas*	Common Copper	Uncommon	Hill Forest 1500–3000
138	*Lycaena panava*	White-bordered Copper	Common	Meadow forest edges 3690
139	*Jamides bochus* Stoll	Dark Cerulean	Common	Forest up to 2400
140	*Jamide celeno*	Common Cerulean	Uncommon	Forest up to 2000
141	*Catochrysops strabo* Fabricius	Forget-me-not Blue	Common	Hill and plain up to 3000
142	*Catochrysops panormus*	Silver Forget-me-not	Uncommon	Low elevation up to 1000
143	*Castalius rosimon*	Common Pierrot	Common	Grassland and forest 2500
144	*Tarucus venosus* Moore	Himalayan Pierrot	Common	Forest edge and scrub 2000
145	*Talicada nyseus*	Red Pierrot	Common	Forest up to 1600
146	*Tarucus nara*	Rounded Pierrot	Common	Grassland and Forest 2000
147	*Freyeria trochylus* Freyer	Grass Jewel	Common	Forest edges up to 1800
F. Sub-family: Theclinae				
148	*Euaspa milionia* Hewitson	Water Hairstreak	Common	Hill forest 1200–2000
149	*Chrysozephyrus syla* Kollar	Silver Hairstreak	Common	Hill forest 1800–3500
150	*Chrysozephyrus birupa* Moore	Fawn Hairstreak	Common	Forest up to 1600
151	*Euaspa ziha Hewitson*	White-spotted Hairstreak	Uncommon	Forest up to 1500
152	*Chrysozephyrus disparatus psedoletha*	Howarth's Hairstreak	Rare	Hill Forest up to 2000
153	*Horaga viola* Moore	Brown Onyx	Rare	Hill Forest up to 2000
154	*Haraga Onyx* Moore	Common Onyx	Uncommon	Hill Forest up to 2000
155	*Iraota timoleon* Stoll	Silvertreak Blue	Uncommon	Hill Forest up to 2000
156	*Chaetoprocta odata peilei* Forster	Walnut Blue	Uncommon	Hill forest 1200–3600
157	*Arhopala rama* Kollar	Dark Himalayan Oakblue	Common	Hill forest 900–2000
158	*Arhopala paraganesa* de Nicéville	Dusky Bush Blue	Rare	Hill Forest up to 2000
159	*Tajuria diaeus* Hewitson	Straight-line Royal	Rare	Hill forest up to 1200
160	*Ancema ctesia* Hewitson	Bio-spot Royal	Uncommon	Forest up to 2000
161	*Pratapa icetas* Hewitson	Dark blue Royal	Rare	Hill sides 1000–2000
162	*Chliaria kina* Hewitson	Blue Tit	Uncommon	Hill Forest up to 2000
163	*Chliaria othona*	Orchid Tit	Uncommon	Hill Forest up to 1500
164	*Deudorix epijarbus* Moore	Cornelian	Uncommon	Forest up to 2500

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
165	*Rapala selira* Moore	Himalayan Red Flash	Common	Hill Forest up to 3000
166	*Arhopala dodonaea* Moore	Pale Himalayan Oakblue	Common	Hill sides 1000-2000
167	*Arhopala amantes*	Large Oakblue	Common	Forest up to 1500
168	*Arhopala ganesa*	Tailless Bush Blue	Very Common	Forest up to 1700
169	*Surendra quercetorum*	Common Acacia Blue	Common	Forest up to 1500
170	*Arhopala atrax* Hewitson	Indian oak Blue	Very Common	Hill Forest up to 2000
171	*Surendra vivarna* Moore	Common Acacia Blue	Common	Forest up to 1200
172	*Rapala nissa* Kollar	Common Flash	Common	Grassland and forest 2000
173	*Rapala varuna*	Indigo Flash	Common	Plain and hills up to 1500
174	*Rapala manea schistacea* Moore	Slate Flash	Common	Plain and hills up to 1900
175	*Rapala iarbus* Fabricius	Indian Red Flash	Uncommon	Grassland and forest 2300
176	*Zesius chrysomallus* Hübner	Red Spot	Rare	Forest low elevation
177	*Catapaecilma major major* Druce	Common Tinsel	Rare	Forest up to 1500
178	*Sinthusa chandrana chandrana* Moore	Broad Spark	Rare	Forest up to 1700
179	*Virachola isocrates* Fabricius	Common Guava Blue	Uncommon	Forest up to 2000
G. Sub-family: Lycaeninae				
180	*Heliophorus brahma*	Golden Sapphire	Uncommon	Hill forest up to 2000
181	*Heliophorus epicles*	Purple Sapphire	Uncommon	Hill forest up to 2000
182	*Heliophorus indicus*	Indian Purple Sapphire	Uncommon	Hill forest up to 2000
183	*Heliophorus sena* Kollar	Sorrel Sapphire	Common	Hill forest up to 2600
184	*Heliophorus tamu*	Powdery Green Sapphire	Common	Hill forest up to 2000
185	*Heliophorusn moorei tytleri*	Azure Sapphire	Common	Hill forest up to 2700
186	*Heliophorus oda* Hewitson	Eastern Blue Sapphire	Rare	Hill forest up to 1800
187	*Arhopala centaurus, 1775*	Centaur Oakblue	Uncommon	Hill forest up to 2400
188	*Arhopala oenea* Hewitson	Hewitson Dull Oakblue	Rare	Hill forest 600–1500
189	*Lycaena pavana* Kollar	White-bordered Copper	Common	Hill forest up to 3000
190	*Lycaena phlaeas baralacha* Moore	Common Copper	Common	Hill forest up to 3500
Family: Nymphalidae				
Sub-family: Satyrinae				
191	*Mycalesis nicotia* Westwood	Bright-eyed Bush Brown	Rare	Hill forest 500–1500
192	*Mycalesis perseus Blasius* Fabricius	Common Bush Brown	Common	Forest up to 1700
193	*Mycalesis francisca Sanatana* Moore	Lilacine Bush Brown	Common	Hill forest 500–2000
194	*Mycalesis mineus* Linnaeus	Darkbrand Bush Brown	Common	Forest edges up to 1500
195	*Mycalesis visala*	Long-branded Bush Brown	Common	Forest edges up to 1000
196	*Lethe sidonis* Doherty	Common Woodbrown	Common	Forest edges up to 3100
197	*Lethe maitrya maitrya* de Nicéville	Bareed Woodbrown	Uncommon	Hill forest 2500–3800
198	*Lethe siderea* Marshall	Scarce Woodbrown	Rare	Hill forest 2000–2500
199	*Lethe insana insana* Kollar	Common Forester	Common	Hill forest 1500–2700
200	*Lethe rohria*	Common Treebrown	Common	Hill forest up to 3000
201	*Lethe verma* Kollar	Straight-banded Treebrown	Common	Hill forest 900–2700
202	*Lethe europa niladana* Fruhstorfer	Bamboo Treebrown	Common	Forest edges up to 3000
203	*Lethe confusa confuse* Auriviilius	Banded Treebrown	Common	Forest edges up to 1700
204	*Lethe baladeva aisa* Fruhstorfer	Treble Silverstreak	Rare	Hill forest 1800–2700
205	*Lethe goalpara*	Large Golden Fork	Rare	Hill forest 1800–3000
206	*Neope yama buckleyi* Talbot	Dusky Labyrinth	Uncommon	Hill forest 1200–2400
207	*Neope pulaha pandyia* Talbot	Veined Labyrinth	Uncommon	Hill forest 1600–2400
208	*Orinoma damaris damaris* Gray	Tiger Brown	Uncommon	Forest 1300–2000

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
209	*Melanitis phedima bela* Cramer	Dark Evening Brown	Uncommon	Hill forest at low elevation
210	*Melanitis leda leda* Linnaeus	Common Evening Brown	Very Common	Forest up to 1200
211	*Melanitis zitenius zitenius* Herbst	Great Evening brown	Very Rare	Forest up to 1700
212	*Elymnias hypermnestra undularis* Linnaeus	Common Palmfly	Common	Forest and garden 1500
213	*Elymnias malelas*	Spotted Palmfly	Uncommon	Forest up to 1500
214	*Ypthima (Dallacha) hyagriva* Moore	Brown Argus	Rare	Forest clearing 1500–2400
215	*Callerebia annada*	Ringed Argus	Rare	Scrubby hill 1500–2500
216	*Callerebia nirmala* Moore	Common Argus	Common	Forest 1300–2800
217	*Callerebia scanda* Kollar	Pallid Argus	Common	Hill forest 1200–2400
218	*Loxerebia narasingha*	Mottled Argus	Rare	Hill forest up to 2000
219	*Ypthima nareda* Kollar	Large Three Ring	Uncommon	Forest up to 600–2500
220	*Ypthima asterope*	Common Three Ring	Uncommon	Forest up to 1500
221	*Ypthima inica*	Lesser Three Ring	Uncommon	Open clearing up to 500
222	*Ypthima sakra* Moore	Himalayan Five Ring	Very Common	Hill forest up to 2000
223	*Ypthima baldus* Fabricius	Common Five Ring	Very Common	Hill forest up to 2000
224	*Ypthima baldus nikea*	Moore's Five Ring	Uncommon	Forest 1300–2800
225	*Ypthima kedarnathensis* Singh	Garhwal Six Ring	Common	Forest up to 1600–2000
226	*Ypthima indecora Moore*	Western Five Ring	Uncommon	Forest up to 1300–1700
227	*Rhaphicera moorei moorei* Butler	Small Tawny Wall	Uncommon	Hill forest 1500–2000
228	*Lasiommata schakra* Kollar	Common Wall	Common	Grassy hillside up to 2500
229	*Aulocera swaha swaha* Kollar	Common Satyr	Common	Open rocky hillside 3000
230	*Aulocera saraswati* Kollar	Striated Satyr	Common	Scrub meadow up to 2000
231	*Aulocera padma* Kollar	Great Satyr	Uncommon	Open hillside 2400–3600
232	*Aulocera brahminus dokwana* Evans	Narrow-banded Satyr	Rare	Open rocky hillside 4000
1. Sub-family: Apaturinae				
233	*Dilipa morgiana* Westwood	Golden Emperor	Rare	Hill forest 1500–2000
234	*Sephisa dichroa* Kollar	Western Courtier	Common	Hill forest 3000
235	*Apatura ambica* Kollar	Indian Purple Emperor	Rare	Hill forest 1500–2600
236	*Euripus nyctelius*	Courtesan	Uncommon	Hill forest 1000
237	*Hestinalis nama* Doubleday	Circe	Uncommon	Hill forest 1500–2000
238	*Hestina persimilis zella* Butler	Siren	Rare	Hill forest up to 2000
2. Sub-family: Charaxinae				
239	*Charaxes dolon dolon* Westwood	Stately Nawab	Rare	Hill Forest up to 2500
240	*Charaxes athmas athamas* Drury	Common Nawab	Uncommon	Hill Forest up to 2000
3. Sub-family: Biblidinae				
241	*Ariadne ariadne*	Angle Castor	Uncommon	Forest up to 2500
242	*Ariadne merione tapestrina* Moore	Common Castor	Common	Forest up to 2500
4. Sub-family: Heliconidae				
243	*Cupha erymanthis*	Rustic	Common	Forest up to 2000
244	*Phalanta phalantha* Drury	Common Leopard	Common	Forest up to 3000
245	*Vagrans egista sinha* Kollar	Vagrant	Uncommon	Forest up to 2000
246	*Argynnis hyperbius* Linnaeus	Indian Fritillary	Uncommon	Grassy hillside up to 3000
247	*Argynnis kamala*	Common Silverstripe	Common	Forest up to 3500
248	*Argynnis childreni sakontala* Kollar	Large Silverstripe	Common	Forest clearing 1200–3000
249	*Argynnis jainadeva*	Himalayan Highbrown Fritillary	Uncommon	Rocky Hillsides 2400–4700
250	*Issoria (lathonia) isaea* Doubleday	Queen of Spain Fritillary	Common	Alpine meadow up to 5000

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
1. Sub-family: Acraeinae				
251	*Cethosia cyane* Drury	Leopard Lacewing	Common	Forest up to 4500
252	*Acraea issoria i* Hübner	Yellow Coster	Common	Forest up to 2500
253	*Acraea violae* Fabricius	Tawny Coster	Common	Forest up to 1500
D. Sub-family: Nymphalinae				
254	*Junonia iphita iphita* Cramer	Chocolate Pancy	Common	Grassland and forest 2100
255	*Junonia orithya*	Blue Pancy	Common	Grassland and forest 2100
256	*Junonia hierta hierta* Fabricius	Yellow Pancy	Common	Grassland and forest 2000
257	*Junonia lemonias lemonias* Linnaeus	Lemon Pancy	Common	Grassland and forest 2000
258	*Junonia atlites atlites* Linnaeus	Grey Pancy	Common	Grassland and forest 1500
259	*Junonia almana almana* Linnaeus	Peacock Pancy	Common	Grassland and forest 2100
260	*Kaniska canace canace* Evans	Blue Admiral	Common	Hill forest 1000-3200
261	*Vanessa indica indica* Herbst	Red Admiral	Common	Forest, meadow 400–3900
262	*Vanessa cardui cardui* Linnaeus	Painted Lady	Common	Grassland and forest 4500
263	*Aglais caschmirensis aesis* Fruhstorfer	Indian Tortoiseshell	Common	Forest, meadow 400–5000
264	*Nymphalis xanthomelas fervescens* Stichel	Large Tortoiseshell	Common	Hill forest 300–3200
265	*Symbrenthia lilaea khasiana* Moore	Common Jester	Common	Hill forest 300–2000
266	*Symbrenthia hypselis*	Spotted Jester	Uncommon	Hill forest 300–2000
267	*Symbrenthia brabira* Moore	Himalayan Jester	Common	Hill forest 1500–2000
268	*Hypolimnas misippus* Linnaeus	Danaid Eggfly	Common	Grassland and forest 3000
269	*Hypolimnas bolina*	Great Eggfly	Common	Grassland and forest 2000
270	*Kallima inachus*	Orange Oakleaf	Common	Forest up to 2100
A. Sub-family: Cyrestinae				
271	*Cyrestis thyodamas*	Common Map	Common	Grassland and forest 2100
272	*Dichorragia nesimachus* Boisduval	Constable	Common	Hill forest 500–2000
273	*Stibochiona nicea* Gray	Popinjay	Common	Forest up to 1500
274	*Psuedergolis wedah* Kollar	Tabby	Common	Hill forest 1000–2000
B. Sub-family: Limentidinae				
275	*Neptis ananta* Moore	Yellow Sailer	Uncommon	Hill forest 400–2300
276	*Neptis hylas*	Common Sailer	Common	Grassland and forest 3000
277	*Neptis soma butleri*	Creamy Sailer	Uncommon	Hill forest up to 2800
278	*Neptis mahendra* Moore	Himalayan Sailer	Common	Hill forest 1700–3000
279	*Neptis sappho astola* Moore	Pallas Sailer	Uncommon	Hill forest up to 2000
280	*Neptis clinia susruta*	Clear Sailer	Uncommon	Forest 500 or low elevation
281	*Neptis sankara sankara* Kollar	Broad Banded Sailer	Common	Hill forest up to 800-2500
282	*Athyma perius* Linnaeus	Common Sergent	Common	Forest edges up to 2700
283	*Athyma asura* Moore	Studded Sergent	Uncommon	Forest edges up to 2700
284	*Athyma selenophora* Kollar	Staff Sergent	Common	Forest edges up to 2000
285	*Athyma opalina* Kollar	Himalayan Sergent	Common	Hill forest 1800–2800
286	*Auzakia danava* Moore	Commodore	Uncommon	Hill forest 500–2000
287	*Limenitis trivena ligyes*	Indian White Admiral	Uncommon	Hill forest up to 2700
288	*Euthalia patala* Kollar	Grand Duchess	Uncommon	Hill forest 400–2500
289	*Euthalia sahadeva*	Green Duke	Rare	Hill forest 400–2000
290	*Symphaedra nais* Forster	Baronet	Common	Forest up to 900
291	*Euthalia aconthea*	Common Baron	Common	Grassland and forest 3000
A. Sub-family: Libytheinae				
292	*Libythea myrrha sanguinalis* Godart	Common Beak	Common	Hill forest 300–2800

	Species name	Common name	Relative abundance	Habitat preference and elevation (m)
293	*Libythia lepita lepita* Moore	Club Beak	Common	Hill forest 300–3000
B. Sub-family: Danainae				
294	*Danaus chrysippus chrysippus* Linnaeus	Plain Tiger	Common	Plain and hills Up to 3000
295	*Danaus genutia*	Striped Tiger	Common	Forest up to 2800
296	*Parantica sita* Kollar	Chestnut Tiger	Common	Forest edges up to 3000
297	*Tirumala limniace*	Blue Tiger	Uncommon	Forest up to 2800
298	*Parantica aglea melanoides* Moore	Glassy Tiger	Common	Forest edges up to 2800
299	*Euploea mulciber Mulciber* Cramer	Striped Blue Crow	Common	Plain and hills Up to 2500
300	*Euploea core* Cramer	Common Indian Crow	Common	Plain and hills Up to 3000

Image 3A–L. Rare rediscoveries of butterflies from the Kedarnath Musk Deer Sanctuary. A—*Melanitis zitenius* | B—*Aeromachus stigmata* | C—*Hasora taminatus* | D—*Catapaecilma major* | E—*Miletus chinensis* | F—*Belenois aurota* | G—*Hestina persimilis* | H—*Pelopidas conjuncta* | I—*Ionolyce helicon* | J—*Heliophorus indicus* | K—*Heliophorus epicles* | L—*Heliophorus indicus*. © Anand Kumar, Priyanshu Kumar, Gourav Lochan, Prachi Arya, Rajeev Lochan.

Image 3M–Aa. Rare rediscoveries of butterflies from the Kedarnath Musk Deer Sanctuary. M—*Heliophorus brahma* | N—*Heliophorus moorei coruscans* | O—*Heliophorus moorei tytleri* | P—*Iraota timoleon* | Q—*Sinthusa chandrana* | R—*Tarucus venosus* | S—*Chliaria othona* | T—*Catochrysops panormus* | U—*Everes huegelii huegelii* | V—*Spindasis vulcanus* | W—*Spindasis elima* | X—*Aricia agestis nazira* | Y—*Neope pulaha* | Z—*Melanitis phedima bela* | Aa—*Arhopala rama*. © Anand Kumar, Priyanshu Kumar, Gourav Lochan, Prachi Arya, Rajeev Lochan.


Image 3Ab–Ac. Rare rediscoveries of butterflies from the Kedarnath Musk Deer Sanctuary. Ab—*Arhopala rama* | Ac—*Heliophorus oda*. © Anand Kumar, Priyanshu Kumar, Gourav Lochan, Prachi Arya, Rajeev Lochan.

1974). The findings of this study not only enrich the existing knowledge of Himalayan butterfly diversity but also underscore the critical need for more extensive and rigorous surveys in the future to ensure the implementation of better conservation strategies. Such efforts are critical to refining conservation strategies, enabling more targeted and effective interventions for species preservation.

CONCLUSION

This exploration of butterfly diversity within KMDS is a foundation for further research and conservation initiatives. A total of 153 additional butterflies' species were updated in the known butterfly fauna of KMDS. Several new records and rediscoveries of butterfly species were documented in the sanctuary. By unravelling the intricate connections between butterflies and their environment, a deeper appreciation for the sanctuary's ecological complexity and the need to preserve it emerged. This comprehensive methodology, combining transect surveys, elevation gradient sampling, and a multifaceted data-collection approach, aimed to provide a thorough understanding of butterfly diversity in the KMDS. One often-overlooked but ecologically significant component of this biodiversity is the diverse butterfly population that graces the Sanctuary's meadows and forests.

Significance

The significance of this research extends beyond the academic realm; it holds practical implications for the conservation and management of KMDS. With threats such as climate change and habitat degradation looming large, an understanding of butterfly species and their interactions within this fragile ecosystem becomes imperative. By unravelling the mysteries of butterfly ecology in Kedarnath, this research contributes valuable insights that will inform conservation strategies and emphasize the need to preserve this Himalayan Sanctuary for future generations.

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ARTICLE

Abundance, habitat preference, and ethnobiological assessment of the invasive Golden Apple Snail *Pomacea canaliculata* (Lamarck, 1822) in selected rice fields in Lanao del Sur, Philippines

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Abstract: This study assessed the abundance, habitat preference, and ethnobiological impacts of the Golden Apple Snail (GAS) *Pomacea canaliculata* in selected rice fields in Lanao del Sur, Philippines. Employing the Lincoln-Petersen estimator, the population was estimated at 184 individuals during the initial sampling and increased to approximately 920 in the subsequent period, reflecting a significant rise over time. The combined density of adults and juveniles ranged 0.75–0.96 individuals per m^2 in the first period, and 2.00–3.39 individuals per m^2 in the second. Adult snails were mostly associated with water and sediment, while juveniles concentrated primarily in sediment. Egg clutch density was higher in the first sampling period (0.30 clutches) compared to the second (0.12 clutches), with leaf sheaths identified as the preferred oviposition site. Water temperature ranged 22.7–27.0 °C, pH 6.83–7.23, relative humidity 83.5–89.2 %, and water depth 4.5–13 cm, indicating that warmer, deeper, and more humid conditions promoted increased activity and abundance. Ethnobiological data revealed that farmers regard GAS as a serious pest that reduces rice yields, threatens livelihoods, and poses health risks, including injuries, pesticide irritation, and schistosomiasis. While traditional methods and synthetic pesticides are used, farmers find these approaches costly, labor-intensive, and only partially effective. Overall, findings highlight that *P. canaliculata* is an abundant, adaptable invasive species threatening rice agriculture, livelihoods, and public health. This underscores the urgent need for integrated, sustainable, and community-based management strategies.

Keywords: Cultural intersection, density, farmer perceptions, integrated pest management, invasive alien species, Lincoln–Petersen estimator, mark–recapture, microhabitat, oviposition, physicochemical factors.

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INTRODUCTION

The Golden Apple Snail (GAS), *Pomacea canaliculata* (Lamarck, 1822), belonging to the family Ampullariidae, is commonly referred to as 'golden kuhol' in the Philippines. This sizable freshwater snail is indigenous to the tropical and subtropical regions of South America (Halwart 1994; Cowie et al. 2006; Hayes et al. 2008). During the 1980s, it was introduced to other regions and subsequently proliferated extensively in Asia for commercial purposes aimed at augmenting human diets and animal feed, owing to its high nutritional value, while simultaneously generating income for both rural communities and affluent nations (Naylor 1996; Cowie et al. 2006; Casal et al. 2017; Heuzé & Tran 2017). Thereafter, domestication efforts expanded to the aquarium trade, biological control of parasitic snail vectors responsible for schistosomiasis, control of aquatic weeds, and utilization as a liquid biofertilizer (Ranamukhaarachchi & Wickramasinghe 2006; Cowie et al. 2017). The presence of GAS in the Philippines was documented between 1982 and 1984, after which it emerged as a notorious agricultural pest in rice cultivation systems (Joshi et al. 2001).

The dispersal of this invasive species has occurred through extensive irrigation networks, subsequently spreading into rice fields, where it feeds on seedlings. The proliferation of GAS posed a substantial threat to rice production and food security in the Philippines, rendering this species a major concern for irrigated rice farmers (Joshi et al. 2001; Adalla & Magsino 2006). Initial reports indicated that the area of GAS infestation in the Philippines ranged from approximately 400,000 ha to more than 800,000 ha, while Filipino farmers incurred substantial expenditures amounting to at least USD 1 billion in efforts to control and eradicate this rice pest (Cagauana & Joshi 2002; Adalla & Magsino 2006). Subsequently, it was classified among the top 100 most invasive alien species worldwide (Joshi 2005b). The extent of infestation continues to escalate, expanding beyond national borders into neighboring southeastern Asian countries and regions farther afield (Joshi 2005a; Ranamukhaarachchi & Wickramasinghe 2006; Hayes et al. 2008; Cowie et al. 2017). Beyond its impact on rice crops, GAS also feeds on and damages adjacent paddy crops such as lotus, taro, and *Ipomoea aquatica* (Ranamukhaarachchi & Wickramasinghe 2006). Moreover, reports indicate that the invasion of such snails has disrupted the ecological functions of wetlands in southeastern Asia, Europe, and North America, reducing native aquatic vegetation and inducing significant habitat alterations, including the dominance of planktonic algae and increased water turbidity (Carlsson et al. 2004; Carlsson 2017).

Hayes et al. (2015) provide a comprehensive review of prior accounts, including phylogenetic and biogeographic studies of *P. canaliculata*. In its native habitat, this organism reproduces only in summer or autumn, whereas in southeastern Asia it reproduces three to four times annually due to the year-round warm climate (Cowie 2002; Hayes et al. 2008). The warm season provides favorable conditions for accelerated growth, thereby shortening the interval between a female's initial oviposition (Estebenet & Martin 2002). The increased growth rate of GAS may offer valuable insights into estimating its abundance. This organism inhabits ecologically diverse habitats and exhibits complex, morphologically divergent populations. This species is prevalent in both natural and managed systems within the Philippines. Morphological differences observed across developmental stages can correlate significantly with habitat type, thereby reflecting density variations in this species (Torres et al. 2011). The organism's behavior suggests that environmental factors may influence the quantity of GAS.

The investigation of species density provides insights into the frequency of animal occurrence within a specified environment. Such analysis contributes to a comprehensive understanding of an area's overall biodiversity. Existing studies clearly establish GAS as a serious agricultural and environmental threat in the Philippines (Joshi et al. 2001; Cagauana & Joshi 2003; Adalla & Magsino 2006; Penaredondo et al. 2015). However, they are largely generalized at regional or national scales and seldom integrate ecological measurements with ethnobiological knowledge at the community level. As a result, the specific patterns of abundance, habitat preferences, and environmental correlates of GAS populations in Barangay Dangiprampiai Proper, Ditsaan-Ramain, Lanao del Sur, and how these intersect with local farmers' management practices, remain undocumented. This gap limits the development of context-appropriate, culturally grounded control strategies for this high-risk area, which is heavily dependent on rice cultivation.

MATERIALS AND METHODS

Study site

This study was conducted in Barangay Dangiprampiai Proper, Ditsaan-Ramain, Lanao del Sur (Image 1). The population was predominantly Meranao, an ethnic group local to the region.

Study research design and ethical considerations

The study employed an observation approach that involved measuring ecological units under natural conditions without experimental manipulation (Hurlbert 1984). This design was chosen because the primary objectives were to estimate the density and structure of GAS populations under typical rice-field management practices and to document farmers' knowledge and perceptions. Manipulating water levels, pesticide use, or farmer practices was not feasible or desirable due to ethical and logistical constraints and the need to maintain the integrity of farmers' fields. The mensurative design emphasizes careful measurement of a specific set of factors of interest (e.g., snail density, developmental stages, habitat characteristics, and farmers' perceptions), while recognizing that not all environmental and management variables influencing the data can be controlled. Unlike manipulative experiments, observational studies involve sampling across different times or locations to capture natural variation (Hurlbert 1984).

Prior to conducting the study, ethical clearance was obtained from the research ethics committee (REC) of Mindanao State University – Marawi (MSU REC Code: 2023-002). Informed consent was secured from both the barangay authorities and the rice field owners at the sampling site. A gratuitous permit (No. 33-BARMM-2022) was also secured from the Ministry of Environment, Natural Resources and Energy (MENRE) of the Bangsamoro Autonomous Region in Muslim Mindanao.

Data gathering procedure

A. Sampling method

The researchers employed the quadrat mark-recapture method during two sampling periods (Image 2). Each period consisted of two phases: the initial capturing (capture phase) and the second capturing (recapture phase). This study primarily adopted a closed-population mark-recapture approach to estimate the population size of mobile organisms, following the methods of Fontoura-da-Silva et al. (2013) and Lettink & Armstrong (2003), which were considered reliable for estimating abundance

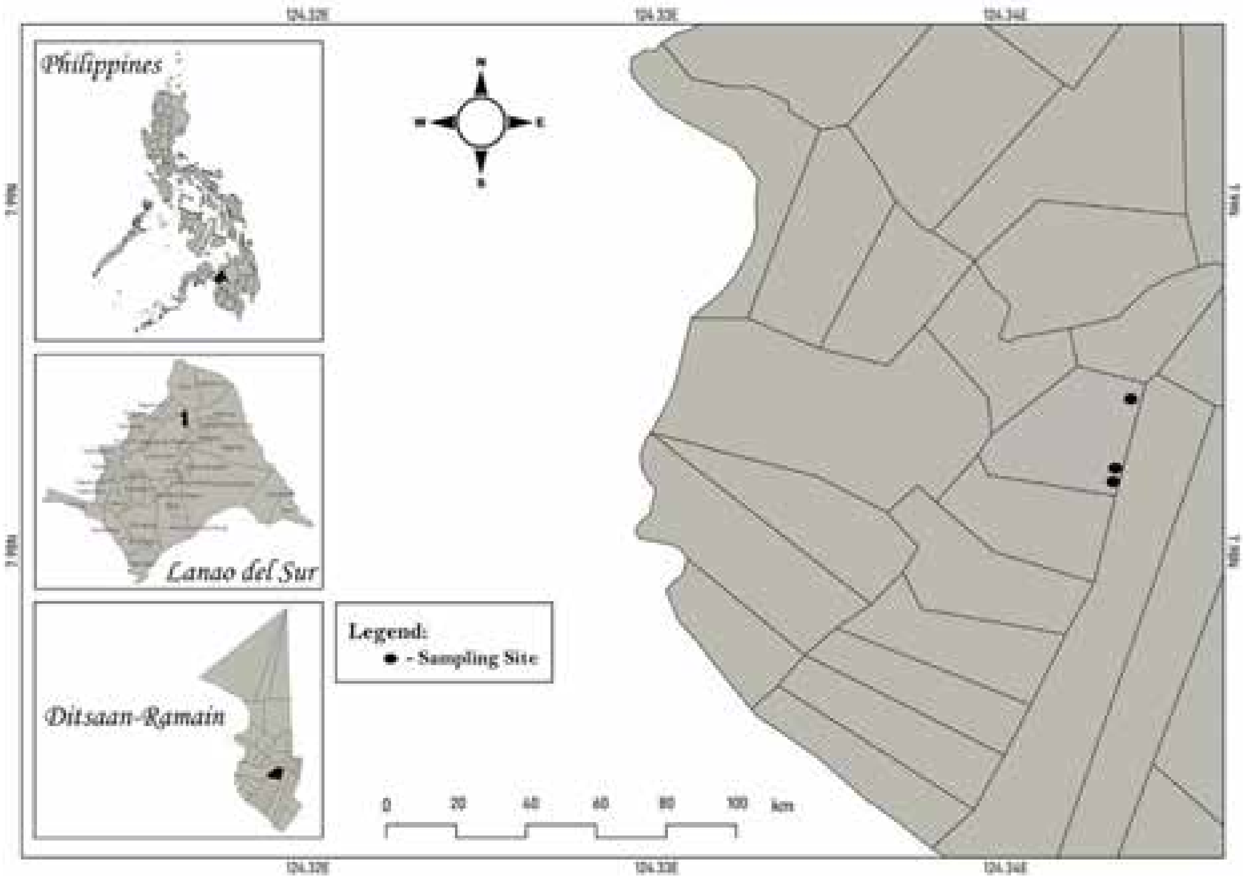

Image 1. Map of the study area showing sampling sites.

Image 2. Established sampling quadrats (A–C) with 46-day-old rice seedlings.© Ashiah M. Dimalutang.

in small, spatially defined areas (Krebs 2014). The quadrat mark-recapture was selected because the relatively slow-moving, easily observable snails in flooded rice fields allow estimation of absolute density and population size with modest field resources, and quadrats provide a standardized sampling unit for comparing snail densities among stations and between sampling periods. A closed-population assumption over the short sampling interval (e.g., 2–3 days) was considered reasonable because major recruitment or mortality were unlikely within this timeframe under typical field conditions.

In the quadrat mark-recapture method, three sampling stations measuring 4 x 4 m (16 m^2) each were established, resulting in a total of 48 quadrats. These quadrats were delineated using plastic rope and bamboo pegs. The number of quadrats and station size were determined to balance logistical constraints with the need to obtain sufficient spatial coverage and sample size to estimate density with acceptable precision. Trapped and encountered GAS within the sampling stations were counted and collected. During the initial capture phase, snails were manually picked up and marked with yellow nail polish on their shells. The marks were allowed to dry thoroughly before the snails were released back into the trapped area where they were originally found (Valentine-Darby et al. 2008; Fontoura-da-Silva et al. 2013). Manual collection was used because it is a standard, low-impact method suitable for shallow, vegetated rice paddies where more complex trapping devices are impractical.

The developmental stages and habitat preferences of the snails were also recorded. The developmental stage of each snail was determined based on shell diameter (Estebenet & Martin 2002), while egg clutch density was assessed by counting egg clusters per unit area (Teo 2004). Egg clusters were evaluated as a potential index of snail abundance due to their conspicuousness and ease of counting. Additionally, the microhabitat of individual snails and egg clutches was documented, and the water level in the rice field was measured. Morphological characterization of the shells followed the criteria outlined by Cowie (2002) and PhilRice (2001). After the first sampling period, the collected snails were identified and verified.

The recapture phase occurred two days after the initial sampling during both sampling periods. This interval was chosen to allow snails sufficient time to resume natural behavior and redistribute within quadrats, while minimizing violations of the closed-population assumption due to recruitment, mortality, or movement in and out of the study area. The recapture phase employed the same methods as the initial phase; however, the snails collected during the recapture phase were not released back into the field. Adult snail shells were retained for detailed morphological analysis. To prepare the collected snails, they were boiled for 30 minutes to remove the flesh, then soaked in soapy water with alum (tawas) powder for three nights to eliminate odor. Afterward, shells were measured for length and diameter to aid in developmental stage classification and sex determination. Sex ratio was determined for each sampling period to explore its relationship with egg clutch density. Sex determination was based solely on shell morphology (Philrice 2001; Teo 2004).

Physico-chemical parameters (water temperature, pH, and relative humidity) were measured during each sampling phase using a field thermometer, a pH meter, and a psychrometer. Prevailing weather conditions were also recorded to provide context for interpreting snail activity and detectability.

B. Ethnobiological survey

The ethnobiological component was designed to complement the ecological data by documenting local knowledge, perceptions, and management practices related to GAS. The eligibility criteria identified male Filipino Meranao farmers with substantial field experience, as they are typically the primary decision-makers for rice cultivation in the area. Participants were certified rice farmers over 30 years old with more than 5 years of field experience in rice cultivation. Respondents were identified and selected through referrals from the barangay chairman and other credible individuals to ensure the authenticity of the information collected. This purposive and referral-based sampling strategy was chosen to target key informants who could provide in-depth, experienced-based insights. A semi-structured questionnaire was prepared following Penaredondo et al. (2015) and Schneiker et al. (2016), and then translated and transcribed as needed to ensure clarity and cultural appropriateness. During the focus group discussions (FGDs), five groups, each consisting of five to seven members, were organized to elicit more detailed and nuanced information, encourage interaction among participants, and validate emerging themes through group discussion.

Data analysis

Density estimation

The mark-recapture method served as the primary basis for estimating the population size at the time of marking and release. Snails captured during the first phase of both sampling periods were marked and released back into their original habitat. After three days, a second set of samples was taken. The number of marked snails that were recaptured in the second sample I, the total number of snails captured in the second sample I, and the total number of marked individuals originally released (M) were recorded to estimate the population size (N). Lincoln-Petersen method was used to determine absolute abundance (Krebs 2014). The following formula was used to compute for (N):

$$R/C = M/N \quad \text{-------->} \quad N = CM/R$$

The physico-chemical parameter analysis was computed as an average across three trials. Meanwhile, ethnobiological assessments were organized and categorically coded into themes.

The study's analytical approach focused on density estimation via the Lincoln-Petersen method and descriptive statistics for several reasons. Its main goal was to establish baseline data on GAS density, stages, sex ratio, environmental factors, and farmers' practices, emphasizing estimation and description over hypothesis testing or complex models. More advanced methods were avoided due to limited sampling stations and quadrats, which constrained spatial and temporal data and risked bias. Sampling relied partly on farmers' willingness to allow repeated access, further limiting opportunities. Ethnobiological data were mainly qualitative and categorical, making thematic analysis more suitable than sophisticated statistical techniques. Thus, simple density estimates and descriptive stats were the most appropriate tools for addressing the questions without overstating precision or scope.

RESULTS

Abundance of GAS

The abundance of GAS across the three established sampling stations was assessed during two sampling periods, corresponding to rice plants aged 46 and 75 days, respectively. In the first sampling period, a total of 36 snails were collected during the capture phase and 46 during the recapture phase, with only 9 adult snails marked with yellow nail polish recovered, and none of the juveniles were recaptured. In the second sampling period, 163 snails were collected during the capture phase and 96 during the recapture phase, with 17 marked snails recaptured.

Based on the Lincoln-Petersen method, the estimated population size was 184 during the first sampling period and 920.47 in the second. This indicates that snail abundance (including both adults and juveniles) was greater in the latter sampling period. The average snail densities for each period are presented in Image 3.

During the first sampling period, adult snails had an average density ranging from 0.56 to 0.90 per m^2, juveniles from 0.06 to 0.19 per m^2, and egg clutches from 0.27 to 0.33 per m^2. In the second sampling period, adult snail density ranged from 1.06 to 1.10 per m^2, juveniles from 0.90 to 2.33 per m^2, and egg clutches from 0.10 to 0.13 per m^2. The combined average density of adults and juveniles ranged from 0.75 to 0.96 per m^2 in the first sampling period and from 3.39 to 2 per m^2 in the second. Furthermore, egg clutches were more abundant in the first sampling period, with an average of 0.30 clutches compared to 0.12 in the second period.

Morphological sex ratio of GAS

A total of 92 adult snails were recaptured, 43 during the first sampling period and 53 during the second. In the latter sampling, four snails were discarded from the analysis due to disintegrated spires, which rendered them unsuitable for further examination. Of the remaining 92 snails, 38 were identified as adult males and 54 as adult females.

Based on morphological characterization, including both internal and external sexual dimorphism, the male-to-female sex ratio was 1:1.53 in the first sampling period and 1:1.33 in the second. These differences in sex ratio highlight the greater abundance of egg clutches observed in the first sampling period, which recorded 16 clutches at a density of approximately 0.30 clutches. In contrast, the second sampling period yielded only six egg clutches, with a density of 0.12 clutches.

Habitat preference

GAS habitat preferences varied across stages and sampling periods, showing that microhabitat use depends on development and field conditions. Snails were found in various microhabitats during both capture and recapture, including leaf surfaces, leaf sheaths, water, and sediment (Images 4 & 5). Sediment was muddy soil, and water was the supernatant layer where snails crawled in paddies. These findings indicate that GAS does not occupy the paddy evenly but instead partitions microhabitats based on behavior, development, and physicochemical conditions.

Adult snails were mainly concentrated in water and sediment across both sampling periods, with some on mature leaves and leaf sheaths where rasping and egg laying occurred. Water and sediment serve as the primary zones for survival, movement, and reproduction, while plant structures serve as temporary feeding and egg-laying sites. The increased adult numbers in water and sediment during the second sampling, including on half-submerged leaf sheaths, may indicate habitat shifts due to better mobility in wetter conditions or higher reproductive activity, with shallow standing water boosting encounter rates, copulation, and reproduction.

In contrast, juvenile snails were predominantly found in the sediment, revealing a clear difference in habitat preference. At this stage, juveniles appear to be more constrained than adults in their ability to use elevated plant surfaces. Their concentration in muddy sediment suggests that this microhabitat provides both physical refuge and immediate access to soft plant tissues, such as leaves and leaf sheaths or to decaying organic matter at the base of rice seedlings. Although their tissues are already developed, their limited climbing capacity and underdeveloped rasping mechanisms likely restrict their use of emergent rice stalks. This explains why juveniles were chiefly found feeding on tissues of leaves and leaf sheaths of young rice seedlings near or within the sediment interface. During the second sampling

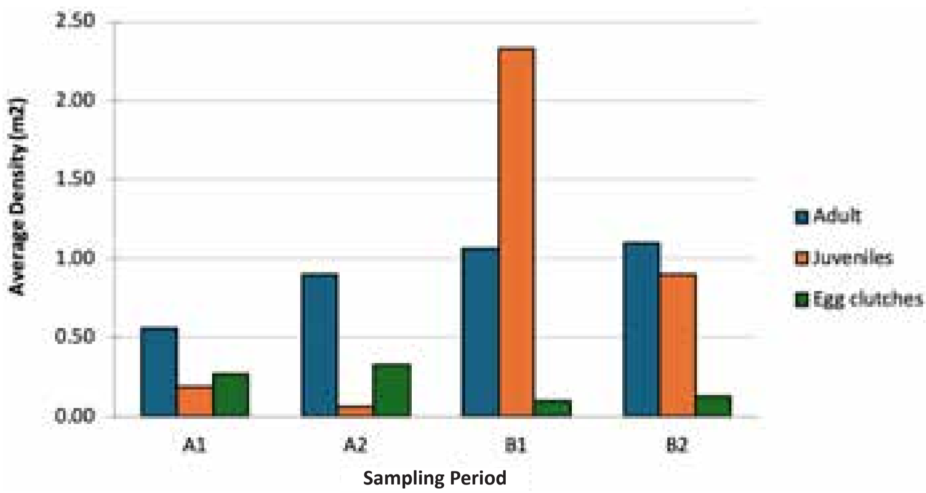

Image 3. Average density of different Pomacean snail stages across both sampling periods. A1–A2 Correspond to the first sampling capture and recapture phases and B1–B2 Correspond to the second sampling capture and recapture phases.

Table 1. Average physico-chemical parameters recorded during the sampling periods.

Physico-chemical parameters	Capture phase		Recapture phase	
	First	Second	First	Second
Temperature (^oC)				
air	20.87	19.30	19.30	18.50
water	26.98	24.19	24.59	22.69
soil	19.45	20.72	19.00	20.06
pH				
water	6.83	7.23	6.83	6.85
soil	6.58	6.65	6.47	6.54
Relative humidity (%)	83.47	88.00	85.55	89.17
Depth (cm)	4.5	12	6.5	13

Table 2. Respondent's profile.

Coded respondents	Age	Gender	Civil status	Years of farming
A01	43	Male	Married	30
A02	45	Male	Married	10
A03	35	Male	Married	10
A04	36	Male	Married	5
A05	35	Male	Married	7
A06	41	Male	Married	9
B07	30	Male	Married	20
B08	55	Male	Married	43
B09	32	Male	Married	10
B10	57	Male	Married	37
B11	60	Male	Married	32
B12	59	Male	Married	35
B13	42	Male	Married	23
C14	32	Male	Married	12
C15	30	Male	Married	5.5
C16	38	Male	Married	10
C17	39	Male	Married	10
C18	30	Male	Married	6
C19	40	Male	Married	20
D20	42	Male	Married	15
D21	40	Male	Married	17
D22	30	Male	Married	10
D23	37	Male	Married	10.5
D24	38	Male	Married	12
E25	43	Male	Married	20
E26	30	Male	Married	11
E27	31	Male	Married	10
E28	42	Male	Married	14
E29	39	Male	Married	10
E30	38	Male	Married	13

period, a higher and more active number of juveniles was recorded in the sediment, with some also found on half-submerged leaf sheaths or floating in the water while feeding. Relative to the first sampling period, this broader microhabitat distribution may reflect either increased activity under favorable water conditions or a slight ontogenetic transition toward more active foraging as juveniles developed. The increased juvenile activity during the second sampling may also be linked to wetter field conditions. Such conditions may reduce the risk of desiccation and soften the sediment, making movement and feeding easier for smaller individuals. Notably, juveniles were absent from water and leaf blades during the first sampling, underscoring that their habitat breadth was narrower earlier in the observation period. An important result from both sampling periods is the apparent avoidance of leaf blades by both adults and juveniles. Neither developmental stage was recorded on leaf blades despite their availability in the paddy. This consistent absence suggests that leaf blades may be less suitable than leaf sheaths or basal tissues, possibly because of their surface texture, exposure, lower structural stability, or reduced accessibility relative to the snail's locomotor and feeding behavior. Since the leaf sheaths are closer to the waterline and provide firmer attachment surfaces, they may offer a more favorable interface for both feeding and resting than the more exposed leaf blade.

The temporal differences between the first and second sampling further indicate that GAS microhabitat use is dynamic rather than fixed. The second sampling showed a greater concentration of both adults and juveniles in water and sediment. This shift may signify changes in water depth, sediment softness, plant architecture, or population activity over time. Such temporal plasticity is ecologically important because it suggests that GAS can rapidly adjust its spatial distribution within rice paddies in response to changing environmental conditions. This flexibility may help explain the persistence of GAS in rice-based systems, as different microhabitats can simultaneously support different life stages.

In addition to the distribution of active snails, the oviposition data provide further evidence of selective habitat use. Egg laying was predominantly observed on hard soil substrates, such as levees, and on emergent plants, such as *Ipomoea aquatica* (locally known as kangkong), in adjacent paddy fields. Egg clutches were also observed on the leaf sheaths of rice crops in both sampling periods. Among the four identified oviposition habitats, leaf sheaths were the most preferred. This

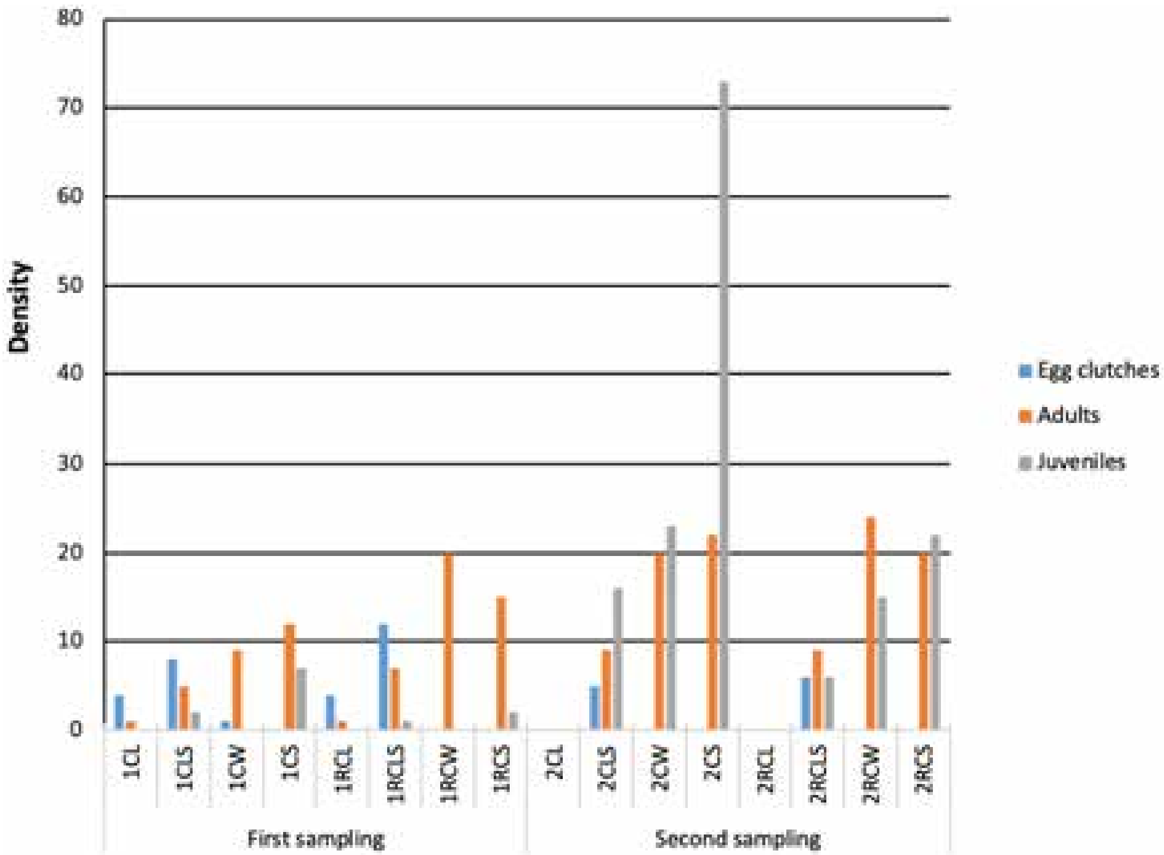

Image 4. Developmental stage density count of snails in their microhabitat: 1—First sampling | CL—Capture Leaf | CLS—Capture Leaf Sheath | CW—Capture Water | CS—Capture Sediment | RCL—Recapture Leaf | RCLS—Recapture Leaf Sheath | RCW—Recapture Water | RCS—Recapture Sediment | 2—Second sampling.

pattern strongly suggests that oviposition site selection is driven by the need for stable, elevated, and relatively dry substrates that reduce the risk of clutch loss or prolonged inundation. Leaf sheaths may represent an optimal oviposition site because they are readily available within the crop stand, positioned above the water surface, and close to feeding areas used by adults. By contrast, the single egg clutch observed floating during the first sampling was likely an atypical case resulting from detachment from an unstable substrate, as no floating or submerged clutches were found in the subsequent sampling. This supports the view that successful oviposition depends on secure attachment to emergent surfaces rather than on random deposition. The use of kangkong and levees suggests that surrounding vegetation and field margins may function as important reproductive refuges. Consequently, management strategies focused only on the rice canopy may underestimate the true reproductive habitat available to GAS. The preference for leaf sheaths, levees, and emergent weeds also implies that habitat complexity within and around paddies may enhance reproductive success by increasing the number of suitable egg-laying substrates. Although eggs were associated with elevated substrates rather than submerged areas, the surrounding moisture regime remains important because humid field conditions may help prevent excessive drying of freshly laid clutches while still allowing them to remain above the waterline.

GAS distribution shows clear ecological partitioning by life stage and function. Sediment and shallow water appear to be the core habitats for movement, feeding, and mating, especially for adults, while juveniles remain more strongly tied to sediment microhabitats. Emergent structures, like leaf sheaths, serve as feeding surfaces and oviposition sites. These patterns reveal the interaction between paddy hydrology, plant structure, and GAS development. This flexible habitat use indicates this species is well adapted to the variable conditions of rice ecosystems, aiding its persistence, dispersal, and pest status in flooded fields.

Physico-chemical factors

The average physico-chemical results are presented in Table 1. During the capture phase of the first sampling,

Image 5. Varying habitat preference of GAS: A & B—Juvenile and adult in sediments | C—Egg clutch in leaf/leaf sheath | D—Adult in water | E & F—Ovipositions in water spinach and levee. © Ashiah M. Dimalutang.

the highest recorded temperature was in water at 26.98 °C, followed by air at 20.87 °C, and soil at 19.45 °C. In the second sampling, water temperature was 24.19 °C, followed by soil and air at 20.72 °C and 19.30 °C, respectively.

For the first sampling, water had a pH of 6.83, and soil had a pH of 6.58. In the second sampling, water had a slightly more alkaline pH of 7.23, while soil had a pH of 6.65. Relative humidity and water depth during the first sampling were 83.47% and 4.5 cm, respectively; these increased to 88.00% and 12 cm in the second sampling. Meanwhile, in the recapture-phase sampling, the highest temperature was again observed in water at 24.59 °C, followed by air at 19.30 °C and soil at 19.00 °C. In the second sampling, water remained the warmest at 22.69 °C, with soil and air measuring 20.06 °C and 18.50 °C, respectively. The pH of the first sampling was 6.83 for water and 6.47 for soil. In the second sampling, pH values were 6.85 for water and 6.54 for soil. Relative humidity and water depth were recorded at 85.55% and 6.5 cm during the first sampling and increased to 89.17% and 13 cm in the second sampling.

Ethnobiological survey

All participants were male, married, of legal age, and had sufficient experience in rice farming (Table 2).

During data analysis, three main themes emerged that enriched the understanding of GAS invasion. These themes addressed several aspects, including the origin of invasion, feeding mechanisms, the extent of damage to the rice system and farmers' livelihoods, factors contributing to the increasing snail population, control measures employed by farmers, and other related concerns like health risks. The identified themes were categorized as: 'What Do I Know', 'What Do I Do,' and 'Presence of Challenges' (Table 3).

DISCUSSION

The Lincoln-Petersen index indicated high GAS abundance, with a density of over 0.5 individuals per m^2 across sampling periods, matching Basilio (1991). This may cause up to 6.5% rice field damage, with densities of 1–8 snails per m^2 linked to up to 93% damage and 20–90 % yield loss (Basilio 1991; Naylor 1996; Joshi 2005b; Arfan

Table 3. Responses on the derived and corresponding sub-themes on P. canaliculata.

Themes	Sub-themes	Responses
Theme I: What Do I Know	General knowledge	Described locally as "rambuwan", pest, and can further inflict injury.
	Origin of its invasion	Brought in the region from neighboring provinces due to flooding or human cultivation. Some believe it developed organically, while others believe it was created by God.
	Feeding mechanism & extent of damage on rice crops	Causes major crop loss by feeding on stems and leaves, and is highly destructive to young rice seedlings. During the wet season, GAS becomes widespread, reproduce quickly, and is difficult to control. Its infestation seriously threatens rice yields and farmers' livelihoods.
	Factors influencing increasing density	Deep water is a prerequisite for reproduction. Infestation worsen during flooding, poorly designed rice fields, in inadequately irrigated, and snails' capacity to withstand dry weather and reappear after rain.
	Boon or Bane	*P. canaliculata* is a bane.
Theme II: What Do I Do	Government Initiatives	Inconsistent efforts in managing the GAS. Some recalled past seminars and the use of a substance called "ukap" to control snails, though most information focused on rodents.
	Traditional methods on snail management	Farmers use labor-intensive strategies such as manual removal, pesticide application, constructing of drainage ditches to regulate population, and feeding the snail to ducks.
	Use of modern synthetic pesticides	Rely on pesticides ('timpla', 'surekill', and 'furadan') to control, ensuring crop survival and healthy growth. Although these are considered essential, some farmers prefer manual removal of snails to avoid the unpleasant odors from chemical use, while other methods, such as lowering water levels, can lead to excessive weed growth.
Theme III: Presence of Challenges	Financial struggles	Many farmers face financial struggles, forcing them to reduce or discontinue the use of synthetic control methods. As a result, they merely tolerate the damage.
	Challenges of farming practices	Lack of a collaborative farming schedule among farmers makes rice fields more vulnerable to pests and complicates pest management.
	Health risks	Physical injuries from stepping on sharp shells can cause bleeding, delayed healing, and schistosomiasis. Additionally, the use of pesticides during fieldwork often led to eye irritation and vision problems.

et al. 2017). Cowie (2002) found that an adult snail can eat about 24 young rice seedlings daily. Snails over 5 cm cause three times as much damage as those under 2 cm; those under 5 mm feed on algae and detritus. Horgan (2018) added that large snails eat older seedlings (30–40 days or more), while hatchlings and small snails feed on young seedlings and cotyledons, as seen in missing rice hills and floating plant fragments.

Egg clutch density declined during the second sampling, likely due to changes in food availability, abiotic factors, and human intervention. Mature seedlings, especially transplanted ones, develop thicker stems that resist snail damage even at high snail densities (Figueroa et al. 2014). These sturdy stems also allow female snails to climb and deposit eggs above water. Studies report that females may delay reproduction when food is limited (Estoy et al. 2002; Tamburi & Martin 2009). Consequently, egg numbers decline during the first reproductive month due to reduced food availability (Estoy et al. 2002; Tamburi & Martin 2009), resulting in fewer egg clutches later, coinciding with reduced food availability during rice maturation and pre-harvest.

Temperature strongly influences the activities of apple snails such as *P. canaliculata* (Wada & Matsukara 2007, 2011; Seuffert et al. 2010; Bae et al. 2021). Water and air temperatures of 15–20 °C decrease egg-laying, while 20–32 °C promote mating. The optimal range for both is 25–30 °C, associated with higher populations (Seuffert & Martin 2013; Bae et al. 2021). High temperatures and dry periods enable snails to grow and mature rapidly in tropical rice paddies (Cowie 2002; Teo 2004), with continuous reproduction and egg-laying (Estebenet & Martin 2002; Stuart et al. 2014). Egg clutches outside optimal temperature are low in density. Egg-laying occurs above water on plant stems or structures. The presence of clutches indicates high pest population growth, as seen during the second sampling. Egg clutch sizes vary, but damage to rice fields mainly comes from high GAS density. Snail damage in irrigated rice depends on crop age, snail size and density, water levels, and environmental factors (Basilio 1991; Horgan 2018; Gilal & Muhammad 2020).

Snails damage rice by rasping seedlings (Horgan 2018). Factors like water depth, seedling age, and snail density influence vulnerability (Litsinger & Estano 1993; Teo 2003). During this period, snails forage, mate, and reproduce (Burela & Martin 2007; Takeichi et al. 2007). When water is above snail shell height, their mobility increases, causing more damage (Sanico et al. 2002; Teo 2003; Liang et al. 2014; Gilal & Muhammad 2020). Water also provides food (young rice seedlings) (Teo 2003). Teo (2003) noted that at water depths over 5 cm, snail damage was 100%, 89.2%, 59.7%, and 46% for rice seedlings at 21, 30, 40, and 50 days old, respectively. Infestation rises during the rainy season, aiding the spread of snails and their invasion. Low snail counts may result from sampling methods and climatic conditions, which affect reproduction. GAS can hibernate by burrowing into mud, slowing metabolism until conditions improve (Rodriguez et al. 2023; Yao et al. 2024). Burrowing 5–10 cm helps snails survive low water and heat (Wada & Yoshida 2000; Zhang et al. 2023). Increased snail density in the second period likely stems from rain raising water levels, encouraging snails to re-emerge and spread (Joshi 2005a; Liang et al. 2014; Seuffert & Martín 2017). Human snail management also influences population levels.

Female Golden Apple Snails are larger than males (PhilRice 2001; Cowie 2002; Estebenet & Martin 2002). Sex was identified by the operculum's shape: concave in females, convex near the margin in males (Xu et al. 2016; Moneva et al. 2012). The observed sex ratio differences highlighted abundant egg clutches in the first sampling, while the lower numbers in the second may have resulted from reduced food availability, seedling maturity, pre-harvest conditions, and the absence of stable leaf sheaths or stems suitable for egg laying. Temperature could also influence this variation. Yusa & Suzuki (2003) reported a typical sex ratio of around 0.5, suggesting a balance between the sexes, but Yusa (2004) notes that some clutches may produce predominantly one sex. Environmental factors (Estebenet & Martin 2002; Gilal & Muhamad 2020) can affect sex ratios. This study's observations support these findings, corroborating the view that environmental conditions influence sex ratio traits.

Snail habitat preferences varied between sampling periods. Adults favored water, leaf sheaths, and sediment, while juveniles mainly occupied leaf sheaths and sediment. Snails prefer to lay eggs on rice seedling leaf sheaths, avoiding submerged clutches, likely due to water's negative effects on eggs and hatching. Habitat use across stages matches that reported in prior studies (Horn et al. 2008). Horn et al. (2008) reported that *Pomacea* spp. Depend on aerial incubation. Submerging eggs can hinder hatching as they may not develop fully or disintegrate. This lack of underwater structural integrity reduces hatching success. GAS prefer to oviposit on firm, aerial substrates like stems, leaf sheaths, rocks, or artificial structures (Horn et al. 2008). This explains the high number of egg clutches on rice seedling leaf sheaths during sampling, as they support egg deposition. Chistopolsky et al. (2023) and Pizani et al. (2005) also found that prolonged water exposure harms embryo development by reducing oxygen and causing early hatching.

Environmental factors significantly influence GAS abundance. Ito (2002) found that pH, dissolved oxygen, and water depth affected overwintering success, while temperature and water velocity did not. Barnes et al. (2008) highlighted that reproductive success depends mainly on temperature and other environmental factors. Bernatis et al. (2016) and Byers et al. (2013) noted pH levels of 5.5 to 9.5 and high humidity support *P. canaliculata* and other Pomacean species, while pH below 5.5 harms growth and survival (Gilal & Muhamad 2020). Elevated humidity and nocturnal rain increase egg oviposition (Teo 2004). Humidity allows snails to stay outside water longer without drying, aiding dispersal (Mueck et al. 2018). Bernatis et al. (2016) observed that over 80% humidity enables adult snails to survive a year on moist sand, versus only 154 days below 60%. Ramakrishnan (2007) showed adults and juveniles survive 70 days at 30⍰ with over 95% humidity, and at 20–25 ⍰ for at least 308 days in 75–95 % humidity, with juveniles desiccating faster. These data align with the second sampling, which recorded high snail densities due to favorable pH and humidity. In summary, the physicochemical factors—temperature, pH, humidity, and water depth—significantly influenced GAS abundance and habitat preferences, with favorable conditions correlating with higher GAS abundance and habitat preferences.

The ethnobiological data showed all respondents knew GAS, called 'rambuwan' in Meranao. They said its spread was due to both intentional and natural processes. It was introduced to the Philippines as food, a dietary protein source, and an income resource for farmers (Joshi et al. 2001; Joshi 2005b). Respondents described GAS feeding mechanisms and damage to rice crops, yields, health, and livelihood. Rambuwans crawl upward, feeding by nipping or scraping rice seedlings. According to Cummins & Klug (1979), *P. canaliculata* is a scraping, shredding, and collecting feeder. Juvenile snails have higher specific ingestion rates than adults, regardless of feeding mechanism or type consumed (Tamburi & Martin 2009). Young rice seedlings, especially those transplanted 18 to 21 days after sowing, are most vulnerable to snail attacks, as noted by Litsinger & Estano (1993) and Teo (2003). Crop damage correlates with the age of rice plants and snails, with high infestation indicated by reduced plant populations, missing plants, and floating leaf fragments, which are signs of damage to newly transplanted rice (Joshi et al. 2001; Teo 2003).

The spread of GAS posed serious threats to human health. GAS is linked to health risks, including skin irritation as an intermediate host for trematodes (Naylor 1996) and digestive infections (Halwart 1994; Naylor 1996). It can also carry *Angiostrongylus cantonensis*, the rat lungworm, which infects humans and can cause fatal eosinophilic meningoencephalitis (Kim et al. 2014; Song et al. 2016). Chemical control methods against GAS often involve persistent organotin compounds, which can cause nail loss, skin issues, blurred vision, and blindness (Sousa et al. 2013). Research shows some *Pomacean* species carry *Schistosoma mansoni* cercariae, causing schistosomiasis (Cantanhede et al. 2014). Transmission usually occurs via infected gastropods like *P. canaliculata*, which act as intermediate hosts (Kim et al. 2014). Schistosomiasis is endemic in parts of the Philippines, especially the southern islands, including the study area, where parasitic infestations are common (Olveda et al. 2014). To control invasive *Pomacea* species globally, various measures have been tested (Joshi 2005b). Effective management needs regulation and education to reduce harm, protect yields, and prevent spread (Schneiker 2016). Eradicating invasive species like GAS is very difficult (Joshi 2005b). Various control measures—cultural, mechanical, and chemical—have been tried to reduce *Pomacea* populations below economic thresholds. However, no method or combination is consistently effective, and the effects on crop yield are uncertain (Byers et al. 2013). An integrated strategy remains the best approach to control *Pomacea* spread.

Traditional methods reported include manual removal of eggs and snails, constructing wire-mesh grills and ditches, and managing irrigation water. Hand-picking remains the most effective non-chemical control for GAS despite being labor-intensive (Joshi 2005b; Kunimoto & Nishikawa 2008; Penaredondo et al. 2015; Constantine et al. 2023). Egg collection improves when sticks are used to encourage oviposition (Cowie 2002). Water management, such as lowering water levels before hand-picking, is effective. Proper irrigation reduces snail mobility (Teo 2003; Wada 2004; Arfan et al. 2017). Deeper ditches in rice paddies help collect snails, which congregate when fields drain (Cowie 2002; Joshi 2005b). Ducks are used to reduce snail populations, but effectiveness depends on the timing of release (Halwart 1994; Teo 2003; Joshi 2005b; Vega et al. 2007; Liang et al. 2014).

Modern synthetic chemical pesticides are common due to their convenience. Local products include timpla (mixture), ukap (Magnum), Surekill, Furadan, tupordi (2-4 D), and Machete. These chemicals act as pesticides, molluscicides, herbicides, and insecticides. Furadan, used for over a century, is highly toxic (Stevens 2003). Recently, molluscicides containing niclosamide and metaldehyde have been preferred for field use (PhilRice 2001). Metaldehyde bait remains effective during heavy rain thanks to slow release (PhilRice 2001; Wada 2004). Despite their popularity, chemical pesticides are costly, causing crop damage and incurring expenses for purchase and manual snail removal (Joshi 2005b). Sustainable farming practices are vital to mitigate GAS damage (Schneiker 2016). Developing low-cost, effective, and environmentally sound management strategies is still challenging (Joshi 2005b).

While this study provides baseline ecological and ethnobiological insights into *P. canaliculata* in Lanao del Sur's rice communities, it has limitations that shape future research directions. Conducted at one site and over two sampling periods, the findings cannot be generalized across different times and locations. Physicochemical data were mainly descriptive, and sex determination was based on morphology. Ethnobiological data came from purposively selected male farmers, which may not represent the broader community or disentangle ecological and social factors. Future research should involve multi-season and multi-site studies to examine abundance and habitat-use consistency across larger rice areas. Controlled experiments are needed to assess how water depth, crop stage, humidity, and substrate affect snail activity, reproduction, and crop damage. Interdisciplinary research should include diverse farmer groups, evaluate stage-specific control strategies, and investigate whether health risks and management barriers impact ecology, economy, and public health. Sustainable management should incorporate alternative solutions that do not add financial burdens, emphasizing government and local initiatives to deliver cost-effective, tailored mitigation strategies.

CONCLUSIONS

The study found that Golden Apple Snail is abundant in both water and sediment during its adult and juvenile stages, where it mates and searches for submerged food sources. Egg clutches are primarily attached to leaf sheaths, providing a safe site for deposition. Favorable environmental conditions further increase snail density and dispersion, thereby influencing both abundance and habitat preferences.

Moreover, the study revealed that the presence of this invasive pest poses a significant threat to local rice farmers, by affecting their livelihoods, health, and production stability. Although traditional practices and modern synthetic pesticides have been used to control pests, these approaches were largely inefficient when applied in isolation. The findings therefore underscore the need for an integrated pest management (IPM) strategy that combines habitat-based monitoring, timely removal of egg clutches, improved field sanitation, water and vegetation management, and judicious use of chemical control only when necessary. Major barriers to effective management included limited financial support, inadequate farming practices, and insufficient education on affordable and safe control measures. Health concerns such as schistosomiasis, colds, and physical injuries were also prevalent. These findings highlight that GAS infestation is not only an agricultural concern but also a rural livelihood and public health issue with broader implications for food security, environmental sustainability, and community well-being.

The researchers therefore strongly advocate for increased government support for disadvantaged farmers through seminars, targeted initiatives, and extension services that promote practical IPM adoption. The public health sector should also take a more active role in educating farmers and local communities about the health risks associated with snail handling and consumption. Likewise, community-level collaboration can strengthen surveillance, coordinated control, and long-term sustainable management. Future research should focus on developing locally appropriate and cost-effective IPM strategies, including ecological, mechanical, and community-based interventions suited to rice-farming communities.

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ARTICLE

An annotated checklist of bryophytes of Rajouri District, Jammu & Kashmir, India

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Abstract: Significant altitudinal variation seen in the area ranging from 490 to 4,700 m has resulted into three distinct climate zones, viz, subtropical, temperate, and alpine in the district Rajouri which is home to a diverse range of plants and animals. The goal of the current study is to record and evaluate the diversity of bryophytes in district Rajouri, Jammu & Kashmir. The checklist comprises of 118 species of bryophytes, out of which one species belongs to hornworts, 47 species to liverworts and the remaining 70 species to the mosses. This article includes an inventory of all known plant species along with their family, local distribution range, elevation, geographic coordinates, and habitat.

Keywords: Bryophyta, climate zones, distribution range, diversity, elevation, habitat, hornworts, liverworts, mosses.

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INTRODUCTION

India is one of the mega biodiversity countries harbouring about 56,177 plant taxa including 22,368 angiosperms, 83 gymnosperms, 1,325 pteridophytes, 2,850 bryophytes, 3,151 lichens, 15,986 fungi, 9,117 algae, and 1,297 microbes (Mao et al. 2025). The Indian bryophytes account for about 5.07 percent of the total plant species of the country.

Jammu & Kashmir has rich bryophyte diversity owing to its suitable climatic conditions (Dar et al. 2012). Banday (1997) investigated the bryophytes of Gulmarg and the surrounding regions, gathering 63 species, including 49 mosses and 14 liverworts. Later Banday et al. (1998) classified 48 liverworts from Kashmir, including 23 thallose and 25 foliose varieties, and noted that there were no hornworts in the area. Prior research on mosses and liverworts in Kashmir was reviewed by Dar (2002), who listed 48 species of liverworts spread across 25 genera in 16 families and 162 species, two subspecies, and nine varieties of mosses spread across 70 genera in 25 families. Likewise, some initial findings on the Ladakh region's liverworts have been published (Dolma & Langer 2012, 2013). Many uncommon, threatened, and endangered taxa have been reported as a result of the exploration of Jammu region's bryoflora, which has also shown a high diversity of liverworts (Tanwir & Langer 2004; Bhagat et al. 2012; Rashid et al. 2012). Riaz et al. (2015) reported 17 mosses belonging to 17 genera in 12 families from Kistwar, Jammu & Kashmir. A preliminary survey of mosses in Rajouri and Poonch districts of Jammu & Kashmir by Sharma et al. (2016) documented 21 species belonging to 16 genera in 11 families. Ismail et al. (2020) listed 420 species of bryophytes from Jammu & Kashmir, of which 328 species distributed over 117 genera and 32 families are mosses, while 91 species distributed across 40 genera and 23 families are liverworts. Only one species of hornworts, *Phaeoceros laevis* is recorded from the state, that too from district Rajouri of the Jammu province. The present study is an attempt to survey the bryophytes of district Rajouri, Jammu & Kashmir and to prepare an updated checklist of these plants in the area.

MATERIALS AND METHODS

The Rajouri District lies between 32°57'–33°34' N and 74°00'–74°48' E in the southern foothills of Pir Panjal Himalaya in the Indian state of Jammu & Kashmir (Image 1). The specimens collected from different habitats were air dried and kept in paper packets. Field data such as name of locality, habitat, longitude, latitude and elevation was also recorded. Collected samples were identified by using the available literature Gangulee (1969–1980), Chopra & Kumra (1988), and Aziz & Vohra (2008) for mosses. The classification of liverworts in this checklist follows the recent molecular framework proposed by Crandall-Stotler et al. (2009). Mosses are classified according to the recent molecular system of Goffinet et al. (2008). Species names and authorship were verified and updated following World Flora Online (WFO 2025). The collected samples have been deposited in the Centre for Biodiversity studies, Baba Gulam Shah Badshah University (BGSBU).

RESULTS

A total of 118 species have been recorded from the district Rajouri based on the present and past collection of bryophytes belonging to one species of hornwort, 47 taxa of liverworts in 26 genera and 19 families, and 70 species of mosses in 44 genera and 19 families.

Enumeration

Hornworts

1. *Phaeoceros laevis* (L.) Prosk., Bull. Torrey Bot. Club 78: 347. 1951. *Anthoceros laevis* L., Sp. Pl. 2: 1139. 1753 (Notothyladaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non- epilithic, 900–2000 m (Rashid et al. 2012).

Liverworts

2. *Acrolejeunea sandvicensis* (Gottsche) Steph., Bot.jahrb. Syst. 23(3): 312.1986. *Phragmicoma sandvicensis* Gottsche., Ann. Sci.Nat., Bot., ser.4,8: 344.1857(Lejeuneaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epiphytic, 700–1700 m (Rashid et al. 2012 as *Trocholejeunea sandvicensis* Mizut.).

3. *Apopellia endiviifolia* (Dicks.) Nebel & D. Quandt., Taxon 65(2): 230. 2016. *Jungermannia endiviifolia* Dicks., Fasc. Pl. Crypt. Brit. 4: 19. 1801(Pelliaceae) (Image 2E)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.4° N, 1,780 m, growing on soil rich in lime, 5.iii.2022, Manju Sharma and Nazia Kouser S36B3 (Rashid et al. 2012 as *Pellia endiviifolia* (Dicks.) Dumort.).

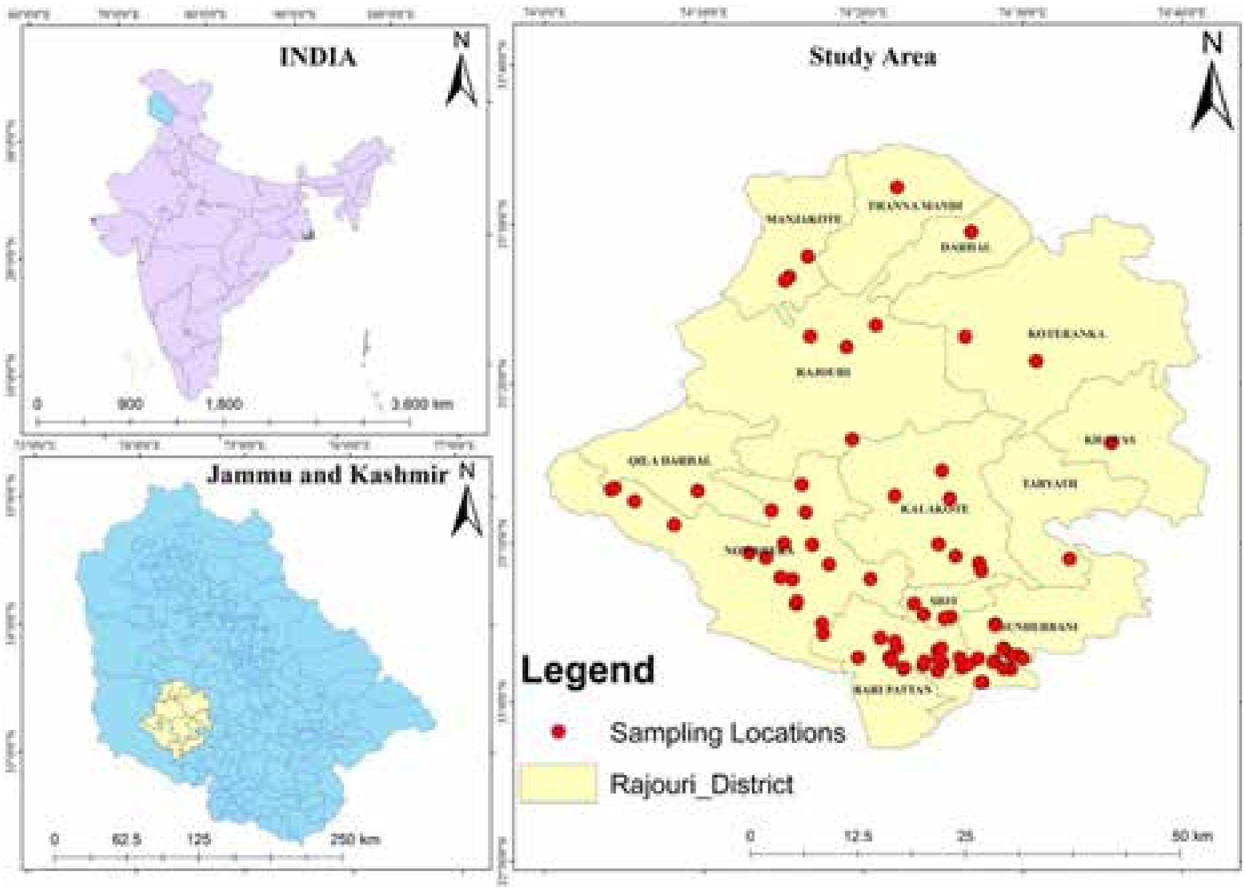

Image 1. The study area—Rajouri District, Jammu & Kashmir.

4. *Asterella blumeana* (Nees) Kachroo, J. Gauhati India Univ. 3:130.1952. *Fimbraria blumeana* Nees, Syn. Hepat.: 564. 1846 (Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Palwal, 74.38° E, 33.04° N, 589.43 m, on soil covered rock, 10.ii.2022, Manju Sharma S9B6 (see also Rashid et al. 2012).

5. *Asterella khasyana* (Griff.) Grolle., Khumbu Himal 1(4): 267. 1966. *Octokepos khasyanus* Griff., Not. Pl. Asiat. 2: 343. 1849(Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kalakote, Karmha, 74.41° E, 33.21° N, 657.02 m, onsoil covered rock, 15.ii.2022, Manju Sharma and others S29B1.

6. *Asterella leptophylla* (Mont.) Grolle, Feddes Repert. 87: 246. 1976. *Fimbraria leptophylla* Mont., Ann. Sci. Nat., Bot., sér. 2,18: 16. 1842 (Aytoniaceae)

Specimen examined: Jammu & Kashmir, Rajouri District, epilithic, non-epilithic, 1,000–2,000 m, (Rashid et al. 2012 as *Asterella reticulata* (Kashyap) Pandé, K.P. Srivast. & Sultan Khan).

7. *Asterella wallichiana* (Lehm. & Lindenb.) Grolle., Khumbu Himal 1(4): 262, 1966. *Fimbraria wallichiana* Lehm. & Lindenb., Nov. Stirp. Pug. 4: 4. 1832 (Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Mangaldai, 74.23° E, 33.15° N, 261.33 m, on soil covered rock,15.ii.2022, Manju Sharma S17B1 (Rashid et al. 2012 as *Asterella angusta* (Steph.) Pandé, K.P. Srivast. & Sultan Khan).

8. *Athalamia pinguis* Falc., Trans. Linn. Soc, London 20:397.1851 (Cleveaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Suderbani, DhokBanyard, 74.25° E, 33.13° N, 604.54 m, grows on swampy soil, 02.ii.2022, Manju Sharma S13B4 (see also Rashid et al. 2012).

9. *Clevea pusilla* (Steph.) Rubas. & D.G. Long., J.Bryol. 33(2): 167.2011. *Gollaniella pusilla* Steph., Hedwigia 44: 74. 1905(Cleveaceae) (Image 2B)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Suderbani, near Beripattan bridge, 74.36°E , 33.06° N, 485.7 m, on soil covered rock, 02.ii.2022, Manju Sharma S1B1 (Rashid et al. 2012 as *Athalamia pusilla* (Stephani) Kashyap).

10. *Conocephalum conicum* (L.) Dumort., Comment. Bot.: 115. 1822.*Marchantia conica* L. Sp. Pl. 2: 1138. 1753 (Conocephalaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, non-epilithic, 1,000–2,000 m (Rashid et al. 2012).

11. *Dumortiera hirsuta* (Sw.) Nees., Nova Acta Phys.-Med, Acad. Caes. Leop.- Carol. Nat.Cur. 12(1): 410.1825. *Marchantia hirsute* Sw., Prodr.: 145. 1788(Dumortieraceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Channi, 74.47° E, 33.08° N, 588.02 m, on rock, rock cervices, 27.ii.2022, Manju Sharma S25B4 (Rashid et al. 2012).

12. *Fossombronia cristula* Austin., Proc. Acad. Nat. Sci. Philadelphia 21 (4): 228.1869 (Fossombroniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Nariyan, 74.27° E, 33.19° N, 654.67 m, growing on soil, 15.ii.2022, Manju Sharma S42B3.

13. *Frullania gaudichaudii* (Nees & Mont.) Nees & Mont., Syn. Hepat.: 435. 1845. *Jabula gaudichaudii*Nees & Mont., Ann. Sci. Nat., Bot., sér. 2, 5: 64. 1836 (Frullaniaceae)

Specimen examined: Jammu & Kashmir, Rajouri District, epilithic, 1,300–1,800 m (Rashid et al. 2012).

14. *Frullania muscicola* Steph., Hedwigia 33: 146. 1894 (Frullaniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,300–1,800 m (Rashid et al. 2012).

15. *Frullania neurota* Taylor, London J. Bot. 5: 400. 1846 (Frullaniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,300–1,800 m (Rashid et al. 2012).

16. *Gymnocolea inflata* (Huds.) Dumort., Recueil Observ. Jungerm.: 17. 1835.*Jungermannia inflata* Huds. Fl.Angl. (ed. 2) 2: 511. 1778(Anastrophyllaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non-epilithic, 900–1,200 m, (Rashid et al. 2012).

17. *Jungermannia atrovirens* Dumort., Syll. Jungerm. Europ.: 51. 1831 (Jungermanniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non-epilithic, 900–1,500 m (Rashid et al. 2012 as *Jungermannia lanceolata* L.).

18. *Lejeunea aloba* Sande Lac., Plagiochila Sandei: 10. 1856. (Lejeuneaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 800–1,100 m (Rashid et al. 2012).

19. *Mannia californica* (Gottsche) L.C. Wheeler, Bryologist 37(5): 88.1934[1935].*Grimaldia californica* Gottsche, Bot. Gaz. 13(5): 114. 1888(Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non- epilithic, 900–1,500 m (Rashid et al. 2012 as *Mannia foreaui* Udar & V. Chandra).

20. *Marchantia emarginata* Reinw., Blume & Nees, Nova Acta Phys.- Med. Acad. Caes. Leop.- Carol. Nat. Cur. 12: 192. 1825 (Marchantiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non-epilithic, 700–1,800 m, (Rashid et al. 2012 as *Marchantia palmata* Reinw., Blume &Nees).

21. *Marchantia paleacea* Bertol., Opusc. Sci. 1(4): 242.1817(Marchantiaceae) (Image 2D)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Brebi, 74.45° E, 33.14° N, 657.0 m, grows on wet rock, 27.ii.2022, Manju sharma, S27B10 (Rashid et al. 2012 as *Marchantia nepalensis* Lehm. & Linden.

22. *Marchantia pappeana* subsp.*robusta* (Steph.) Bischl., Bryophyt. Biblioth. 45: 91. 1993. *Marchantia robusta* Steph., Candollea 14: 111. 1953 (Marchantiaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, non-epilithic, 1,700–2,500 m (Rashid et al. 2012 as *Marchantia kashyapii* Udar & Shaheen).

23. *Marchantia polymorpha* L., Sp. Pl. 2: 1127. 1753 (Marchantiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 700–2,000 m (Rashid et al. 2012).

24. *Marchantia subintegra* Mitt., J. Proc. Linn. Soc., Bot. 5: 125. 1861 (Marchantiaceae)

Specimen examined: India, Jammu & Kashmir,

Image 2. A—*Ectropothecium ramuligerum* | B—*Clevea pusilla* | C—*Brachythecium salebrosum* | D—*Marchantia paleacea* | E—*Apopellia endiviifolia* | F—*Plagiochasma appendiculatum*. © Manju Sharma.

Rajouri District, non- epilithic, 600–1,700 m (Rashid et al. 2012).

25. *Plagiochila chinensis* Steph., Mém. Soc. Sci. Nat. Math. Cherbourg 29: 233. 1894 (Plagiochilaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 700–2,000 m (Rashid et al. 2012).

26. *Plagiochila korthalsiana* Molk. ex Sande Lac., Ned. Kruidk. Arch. 3(4): 416. 1855 (Plagiochilaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, non- epilithic, 700–2,000 m (Rashid et al. 2012 as *Plagiochila accedens* Steph. and *P. woronofii* Steph.).

27. *Plagiochila parvifolia* Lindenb., Sp. Hepat. (Lindenberg) (fasc. 1): 28. 1839 (Plagiochilaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 600–1,800 m (Rashid et al. 2012).

28. *Plagiochasma appendiculatum* Lehm. & Linden., Nov. Stirp. Pug. 4:14.1832(Aytoniaceae) (Image 2F)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, 74.49° E, 33.09° N, 586.2 m, on rock, in rock crevices, 5.ii.2022, Manju sharma S8B2 (see also Rashid et al. 2012).

29. *Plagiochasma intermedium* Lindenb. & Gottsche, Syn. Hept.: 513. 1846 (Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, non- epilithic, 900–2,500 m (Rashid et al. 2012).

30. *Plagiochasma pterospermum* C.Massal., Mem. Accad. Verona 73(2): 46.1897 (Aytoniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kalal, 74.23° E, 33.15° N, 261.33 m, on rock, soil covered rock,15.ii.2022, Manju Sharma S21B1 (Rashid et al. 2012 as *Plagiochsma articultum* Kashyap).

31. *Plectocolea stygia* (Nees) Bakalin & S.S.Choi., Plants 12 (23, 3935) : 5. 2023.*Chiloscyphus stygius* Nees, Syn. Hepat.: 189. 1845 (Solenostomataceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Brebi, 74.45° E, 33.14° N, 657.0 m, on rock, rock cervices,27.ii.2022, Manju Sharma S27B11.

32. *Porella acutifolia* (Lehm. & Lindenb.) Trevis., Mem. Reale Ist. Lombardo Sci., Ser. 3, Cl. Sci. Mat. 4: 408. *Madotheca acutifolia* Lehm & Lindenb., Nov. Stirp. Pug. 7: 8. 1838(Porellaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 900–1,700 m (Rashid et al. 2012).

33. *Porella caespitans* (Steph.) P.Syd., Just's Bot. Jahresber. 21(1): 232. 1896.*Madotheca caespitans* Steph., Mém. Soc. Sci. Nat. Mth. Cherbourg 29: 218. 1894(Porellaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,100–1,600 m (Rashid et al. 2012).

34. *Porella campylophylla* (Lehm. & Lindenb.) Trevis., Mem. Reale ist. Lombardo Sci., Ser. 3, Cl. Sci. Mat. 4: 408. 1877.*Jungermannia cmpylophylla* Lehm.& Lindenb., Nov. Strip. Pug. 6: 40. 1834(Porellaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,300–1,800 m (Rashid et al. 2012).

35. *Porella chinensis* (Steph.) P.Syd., Just's Bot. Jahresber. 21(1): 232. 1896. *Madotheca chinensis* Steph., Mém. Soc. Sci. Nat. Math. Cherbourg 29: 218. 1894 (Porellaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,100–1,800 m (Rashid et al. 2012).

36. *Porella platyphylla* (L.) Pfeiff., Fl. Niederhessen 2: 234. 1855.*Jungermannia platyphylla* L. Sp. Pl. 2: 1134. 1753(Porellaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1100–1,800 m (Rashid et al. 2012).

37. *Radula complanata* (L.) Dumort., Syll. Jungerm. Europ.: 38.1831. *Jungermannia complanata* L., Sp. Pl. 2: 1133. 1753 (Radulaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non-epilithic, epiphytic, 900–1,900 m (Rashid et al. 2012).

38. *Reboulia hemisphaerica* (L.) Raddi, Opusc. Sci. 2(6): 357.1818.*Marchantia hemisphaerica* L., Sp. Pl. 2: 1138. 1753(Aytoniaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Dabbar, 74.23° E, 33.15° N, 261.33 m, on rock, soil covered rock,15.ii.2022, Manju Sharma, S19B4(see also Rashid et al. 2012).

39. *Riccardia multifida* (L.) Gray., Nat. Arr. Brit. Pl. 1: 684. 1821.*Jungermannia multifida* L., Sp. Pl. 2: 1136. 1753(Aneuraceae)

Specimen examined: India, Jammu & Kashmir, Rajouri

District, epiphytic, 700–2,000 m (Rashid et al. 2012).

40. *Riccia aravalliensis* Pandé & Udar., J. Indian Bot. Soc. 36(3): 249. 1957. (Ricciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non- epilithic, 800–1,800 m (Rashid et al. 2012).

41. *Riccia discolor* Lehm. & Lindenb., Nov. Stirp. Pug. 4: 1. 1832 (Ricciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epiphytic, 700–1,900 m (Rashid et al. 2012).

42. *Riccia huebeneriana* Lindenb., Nova Acta phys.-Med. Acad. Caes. Leop.- Carol. Nat. Cur. 18(1) : 504d.1836[1837] (Ricciaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on soil, 18.ii.2022, Manju Sharma S31B1.

43. *Riccia warnstorfii* Limpr.ex Warnst., Verh. Bot. Vereins Prov. Brandenburg 27(2): 85. 1885 (Ricciaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, non-epilithic, 700–1,900 m (Rashid et al. 2012).

44. *Scapania verrucosa* Heeg., Rev. Bryol. 20: 81. 1893 (Scapaniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, non epilithic, 900–1,900 m (Rashid et al. 2012).

45. *Solenostoma fusiforme* (Steph.) R.M.Schust., Hepat. Anthocerotae N.Amer. 2:944.1969.*Nardia fusiformis* Steph. Bull. Herb. Boissier 5(2): 99. 1897(Solenostomataceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Peli, 74.45° E, 33.53° N, 702.72 m, growing on soil,25.ii.2022, Manju Sharma S2B7.

46. *Targionia hypophylla* L., Sp.Pl. 2:1136.1753(Targioniaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Julla Water Point, 74.36° E, 33.06° N, 485.7 m, on rock, soil covered rock, 02.ii.2022 Manju Sharma 2024, S1B4, S5B1 (see also Rashid et al. 2012).

47. *Targionia indica* Udar & A.Gupta, Geophytology 13:83.1983 (Targioniaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, Dhoka, 74.36° E, 33.06° N, 485.7 m, on rock, in rock crevices,02.ii.2022, Manju Sharma S4B4.

48. *Tuzibeanthus chinensis* (Steph.) Mizut., J. Hattori Bot.Lab.24:151.1961,*Ptychanthus chinensis* Steph., Sp.Hepat 4: 744.1912 (Lejeuneaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, epiphytic, 700–1,700 m (Rashid et al. 2012).

Mosses

49. *Amblystegium serpens* (Hedw.) Schimp., Bryol. Eur. 6: 53. 1853.*Hypnum serpens* Hedw., Sp. Musc. Frond.: 268. 1801(Amblystegiaceae).

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,005 m (Sharma et al. 2016).

50. *Atrichum longifolium* Cardot & Dixon ex Gangulee, Mosses E. India 1: 81. 1969 (Polytrichaceae)

Specimen examined : India, Jammu & Kashmir, Rajouri District, non- epilithic, 1047 m (Sharma et al. 2016).

51. *Barbula marginatula* Müll. Hal. ex Gangulee, Nova Hedwigia 12: 424.1966 [1967] (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kalal, 74.27° E, 33.07° N, 576.06 m, growing in rock cervices,20.x.2022, Manju Sharma S21B1.

52. *Brachymenium longicollum* Thér., Bull. Soc. Bot. Genève 26: 85.1936 (Bryaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Sarkani, 74.25° E, 33.13° N, 490.23 m, growing on soil rich in lime, 01.ii.2022, Manju Sharma S44B1.

53. *Brachythecium garvovaglioides* Müll. Hal., Bot. Ital., n.s. 4: 270. 1897 (Brachytheciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, BGSBU, 74.34° E, 33.39° N, 1,176.9 m, growing on dead wood, leaves and on organic debris, 11.xi.2023, Manju Sharma S30M2.

54. *Brachythecium salebrosum* (Hoffm. ex F.Weber & D.Mohr) Schimp., Bryol. Eur. 6: 20. 1853. *Hypnum salebrosum* Hoffm. ex F.Weber & D.Mohr, Index Mus. Pl. Crypt.: 2[verso]. 1803 (Brachytheciaceae) (Image 2C)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Darhal, 74.44° E, 33.49° N, 1,738.55 m, growing in rock crevices,25.xi.2023, Manju Sharma and Nazia Kouser S40B9.

55. *Bryoerythrophyllum recurvirostrum* (Hedw.) P.C.Chen., Stud. Ostasiat. Art, Pottiaceae 1:5.1940. *Weissia recurvirostra* Hedw., Sp. Musc. Frond.: 71. 1801 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Dhoka, 74.25° E, 33.13° N, 654.6 m, growing on soil, 8.iii.2023, Manju Sharma S4B4.

56. *Bryoerythrophyllum wallichii* (Mitt) P.C.Chen, Stud. Ostasiat. Art. Pottiaceae 1: 5. 1940. *Desmatodon wallichii* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1: 38. 1859 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Ralua, 74.25° E, 33.13° N, 702.5 m, growing on soil, 6.iii.2023, Manju Sharma S33B1.

57. *Bryum argenteum* Hedw., Sp. Musc. Frond.: 181.1801 (Bryaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Laman, 74.47° E, 33.04° N, 587.94 m, growing on soil rich in lime, 2.iii.2022, Manju Sharma S11B1.

58. *Ceratodon purpureus* (Hedw.) Brid., Bryol. Univ. 1: 480. 1826. *Dicranum purpureum* Hedw. Sp. Musc. Frond.: 136. 1801 (Ditrichaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kungra, 74.37° E, 33.04°N, 491.35 m, growing in rock crevices, 6.iii.2023, Manju Sharma SB5B5.

59. *Ceratodon purpureus* subsp. *stenocarpus* (Bruch &Schimp.) Dixon, New Zealand Inst.Bull. 3(2): 50. 1914. *Ceratodon stenocarpus* Bruch & Schimp, Bryol. Eur. 2: 146 (fasc. 29-30. Mon. 4). 1846 (Ditrichaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, BGSBU, 74.34° E, 33.39° N, 1,176.9 m, growing on rocks,11.xi.2023, Manju Sharma BS30B4.

60. *Chionoloma subduriusculum* (Müll.Hal.) M.Menzel., Willdenowia 22: 198. 1992. *Barbula subduriuscula* Müll.Hal., Linnaea 38: 554. 1874 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, DhokBanyard, 74.25° E, 33.13° N, 604.54 m, growing on rock rich in lime, 5.iii.2022, Manju Sharma S13B3.

61. *Chionoloma tenuirostre* (Hook. & Taylor) M.Alonso, M.J.Cano & J.A.Jiménez., Taxon 65(1): 15. 2016. *Weissia tenuirostris* Hook. & Taylor, Muscol. Brit. (ed. 2): 83. 1827 (Pottiaceae)

Specimen examined: India, Jammu and Kashmir, Rajouri, DhokBanyard, 74.25° E, 33.13° N, 604.54 m, growing on rock rich in lime, 3.iii.2022, Manju Sharma S13B3 (Sharma et al. 2016 as *Trichostoma tenuirostre* (Hook. & Taylor) Lindb.).

62. *Claopodium assurgens* (Sull. & Lesq.) Cardot, Bull. Soc. Bot. Genève 3: 283. 1911. *Hypnum assurgens* Sull. & Lesq., Char. New Musci: 5. 1859 (Brachytheciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,047 m (Sharma et al. 2016).

63. *Dicranella mollicula* (Mitt.) A.Jaeger., Ber. Thätigk. St. Gallischen Naturwiss. Ges. 1870-71: 381. *Leptotrichum molliculum* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1: 11. 1859 (Dicranellaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Budhal, 74.43° E, 33.38° N, 1,560.52 m, growing on Soil, 2.iii.2022, Manju Sharma S32B4.

64. *Ditrichum tortuloides* Grout, Bryologist 30: 4. 1927. (Ditrichaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Minka, 74.36° E, 33.04° N, 537.16 m, growing on soil, 6.iii.2023, Manju Sharma S9B6.

65. *Ectropothecium manii* Broth., Nat. Pflanzenfam. 1(3): 1066. 1908 (Hypnaceae)

Habitat: India, Jammu & Kashmir, Rajouri District, epilithic, 1,005 m (Sharma et al. 2016).

66. *Ectropothecium ramuligerum* Dixon, J. Bombay Nat. Hist. Soc. 39: 793. 1937. (Hypnaceae) (Image 2A)

Specimen examined: India, Jammu & Kashmir, Rajouri District, BGSBU, 74.34° E, 33.39° N, 1,176.9 m, growing in rock crevices, 11.xi.2023, Manju Sharma BS30B2.

67. *Fissidens bryoides* Hedw., Sp. Musc. Frond.: 153.1801. (Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Darhal, 74.44° E, 33.49° N, 1,738.55 m, growing on soil rich in lime, 25.xi.2023, Manju sharma S40B7.

68. *Fissidens crispulus* var. *robinsonii* (Broth.) Z.Iwats. & Z.H.Li, Moss Fl. China 2: 26. 2001. *F. robinsonii* Broth., Philipp. J. Sci., C. 13: 204. 1918 (Fissidentaceae)

Habitat: India, Jammu & Kashmir, Rajouri District, non-epilithic, 1,047 m (Sharma et al. 2016 as *F. robinsonii* Broth.).

69. *Fissidens ganguleei* Nork., Mosses E.India 2: 527.1971 (Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sayal, 74.35° E, 33.06° N, 527.41 m, growing on soil rich in lime, 18.iii.2022, Manju Sharma S15B2.

70. *Fissidens grandifrons* Brid., Muscol. Recent. Suppl. 1: 170. 1806.(Fissidentaceae)

Specimenexamined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.47° N, 1,780.32 m, growing on soil rich in lime, 5.iii.2022, Manju Sharma S36B3.

71. *Fissidens griffithii* Gangulee., Nova Hedwigia 8:143.1964 (Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Palwal, 74.38° E, 33.04° N, 589.43 m, growing on soil rich in lime,10.ii.2022, Manju Sharma and others S7B6.

72. *Fissidens involutus* Wilsom ex Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2) 138.1859. (Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Suderbani, Jullawaterpoint, 74.46° E, 33.03° N, 503 m, growing on soil rich in lime, 02.ii.2022, Manju Sharma S1B3 (Sharma et al. 2016 as *F. plagiochiloides*).

73. *Fissidens laxitextus* Broth. ex Gangulee, Nova Hedwigia 8: 144.1964.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Jullawaterpoint, 74.46° E, 33.03° N, 502.33 m, growing on soil rich in lime, 02.ii.2022, Manju Sharma S1B2.

74. *Fissidens leptopelma* Dixon., J. Bombay Nat. Hist. Soc. 39: 733.1937.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Channi Prat, 74.47° E, 33.07° N, 542.6 m, growing on soil rich in lime. 27.ii.2022, Manju Sharma S26B5.

75. *Fissidens pellucidus* Hornsch., Linnaea 15: 146.1841.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Dabbar, 74.26° E, 33.12° N, 249.2 m, growing on soil rich in lime, 18.iii.2022, Manju SharmaS19B4.

76. *Fissidens polysetulus* Müll.Hal. ex Gangulee & Nork., Mosses E. India 2: 525. 1971.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Baripattan, 74.36° E, 33.06° N, 485.7 m, growing on soil rich in lime, 02.ii.2022, Manju Sharma S10B1.

77. *Fissidens pulchellus* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2): 140. 1859.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Manglamata, 74.06° E, 33.22° N, 809.05 m, growing on soil rich in lime, 20.ii.2022, Manju Sharma S23B5.

78. *Fissidens taxifolius* Hedw., Sp. Musc. Frond. :155.1801.(Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Suderbani, DhokBanyard, 74.25° E, 33.13° N, 604.54 m, growing on soil rich in lime, 02.ii.2022, Manju Sharma S13B5.

79. *Fissidens zollingeri* Mont., Ann. Sci. Nat., Bot., sér. 3, 4: 114.1845- (Fissidentaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Suderbani, Jullawaterpoint, 74.47° E, 33.04° N, 587.94 m, growing on soil rich in lime, 07.iii.2022, Manju Sharma S5B1.

80. *Ganguleea angulosa* (Broth. & Dixon) R.H.Zander., Phytologia 65: 427.1989. *Merceyopsis angulosa* Broth. & Dixon, J. Bot. 48: 302. 1910 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanger, 74.36° E, 33.05° N, 585.42 m, growing in rock cervices, 17.ii.2022, Manju Sharma S8B2.

81. *Gemmabryum exile* (Dozy &Molk.) J.R.Spence & H.P.Ramsay., Phytologia 87(2): 67. 2005. *Bryum exile* Dozy & Molk., Musc.Frond.Archip. lnd.: 3. 1844 (Bryaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Sarkani, 74.25° E, 33.13° N, 490.23 m, growing on soil rich in lime, 1.ii.2022, Manju Sharma S31B1.

82. *Hageniella isopterygioides* Dixon, J. Bombay Nat. Hist. Soc. 39: 791.1937 (Hypnaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Julla Waterpoint 74.46° E, 33.03° N, 502.23 m, growing in rock crevices, 5.iii.2023, Manju Sharma S1B1.

83. *Haplocladium angustifolium* (Hampe & Müll. Hal.) Broth., Nat. Pflanzenfam. 229 [1, 3]: 1008.1907. *Hypnum angustifolium* Hampe & Müll.Hal., Bot. Zeitung (Berlin) 13(45): 788. 1855 (Leskeaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Budhal, 74.43° E, 33.38° N, 1,560.52 m, growing on soil, 2.iii.2022, Manju Sharma S32B2.

84. *Hymenostylium recurvirostrum* (Hedw.) Dixon., Rev. Bryol. Lichénol. 6: 96. 1933 [1934]. *Gymnostomum recurvirostrum* Hedw., Sp. Musc. Frond.: 33. 1801 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, BGSBU, 73.34° E, 33.39° N, 1,176.9 m, growing in rock cervices, 5.x.2022, Manju Sharma S30B1.

85. *Hyophila involuta* (Hook.) A.Jaeger, Ber. Thätigk. St. Gallischen Naturwiss. Ges. 1871–72: 354. 1873. *Gymnostomum involutum* Hook., Musci Exot. 2: 154. 1819(Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 2,095 m (Sharma et al. 2016).

86. *Hyophila nymaniana* (M. Fleisch.) M. Menzel., Willdnowia 22: 198. 1992. *Gluphomitrium nymanianum* M. Fleisch., Musci Buitenzorg 1: 372. 1904 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Nonial, 74.21° E, 33.15° N, 590.92 m, growing on rock cervices,25.xi.2022, Manju Sharma S22B1.

87. *Hydrogonium arcuatum* (Griff.) Wijk & Margad., Taxon 7: 289.1958. *Barbula arcuata* Griff., Calcutta J. Nat. Hist. 2: 491. 1842 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Brebi, 74.45° E, 33.14° N, 613.3 m, growing on rocks,30.ii.2022, Manju Sharma S27B10.

88. *Hydrogonium orientale* (F.Weber) Jan Kuăera., Taxon 62(1): 35. 2013. *Trichostomum orientale* F.Weber, Arch. Syst. Naturgesch. 1(1): 129. 1804 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kund, 74.48° E, 33.03° N, 628.56 m, growing in rock cervices,10.x.2022, Manju Sharma S14B4.

89. *Leptodontium flexifolium* (Dicks.) Hampe ex Lindb., Öfvers. Kongl. Vetensk.- Akad. Förh. 21:227.1864. *Bryum flexifolium* Dicks., Fasc. Pl. Crypt. Brit. 4: [29]. 1801 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Budhal, 74.43° E, 33.38° N, 1,560.52 m, growing on rocks, 4.x.2023, Manju Sharma S32B3.

90. *Leptostomopsis systylia* (Müll.Hal.) J.R.Spence & H.P.Ramsay., Phytologia 87(2): 70.2005. *Bryum systylium* Müll.Hal., Syn.Musc.Frond. 1(2): 320. 1848 (Bryaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on soil rich in lime, 28.xi.2023, Manju Sharma S31B1.

91. *Leucomium decolyi* Broth. ex Gangulee, Mosses E. India 6: 1528. 1977. *Symphysodontella borii* Dixon J. Bombay Nat. Hist. Soc. 39: 781. 1937 (Leucomiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Julla waterpoint 74.46° E, 33.03° N, 502.23 m, growing on soil, 5.iii.2023, Manju Sharma S1B2.

92. *Longiella distichacea* (Mitt.) J.T.Wynns, Bryologist 123(4): 639.2020. *Stereodon distichaceus* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2): 105. 1859 (Neckeraceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, BGSBU, 74.34° E, 33.39° N, 1,176.9 m, growing on soil, 11.x.2023, Manju Sharma AS30B1.

93. *Molendoa roylei* (Mitti.) Broth., Nat. Pflanzenfam. 1(3): 391.1902. *Anoectangium roylei* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1: 30. 1859 (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Breri, 74.24° E, 33.15° N, 565.65 m, growing in rock cervices,15.x.2022, Manju Sharma S20B6.

94. *Myurium borii* (Dixon) Magill, J. Hattori Bot. Lab. 48: 68. 1980. (Myuriaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Channi Prat, 74.47° E, 33.07° N, 542.6 m, growing on soil, 27.ii.2022, Manju Sharma S26B3.

95. *Orthomnion javense* (M.Fleisch.) T.J.Kop., Ann. Bot. Fenn. 17: 53. 1980. *Mnium javense* M. Fleisch, Musci Buitenzorg 2: 585. 1904 (Mniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on soil, 28.xi.2023, Manju Sharma S31B1.

96. *Orthomnion* Wilson, Hooker's J. Bot. Kew Gard. Misc. 9: 368. 1857 (Mniaceae)

Habitat: India, Jammu & Kashmir, Rajouri District, non- epilithic, 1,047 m (Sharma et al. 2016).

97. *Oxyrrhynchium swartzii* (Turner) Warnst., Krypt.-Fl. Brandenburg, Laubm. 2: 784.1905. *Hypnum swartzii* Turner, Muscil. Recent. Suppl. 2: 104. 1812 (Brachytheciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Mangalnar, 74.25° E, 33.44° N, 1,238.5 m, growing on rocks, 7.xi.2023, Manju Sharma S43B5.

98. *Oxyrrhynchium vagans* (A.Jaeger) Ignatov & Huttunen., Arctoa 11: 273. 2002 [2003]. *Rhynchostegium vagans* A.Jaeger, Ber. Thätigk. St. Gallischen Naturwiss.

Ges. 1876-77: 369. 1878 (Brachytheciaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on bark, 18.ii.2022, Manju Sharma S31B4.

99. *Papillidiopsis luxurians* (Dozy &Molk.) W.R.Buck & B.C.Tan, Acta Bryolichenol. Asiat. 1: 12. 1989[1990]. *Hypnum luxurians* Dozy & Molk. Musc. Frond. Archip. Ind.: 12. 1844 (Sematophyllaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Panglote, 74.32° E, 33.27° N, 825.24 m, growing on soil, 2.iii.2022, Manju Sharma S28B1.

100. *Philonotis angusta* Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1: 61. 1859. (Bartramiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Budhal, 74.43° E, 33.38° N, 1,560.52 m, growing on soil, 2.iii.2022, Manju Sharma S32B3.

101. *Philonotis mollis* (Dozy &Molk.) Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1: 60. 1859. *Bartramia mollis* Dozy & Molk., Musc. Frond. Archip. Ind.: 2. 1844 (Bartramiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Kuldabi, 74.42° E, 33.02° N, 608.45 m, growing on soil, 5.iii.2023, Manju Sharma S12B3.

102. *Philonotis turneriana* (Schwägr.) Mitt, J. Proc. Linn. Soc., Bot., Suppl. 1:62.1859. *Bartramia turneriana* Schwägr., Sp. Musc. Frond., Suppl. 3, 1(2): 238. 1828 (Bartramiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on soil, 18.ii.2022, Manju Sharma S31B1.

103. *Plagiobryum zieri* (Dicks. ex Hedw.) Lindb., Öfvers. Kongl. Vetensk.-Akad. Förh. 19(10): 606. 1862 [1863]. *Bryum zieri* Dicks ex Hedw, Sp.Musc.Frond.: 182. 1801 (Bryaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Julla waterpoint, 74.46° E, 33.03° N, 502.23 m, growing on soil rich in lime, 5.iii.2022, Manju Sharma S1B4.

104. *Plagiomnium japonicum* (Lindb.) T.J. Kop., Ann. Bot. Fenn. 5: 146. 1968. *Mnium japonicum* Lindb., Contr. Fl. Crypt.As,: 226. 1872[1873] (Mniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Thanamandi, 74.36° E, 33.53° N, 1,708.65 m, growing on soil, 28.xi.2023, Manju Sharma S31B3.

105. *Pohlia elongata* Hedw., Sp. Musc. Frond.: 171. 1801 (Mniaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Jullawaterpoint, 74.46° E, 33.03° N, 502.23 m, growing on soil, 5.iii.2022, Manju Sharma S1B3.

106. *Pseudokindbergia dumosa* (Mitt.) Min Li, Y.F.Wang, Ignatov & B.C.Tan., Cryptog., Bryol. 36(1): 61. 2015. *Hypnum dumosum* Mitt., J. Proc. Linn. Soc., Bot., Suppl, 1: 80. 1859 (Brachytheciaceae)

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.4° N, 1,780.32 m, growing on soil, 8.xi.2023, Manju Sharma S37B2.

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Sodapani, 74.25° E, 33.44° N, 1,238.5 m, growing on rocks, 8.xi.2023, Sharma and others S41B1.

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.47° N, 1,580.32 m, growing on rocks, 10.xi.2023, Manju Sharma S36B1.

110. *Rhodobryum roseum* (Hedw.) Limpr., Laubm. Deutschl. 2(20): 445. 1892. *Mnium roseum* Hedw. Sp. Musc. Frond.: 194. 1801 (Bryaceae)

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.4° N, 1,580.32 m, growing on soil, 8.xi.2023, Manju Sharma S37B4.

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Manjakote, 74.25° E, 33.4° N, 1,580.32 m, growing on soil, 8.xi.2023, Manju Sharma and Nazia Kouser S37B3 (Sharma et al. 2016 as *T. subintegra* Dixon).

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Specimen examined: India, Jammu & Kashmir, Rajouri District, epilithic, 1,047 m (Sharma et al. 2016).

114. *Trichostomum contractum* R.H.Zander., Bull. Buffalo Soc. Nat. Sci. 32: 92. 1993 (Pottiaceae)

Specimen examined: India, Jammu and Kashmir, Rajouri, Bakore, 74.51°E, 33.35°N, 1715.89 m, growing on rocks,9.11.2023, Manju Sharma and Nazia Kouser, S38B2.

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Sunderbani, Julla waterpoint 74.46° E, 33.03° N, 502.23 m, growing on rock rich in lime, 29.xi.2022, Manju Sharma S1B5.

117. *Weissia controversa* Hedw., Sp. Musc. Frond.: 67. 1801. (Pottiaceae)

Specimen examined: India, Jammu & Kashmir, Rajouri District, Sodapani, 74.25° E, 33.44° N, 1,380.89 m, growing on rocks, 5.x.2023, Manju Sharma and Nazia Kouser S41B1.

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Specimen examined: India, Jammu & Kashmir, Rajouri District, Peli, 74.45° E, 33.53° N, 702.72 m, growing in rock cervices, 25.ii.2022, Manju Sharma S2B3.

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COMMUNICATION

First successful post-release breeding of captive-bred White-rumped Vultures *Gyps bengalensis* (Accipitriformes: Accipitridae) in the wild at Buxa Tiger Reserve, India

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Abstract: The population of White-rumped Vulture *Gyps bengalensis* declined catastrophically across South Asia during the 1990s due to diclofenac poisoning, prompting captive-breeding programmes aimed at eventual species recovery through reintroduction. Between 2021 and 2023, the Buxa Vulture Conservation Breeding Centre and Aviary in West Bengal released 31 captive-bred individuals into Buxa Tiger Reserve. In 2023, six released birds formed three pairs and constructed nests; one pair (tags N3 ♂ and P6 ♀) successfully hatched and fledged a chick after a 112-day nestling period in 2024. The two remaining nests failed during incubation, likely due to first-breeder failure. This represents the first confirmed post-release reproduction of captive-bred *Gyps bengalensis* in India, and the second documented site globally — successful breeding by captive-bred released birds was previously reported only from Nepal. This observation provides initial evidence that captive-bred individuals can successfully reproduce when released into an NSAID-safe landscape.

Keywords: Conservation breeding, Critically Endangered, Diclofenac, NSAID-safe zone, platform transmitter terminal, reintroduction, satellite telemetry, vulture conservation.

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INTRODUCTION

The White-rumped Vulture *Gyps bengalensis* was once among the most abundant large scavenging raptors of the Indian subcontinent, but populations declined by more than 99% during the 1990s and early 2000s due to poisoning from the veterinary non-steroidal anti-inflammatory drug (NSAID) diclofenac (Oaks et al. 2004; Shultz et al. 2004; Prakash et al. 2007), and the species is currently listed as 'Critically Endangered' (IUCN 2024). In response, a national conservation breeding programme was initiated in India in the early 2000s with the dual aim of preventing extinction and supporting future reintroductions once environmental threats had been mitigated (MoEF 2006).

While captive breeding and release have been achieved at multiple Indian centres, evidence of successful post-release reproduction by captive-bred individuals — a key benchmark of behavioural competence and ecological adaptation — has remained largely undocumented. Between 2021 and 2023, 31 captive-bred White-rumped Vultures were released from the Buxa Vulture Conservation Breeding Centre and Aviary (BVCBC&A) into Buxa Tiger Reserve, West Bengal. Here we report the first confirmed case of successful post-release breeding by captive-bred White-rumped Vultures in India and discuss its implications in the context of comparable vulture reintroduction programmes worldwide.

MATERIALS AND METHODS

Study Area

The study was conducted in Buxa Tiger Reserve (760.87 km²), West Bengal, India, bordered by Bhutan to the north and Assam to the east. The reserve lies at the junction of the Central Himalayas, Lower Gangetic Plains, and Brahmaputra Valley (NTCA 2016), with an elevation of 60–1,750 m and a tropical moist deciduous forest dominated by Sal *Shorea robusta* (Image 1). The breeding season of White-rumped Vultures in the region typically extends from October to May, with egg-laying between October and December and fledging by April–May (Manigandan et al. 2024).

Release and tagging

The BVCBC&A, located at Rajabhatkhawa village within Buxa Tiger Reserve, was established by the Forest Department, Govt. of West Bengal, to revive the wild populations of selected vulture species through conservation breeding. The centre maintains populations of three Critically Endangered *Gyps* species of vultures, namely, the White-rumped Vulture *Gyps bengalensis*, Slender-billed Vulture *Gyps tenuirostris*, and Long-billed Vulture *Gyps indicus* (Table 1); however, to date only captive-bred White-rumped Vultures have been released. Sub-adult captive-bred White-rumped Vultures (2–4 years old) bred at the BVCBC&A under standard conservation-breeding protocols were selected for release. Birds were transferred to a 30.48 × 12.19 × 6.10 m pre-release aviary in the reserve core (Image 2) three months prior to release for acclimatisation; food was provided both inside and outside the aviary to encourage interaction with wild conspecifics (Terrasse et al. 2004). All the birds were previously fitted with polyvinyl chloride coloured leg rings and microchips as identification. One month before release, each bird was fitted with wing tags and a 70 g solar-powered Platform Transmitter Terminal (PTT; Microwave Telemetry Inc., Columbia, MD, USA) attached using the thoracic X-strap method (Anderson et al. 2020), with linen thread sewn through the sternum cross-point as a biodegradable weak link. Total device weight (~85 g) remained well below 3% of body mass (birds 4.2–5.2 kg; Kenward 2001). The entire conservation breeding of vultures at the centre and the release of captive-bred birds with PTT are approved by the Government of West Bengal. After attaching the PTTs, harness-related abnormalities in flight, feeding, preening, and bathing were monitored in the pre-release aviary; none were observed in the 31 individuals. Subsequent long-distance movements across Nepal, Bhutan, Assam, and the Bangladesh border, together with successful breeding, further confirmed unimpaired function. PTT detachment generally occurred 4–5 years post-release. Releases occurred in 2021 (n = 10), 2022 (n = 10), and 2023 (n = 11).

NSAID safety surveys

Under-cover veterinary-NSAID availability surveys were conducted in three districts of West Bengal surrounding Buxa Tiger Reserve (Alipurduar, Coochbehar, Jalpaiguri) in 2021–22 (n = 42 pharmacies) and 2023–24 (n = 44 pharmacies), as part of a long-term surveillance programme operating within a 100-km radius of the BVCBC&A since 2009. Surveys followed the covert two-person decoy protocol developed for the multi-country South Asian NSAID surveillance programme (Cuthbert et al. 2011; Galligan et al. 2020): a local field staff member, posing as a cattle owner, requested *"a painkiller for an injured cow"* from each pharmacy without naming any

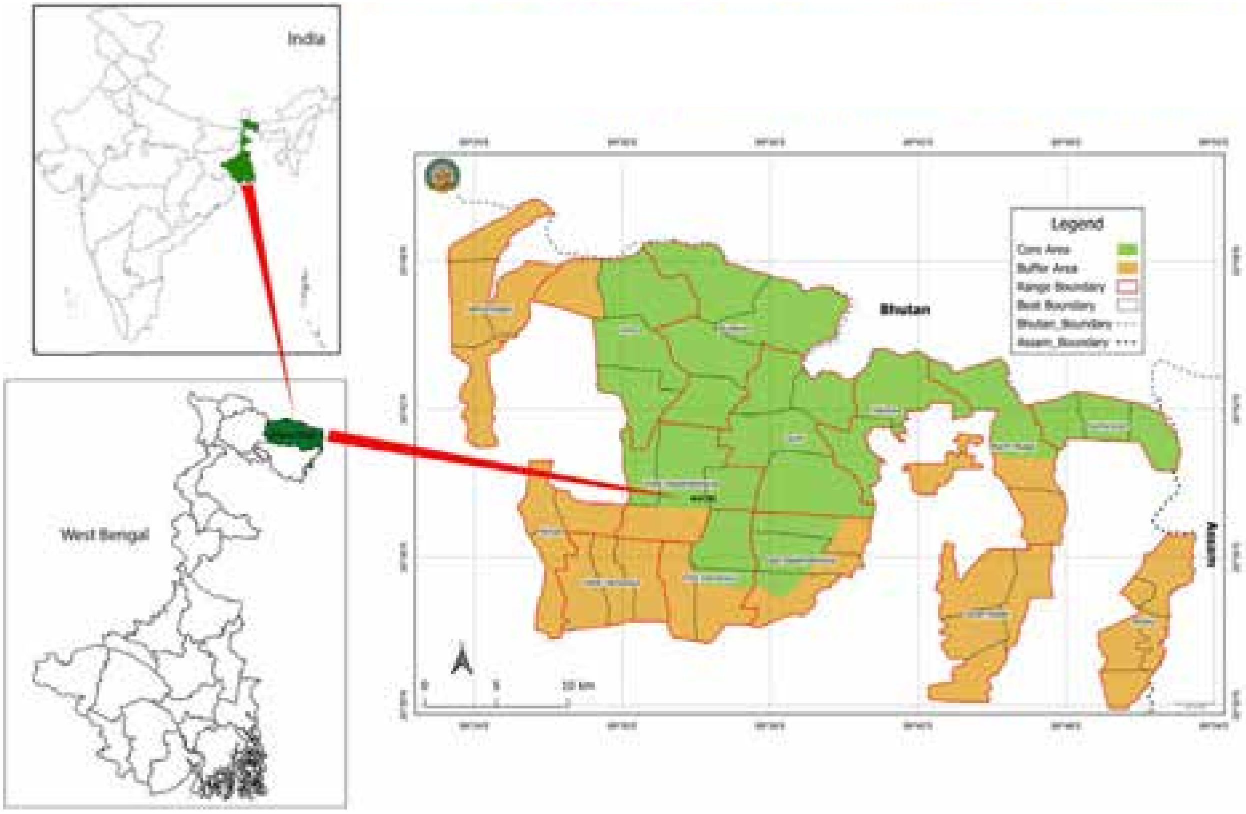

Image 1. Location of the Buxa Vulture Conservation Breeding Centre and Aviary (BVCBC&A), Rajabhatkhawa.

specific drug, and the first drug offered was purchased. The active ingredient of each drug was identified from the manufacturer's product labelling and consolidated at BVCBC&A. No diclofenac was offered or dispensed in any of the 86 pharmacies surveyed across the two release-period rounds.

Image 2. Pre-release aviary of the Buxa Vulture Conservation Breeding Centre and Aviary (BVCBC&A), Rajabhatkhawa.

Post-release monitoring

Of the 31 captive-bred individuals released between 2021 and 2023, six birds formed three breeding pairs by the 2023 breeding season; the remainder did not engage in breeding behaviour during the study period.

Released birds were monitored throughout by two biologists and four trained field staff using telemetry, ground observation, and camera trapping, with increased intensity during the breeding season (October–May). A pair was defined as two GPS-tagged individuals consistently co-locating at a nest tree with observed pair-bonding behaviour (displays, copulation, nest-material collection, and nest building).

PTT locations were monitored regularly; a stationary signal persisting for more than 48 hours triggered immediate deployment of a ground-truthing team to verify the status of the individual (living, sick, injured,

Table 1. Stock-population of vultures at the Buxa Vulture Conservation Breeding Centre & Aviary (BVCBC&A), Rajabhatkhawa, in 2021.

Vulture Species	Wild-caught	Captive-bred	Total
White-rumped Vultures	42	51	**93**
Slender-billed Vultures	12	6	**18**
Long-billed Vultures	14	18	**32**
Total	**68**	**75**	**143**

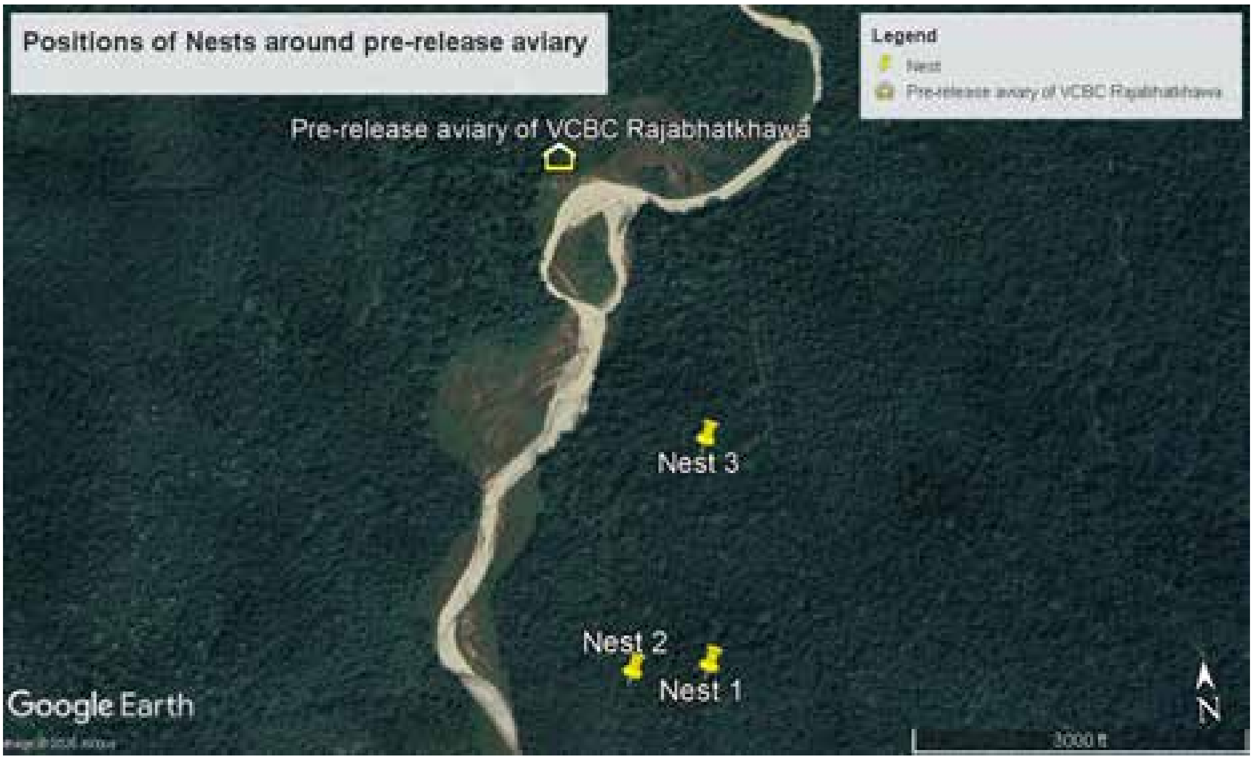

Image 3. Satellite image showing locations of nests around the pre-release aviary in 2023 (Google Earth Image).

Table 2. Summary of nesting attempts by released White-rumped Vultures in Buxa Tiger Reserve (2023–2024).

Nest ID	Pair (Tag ID)	Nest Detection Date	Egg Detection Date	Outcome	Key Observations
Nest 1	P3 (♂) – P2 (♀)	25 Nov 2023	6 Dec 2023	Failed	Activity ceased during incubation (3–6 weeks); no disturbance recorded
Nest 2	N3 (♂) – P6 (♀)	1 Dec 2023	1 Dec 2023	Successful	Chick hatched ~20 Jan 2024; fledged 11 May 2024 (~112 days observed); nest ~1.56 km from aviary
Nest 3	N5 (♂) – N12 (♀)	15 Dec 2023	26 Dec 2023	Failed	Activity ceased during incubation; cause undetermined

dead or PTT detachment). Whenever any carcass of the released birds was recovered, post-mortem examination was carried out by qualified veterinarians at BVCBC&A or, in collaboration with veterinary services of the country concerned for cross-border cases (as carcasses were found in Bhutan). Across the post-release period (2021–2025), seven mortalities of released birds were documented, attributed to leopard predation, electrocution, slingshot injury, traumatic shock and starvation; none were related to NSAID poisoning. Visceral gout—the pathognomonic indicator of NSAID poisoning in Gyps vultures (Oaks et al. 2004)—was not detected in any case where post-mortem examination was conducted.

Observations

Released White-rumped Vultures showed high survival, normal ranging behaviour, integration with wild conspecifics, and species-typical foraging. The first cohort of 10 birds released in 2021 reached breeding age by 2023. During the 2023 breeding season, several pairs from this cohort showed nesting behaviour, including pair displays, copulation, and nest-material collection. GPS data analysis identified frequent visits to clustered locations within a 2-km radius of the pre-release aviary, leading to the discovery of three nests, all built on silk-cotton trees *Bombax ceiba* (Image 3) at approximately 30 m height with species-typical architecture. Nest-site access was constrained by terrain and the presence of Asian Elephants *Elephas maximus* and Gaurs *Bos gaurus*, but visual monitoring was conducted from a distance.

Nest details and outcomes are summarised in Table 2. Eggs were confirmed in all three nests between late November and early December 2023. Two nests (Nest

Image 4a. Satellite image showing movement pattern of P6 from December 2023 to March 2024.

Image 4b. Satellite image showing movement pattern of N3 from December 2023 to March 2024.

Image 5. First wild-fledged White-rumped Vulture nestling at Nest 2, BVCBC&A reintroduction programme, Buxa Tiger Reserve. © VCBC, Buxa.

1 and Nest 3) failed during incubation, with parental visits ceasing by mid-January 2024 — approximately 3–6 weeks after egg confirmation and well before expected hatching dates. No signs of predation or anthropogenic disturbance were recorded. The identified nests were visited at least weekly by the ground monitoring team, while telemetry data were checked continuously to confirm the presence of breeding adults at the nests. Because nests were located approximately 30 m above ground within the reserve core, direct visual observation of eggs from the ground was not possible. Initial presence of an egg was inferred from the onset of sustained incubation behaviour of the breeding birds, and when the birds were found not visiting the nests for more than 24 hours (confirmed by telemetry data), a short unmanned aerial vehicle (UAV) flight was conducted to check the condition of the nest, presence of an egg or any other sign of nest disturbance. Nest structures were inspected (with binoculars) for damage during each ground visit. However, no indications of nest disturbance, structural damage, or predator activity were recorded at any of the three nests.

The successful pair, wing-tagged N3 (♂) and P6 (♀), were 3.1 years old when released in 2021. Their initial visit to the nesting tree was confirmed using telemetry in the second week of October 2023 (Image 4a,b). Hatching at Nest 2 was confirmed on 20 January 2024 through the first recorded begging calls — yielding an observed incubation period of approximately 50 days, slightly shorter than the 56 days reported for the species (Naoroji 2006). The discrepancy likely reflects egg laying occurring a few days before first visual confirmation of the egg.

The nestling was first sighted from the ground on 23 February 2024, when approximately 34 days old (Images 5 & 6). It fledged on 11 May 2024 after 112 days, from a nest located 1.56 km south-east of the pre-release aviary. The fledged juvenile was subsequently observed near the pre-release aviary on 3 July 2024.

Image 6. An adult of the successful breeding pair attending the nestling at Nest 2, Buxa Tiger Reserve. © VCBC, Buxa.

DISCUSSION

These observations provide early evidence that captive-bred White-rumped Vultures released into the wild can survive, integrate into local landscapes, attain reproductive maturity within expected timeframes, and successfully reproduce. Nesting was concentrated within ~2 km of the pre-release aviary, consistent with strong initial site fidelity during early post-release establishment. The use of *Bombax ceiba* and species typical nest architecture indicates appropriate habitat selection by released individuals. The successful pair fledged a chick after approximately 112 days, slightly longer than the 104-day nestling period reported in Pakistan (Gilbert et al. 2002), most likely reflecting delayed initial detection of the nestling rather than extended development. The two failed nests are most plausibly attributed to first-breeder failure, consistent with the well-documented pattern of inexperienced breeders systematically performing more poorly than experienced ones (Cam & Monnat 2000).

This timeline can be contextualised against other vulture reintroduction programmes. Eurasian Griffon Vultures *Gyps fulvus* released in southern France from 1981 produced their first successful breeding in 1982 and grew to ~110 pairs by 2003 (Terrasse et al. 2004); Cinereous Vultures *Aegypius monachus* released in the same landscape from 1992 produced their first successful breeding pair four years later (Terrasse et al. 2004). In Bulgaria, reintroduced Cinereous Vultures showed pair formation one year after the first releases and produced their first wild-fledged chick three years post-release (Ivanov et al. 2023). For White-rumped Vultures specifically, releases in Nepal beginning in November 2017 produced the first known post-release breeding events of this species in the wild (Mallord et al. 2024); the present case at Buxa is the second documented site globally and the first in India. The Buxa programme — first wild-fledged chick three years after the first release — is consistent with timelines documented in these comparable programmes, and demonstrates that captive-bred *Gyps bengalensis* can adapt rapidly to free-ranging conditions when released into an NSAID-safe landscape.

Limitations of the study

Several limitations apply. The sample is small (three nests, one successful breeding event), and the findings should be considered preliminary rather than representative of population-level trends. Direct nest access was restricted by terrain and large-mammal presence, introducing uncertainty into the precise timing of egg-laying and hatching. The causes of nest failure could not be determined directly. Continued monitoring will be required to establish whether early-stage spatial clustering reflects long-term habitat preference or transient establishment behaviour.

CONCLUSION

This first documented post-release breeding by captive-bred White-rumped Vultures in India represents a critical milestone for the recovery of a Critically Endangered species, supporting the underlying premise of the Indian Vulture Action Plan (MoEF 2006). Sustained release effort, ongoing monitoring, and continued NSAID surveillance in the release landscape will be essential to consolidate this success into a self-sustaining wild population and to extend reintroduction efforts to other South Asian *Gyps* species.

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COMMUNICATION

A checklist of the avifauna of the Noakhali Science and Technology University campus, Noakhali, Bangladesh

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Abstract: A study was conducted on the avifauna of the Noakhali Science and Technology University (NSTU) campus, Noakhali, Bangladesh, from October 2023 to July 2024. Ninety species of birds belonging to 44 families and 13 orders were identified, of which 51 species were non-passerines, and 39 species were passerines. Among the birds, 73 species were residents, 12 species were winter visitors, four species were recorded as both residents and winter visitors, and one species was a passage migrant. Of the recorded birds, three species were very common, six species were common, 18 species were uncommon, 35 species were few, and 28 species were rare. The local status of these birds in NSTU has also been compared with their national status in Bangladesh. Anthropogenic activities such as human interventions, construction projects, pollution, agriculture, and deforestation were prevalent at the NSTU campus, posing potential threats to birds. Therefore, it is essential to implement appropriate measures to conserve this unique habitat.

Keywords: Anthropogenic activities, birds, habitat fragmentation, Lesser Whistling Duck, point count, relative frequency.

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Author contribution: ARJ and TA conceptualized and designed the study. ARJ and MRR conducted the field surveys and compiled the data. ARJ and TA analyzed the data and prepared the manuscript. All authors reviewed and approved the final manuscript.

INTRODUCTION

Bangladesh has rich plant and animal diversity because of its fertile soil and moderate climatic conditions. The sub-tropical monsoon climate shows three climatological seasons: pre-monsoon (hot) March to May; monsoon (rainy season) - June to October, and winter (dry) - November to February (Ahmad 1968). Bangladesh, covering a land mass of 147,570 km^2, has 650 bird species; of these, 302 are residents, 176 are seasonal visitors, and 143 are vagrants (Siddiqui et al. 2008).

One of the most important ecological indicators for determining habitat quality, maintaining the trophic level, and evaluating the general health of an ecosystem is the diversity of avifauna (Whelan et al. 2008; Mathibalan et al. 2026). They are highly susceptible to changes in the habitat in which they live due to people's disrespect for their protection and conservation (Sarker et al. 2001). Birds provide all four categories of ecological services: provisioning, regulating, cultural, and supporting (Whelan et al. 2008). Through the services offered by birds, they indirectly and directly benefit humans as bio-indicators, pollinators, seed dispersers, predators, scavengers, and ecosystem engineers (Sekercioglu 2006; Wenny et al. 2011).

The diversity of avifauna in different educational institution campuses of Bangladesh has been studied by many authors. Mohsanin & Khan (2009) worked on the status and seasonal occurrence of the birds in Jahangirnagar University Campus, Dhaka; whereas Reza et al. (2012) recorded the birds of the Rajshahi University Campus, Rajshahi. Chowdhury et al. (2014) conducted a study on the checklist of avian fauna of the Dhaka University Campus, Dhaka; while Kabir et al. (2017) documented a checklist of the avian fauna of the Chittagong University campus, Chittagong.

Noakhali Science and Technology University (NSTU) is a notable habitat for plants and birds. This habitat functions as a feeding, resting and breeding ground for many birds. In addition to birds, various amphibians, reptiles and mammals are also observed in this habitat. However, no recent work has been done on the avifauna of the NSTU campus. So, the present work was undertaken to list the avifauna of the NSTU campus with special reference to their country status, relative frequency and anthropogenic threats, which will provide some basic information for future investigation and conservation of the birds in the NSTU campus.

MATERIALS AND METHODS

STUDY AREA

NSTU is a public university in the coastal terrain of Noakhali, Bangladesh. It is situated at Sonapur, Noakhali Sadar Upazila, which is 8 km south of Maijdee Town (22.792^o N, 91.102^o E; Image 1). The NSTU campus covers a land area of 101 ac (0.41 km^2). The total area constitutes 5% permanent wetlands, 10% seasonal wetlands , 15% agricultural lands, 5% playgrounds, 35% constructed storied building sites, and 30% other areas. This area is adorned with beautiful natural resources. Both indigenous and exotic plant species inhabit this area. The study area is covered with a wide variety of trees like Haritaki *Terminalia chebula*, Koroi *Albizia procera*, Jarul *Legestroemia speciosa*, Jhau *Tamarix dioica*, Sissu *Dalbergia sissoo*, Mandar *Erythrina variegate*, Banyan *Ficus benghalensis*, and Acacia *Acacia auriculiformis*. Fruit-bearing plants, such as Mango *Mangifera indica*, Jackfruit *Artocarpus heterophylus*, Coconut *Cocos nucifera*, Boroi *Zizyphus mauritiana*, Banana *Musa acuminata*, and Papaya *Carica papaya* are also seen in this area. In the agricultural lands, different types of crops are cultivated, such as, Rice *Oryza sativa* and Sunflower *Helianthus* sp. There are some experimental plots in which Watermelon *Citrullus lanatus*, Dragon Fruit *Selenicereus* sp., Chilli *Capsicum* sp., Carrot *Daucus carota*, and Tomato *Solanum lycopersicum* are cultivated.

The area is under a tropical climate, and it has significant rainfall most months, with a short dry season. The monthly temperature, humidity and precipitation were varied during the study period. May recorded the highest temperature at (41°C), while the lowest temperature (18°C) was observed in January; the maximum humidity (80%) was in July and the minimum (52%) in February. July experienced its highest level of precipitation, reaching 671 mm.

Methods

The study was conducted from October 2023 to July 2024. Bird surveys were conducted on four days per month. The timing of the fieldwork was selected based on the visibility of avian species. A total of 40 days were spent bird-watching throughout the study period. In addition to that some human disturbances were also documented during the present study.

Regular surveys were conducted along existing roads and walking trails of the NSTU campus from 0700–1700 h. Birds were surveyed using point count method, with a distance of 100 m between adjacent points (Bibby et al. 2000). The duration at each point for counting signs,

Image 1. Map of the Noakhali District showing the study area.

recording calls, and observing birds was 5 min. Bushnell (10x42) binocular was used to observe bird species. Whenever a bird called, flew, moved around plants and trees, or nested on a tree or bushes, pictures and video clips were taken whenever feasible to identify birds accurately at the generic and species level. Opportunistic sightings were also included in the checklist. The recorded birds were identified with the help of the books (Siddiqui et al. 2008; Grimmett et al. 2021).

The relative frequency of the available bird species has been assessed as very common (VC): seen during 80–100 % of the field visits; common (C): found during 50–79 % of the field visits; uncommon (UC): observed during 20–49 % of the field visits; few (F): met less than 19% field visits and rare (R): found occasionally (Khan 1982; Kabir et al. 2017). All the avian species have been categorized as residents, winter migrants, resident and winter migrants, and passage migrants following Siddiqui et al. (2008).

RESULTS

Species composition

Ninety species of birds representing 44 families and 13 orders were observed from the NSTU campus during October 2023–July 2024; of which 51 (56.67%) species were non-passerine and 39 (43.33%) passerine (Table 1). Among the recorded 90 species of birds, 25 species are water birds. The resident birds represented the major composition (73 species, i.e., 81.11%) in the campus and passage migrants constituted the lowest proportion (1 species, i.e., 1.11%) (Image 3). Among the orders, Passeriformes constituted the highest number (39 species, i.e., 43.33%) and three orders (Suliformes, Apodiformes and Anseriformes) represented one (1.11%) species each (Table 1; Image 2).

Among the 44 families, Ardeidae had the dominating number, nine species (10%) of Rallidae five species (5.55%); Sturnidae, Cuculidae, Columbidae, and Picidae had four species (4.44%) each; Corvidae, Dicruridae, Nectariniidae, Estrildidae, Cisticolidae, Accipitridae, Alcedinidae, and Charadriidae had three species (3.33%) each; Muscicapidae, Motacillidae, Megalaimidae, Scolopacidae, and Strigidae had two species (2.22%) each; and all rest of the families had one species (1.11%) (Table 1).

Relative frequency

Frequency of observation showed that three species were very common, six species were common, 18 species were uncommon, 35 species were few and 29 species were rare. The status of these birds in NSTU has also been compared with the country's status (Image 3).

Species classified under the few category constituted the largest proportion of the assemblage, accounting for 38.89% (35 species), and the very common species represented the lowest (3.33%, 3 species) in the NSTU (Image 4). The Black Drongo *Dicrurus macrocercus*, Oriental Magpie-Robin *Copsychus saularis* and Red-vented Bulbul *Pycnonotus cafer* were recorded as very common bird species.

Problems and threats

The anthropogenic activities such as habitat fragmentation, construction and infrastructure development, destruction of habitat, pollution, agricultural intensification, overuse of agrochemicals, and subsistence hunting of birds have been documented to negatively impact birds and their activity patterns in the study area. Water, sound and plastic pollution, pesticides, and heavy metals harm birds directly and indirectly. Pesticides can be toxic, and birds often ingest plastics or get entangled in them. Structural development, agriculture, deforestation, grass and reed burning and other land use changes directly destroy the natural habitats of birds. These activities impacted birds through habitat fragmentation. Direct human threats like poaching, hunting, stone throwing, etc., also harm water and forest birds. Because it is still evolving, the avifauna has a hard time figuring out where to nest, where to

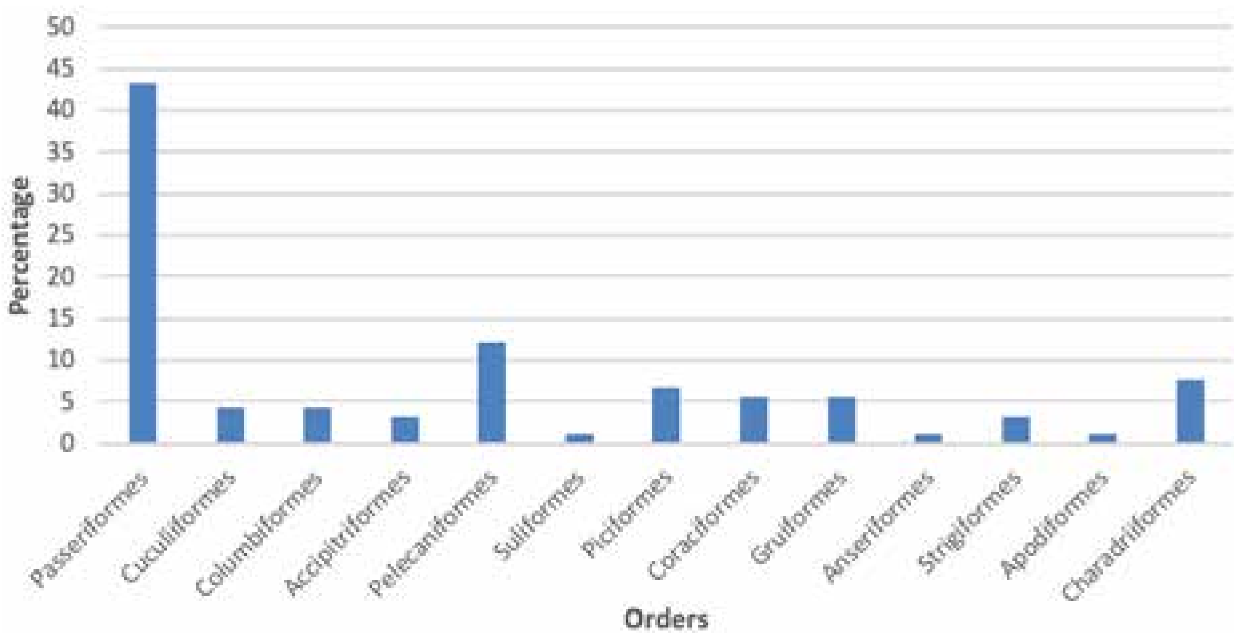

Image 2. Birds under different orders observed in the NSTU campus.

Table 1. Observed bird species at the NSTU campus, Noakhali, Bangladesh.

	Common name	Scientific name	Family	NSTU status	Relative frequency (%)	Country status
	Order: 1. Passeriformes					
1	Rufous Treepie	*Dendrocitta vagabunda* (Latham, 1790)	1. Corvidae	F	10	Resident
2	Large-billed Crow	*Corvus macrorhynchos* (Wagler, 1827)		R	7.5	Resident
3	House Crow	*Corvus splendens* (Vieillot, 1817)		F	15	Resident
4	Black-hooded Oriole	*Oriolus xanthornus* (Linnaeus, 1758)	2. Oriolidae	UC	32.5	Resident
5	White-throated Fantail	*Rhipidura albicollis* (Vieillot, 1818)	3. Rhipiduridae	UC	32.5	Resident
6	Bronzed Drongo	*Dicrurus aeneus* (Vieillot, 1817)	4. Dicruridae	F	12.5	Resident
7	Black Drongo	*Dicrurus macrocercus* (Vieillot, 1817)		VC	82.5	Resident
8	Ashy Drongo	*Dicrurus leucophaeus* (Vieillot, 1817)		F	10	Winter visitor
9	Small Minivet	*Pericrocotus cinnamomeus* (Linnaeus, 1766)	5. Campephagidae	F	17.5	Resident
10	Common Iora	*Aegithina tiphia* (Linnaeus, 1758)	6. Aegithinidae	R	7.5	Resident
11	Barn Swallow	*Hirundo rustica* (Linnaeus, 1758)	7. Hirundinidae	R	7.5	Resident +Winter visitor
12	Oriental Magpie-Robin	*Copsychus saularis* (Linnaeus, 1758)	8. Muscicapidae	VC	85	Resident
13	Red-throated Flycatcher	*Ficedula albicilla* (Pallas, 1811)		R	5	Winter visitor
14	Orange-headed Thrush	*Geokichla citrina* (Latham, 1790)	9. Turdidae	R	5	Resident
15	House Sparrow	*Passer domesticus* (Linnaeus, 1758)	10. Passeridae	C	60	Resident
16	White Wagtail	*Motacilla alba* (Linnaeus, 1758)	11. Motacillidae	F	10	Winter visitor
17	Citrine Wagtail	*Motacilla citreola* (Pallas, 1776)		R	5	Winter visitor
18	Baya Weaver	*Ploceus philippinus* (Linnaeus, 1766)	12. Ploceidae	F	12.5	Resident
19	Indian Pied Starling	*Gracupica contra* (Linnaeus, 1758)	13. Sturnidae	C	62.5	Resident
20	Chestnut-tailed Starling	*Sturnus malabaricus* (Gmelin, 1789)		C	50	Resident
21	Jungle Myna	*Acridotheres fuscus* (Wagler, 1827)		F	10	Resident
22	Common Myna	*Acridotheres tristis* (Linnaeus, 1766)		F	17.5	Resident
23	Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	14. Cisticolidae	UC	37.5	Resident
24	Plain Prinia	*Prinia inornata* (Sykes, 1832)		R	7.5	Resident
25	Dark-necked Tailorbird	*Orthotomus atrogularis* (Temminck, 1836)		F	12.5	Resident
26	Blyth's Leaf Warbler	*Phylloscopus reguloides* (Blyth, 1842)	15. Phylloscopidae	F	12.5	Winter visitor
27	Blyth's Reed Warbler	*Acrocephalus dumetorum* (Blyth, 1849)	16. Acrocephalidae	R	7.5	Winter Visitor
28	Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus, 1766)	17. Pycnonotidae	VC	85	Resident
29	Red-whiskered Bulbul	*Pycnonotus jocosus* (Linnaeus, 1758)		R	7.5	Resident
30	Purple-rumped Sunbird	*Leptocoma zeylonica* (Linnaeus, 1766)	18. Nectariniidae	UC	22.5	Resident
31	Purple Sunbird	*Cinnyris asiaticus* (Latham, 1790)		F	10	Resident
32	Little Spiderhunter	*Arachnothera longirostra* (Latham, 1790)		R	5	Resident
33	Chestnut Munia	*Lonchura atricapilla* (Vieillot, 1807)	19. Estrildidae	UC	32.5	Resident
34	White-rumped Munia	*Lonchura striata* (Linnaeus, 1766)		UC	20	Resident
35	Scaly-breasted Munia	*Lonchura punctulata* (Linnaeus, 1758)		UC	25	Resident
36	Great Tit	*Parus major* (Linnaeus, 1758)	20. Paridae	F	10	Resident
37	Long-tailed Shrike	*Lanius schach* (Linnaeus, 1758)	21. Laniidae	UC	30	Resident
38	Common Woodshrike	*Tephrodornis pondicerianus* (Gmelin, 1789)	22. Vangidae	F	12.5	Resident
39	Indian White-eye	*Zosterops palpebrosus* (Temminck, 1824)	23. Zosteropidae	R	7.5	Resident

	Common name	Scientific name	Family	NSTU status	Relative frequency (%)	Country status
	Order: 2. Cuculiformes					
40	Asian Koel	*Eudynamys scolopaceus* (Linnaeus, 1758)	24. Cuculidae	F	10	Resident
41	Greater Coucal	*Centropus sinensis* (Stephens, 1815)		UC	35	Resident
42	Common Cuckoo	*Cuculus canorus* (Linnaeus,1758)		F	10	Passage migrant
43	Plaintive Cuckoo	*Cacomantis merulinus* (Scopoli, 1786)		R	5	Resident
	Order: 3. Columbiformes					
44	Rock Dove	*Columba livia* (Linnaeus, 1758)	25. Columbidae	UC	35	Resident
45	Eastern Spotted Dove	*Spilopelia chinensis* (Scopoli, 1786)		C	50	Resident
46	Eurasian Collared Dove	*Streptopelia decaocto* (Frivaldszky, 1838)		C	50	Resident
47	Red Collared Dove	*Streptopelia tranquebarica* (Hermann, 1804)		UC	42.5	Resident
	Order: 4. Accipitriformes					
48	Brahminy Kite	*Haliastur indus* (Boddaert, 1783)	26. Accipitridae	C	50	Resident
49	Black Kite	*Milvus migrans* (Boddaert, 1783)		F	12.5	Resident
50	Grey-headed Fish Eagle	*Icthyophaga ichthyaetus* (Horsfield, 1821)		F	10	Resident
	Order: 5. Pelecaniformes					
51	Indian Pond Heron	*Ardeola grayii* (Sykes, 1832)	27. Ardeidae	UC	22.5	Resident
52	Little Egret	*Egretta garzetta* (Linnaeus, 1766)		UC	22.5	Resident
53	Inter mediate Egret	*Ardea intermedia* (Wagler, 1829)		F	12.5	Resident
54	Grey Heron	*Ardea cinerea* (Linnaeus, 1758)		R	5	Resident +Winter visitor
55	Great White Egret	*Ardea alba* (Linnaeus, 1758)		UC	22.5	Resident
56	Cinnamon Bittern	*Ixobrychus cinnamomeus* (Gmelin, 1789)		F	12.5	Resident
57	Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)		F	12.5	Resident
58	Yellow Bittern	*Ixobrychus sinensis* (Gmelin, 1789)		R	7.5	Resident
59	Purple Heron	*Ardea purpurea* (Linnaeus, 1766)		R	5	Resident
60	Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	28. Threskiornithidae	R	5	Winter visitor
61	Asian Openbill	*Anastomus oscitans* (Boddaert, 1783)	29. Ciconiidae	F	10	Resident
	Order: 6. Suliformes					
62	Little Cormorant	*Microcarbo niger* (Vieillot, 1817)	30. Phalacrocoracidae	UC	22.5	Resident
	Order: 7. Piciformes					
63	Fulvous-breasted Woodpecker	*Dendrocopos macei* (Vieillot, 1818)	31. Picidae	F	12.5	Resident
64	Black-rumped Flameback	*Dinopium benghalense* (Linnaeus, 1758)		R	5	Resident
65	Common Flameback	*Dinopium javanense* (Ljungh, 1797)		R	5	Resident
66	Eurasian Wryneck	*Jynx torquilla* (Linnaeus, 1758)		R	2.5	Winter visitor
67	Lineated Barbet	*Psilopogon lineatus* (Vieillot,1816)	32. Megalaimidae	F	17.5	Resident
68	Blue-eared Barbet	*Psilopogon cyanotis* (Blyth, 1847)		F	10	Resident
	Order: 8. Coraciiformes					
69	Green Bee-eater	*Merops orientalis* (Latham, 1802)	33. Meropidae	UC	25	Resident
70	Common Kingfisher	*Alcedo atthis* (Linnaeus, 1758)	34. Alcedinidae	F	12.5	Resident
71	Stork-billed Kingfisher	*Pelargopsis capensis* (Linnaeus, 1766)		R	5	Resident
72	White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)		F	10	Resident
73	Common Hoopoe	*Upupa epops* (Linnaeus, 1758)	35. Upupidae	F	10	Resident

	Common name	Scientific name	Family	NSTU status	Relative frequency (%)	Country status
	Order: 9. Gruiformes					
74	Brown Crake	*Zapornia akool* (Sykes, 1832)	36. Rallidae	F	10	Resident
75	White-breasted Waterhen	*Amaurornis phoenicurus (*Pennant, 1769)		UC	25	Resident
76	Grey-headed Swamphen	*Porphyrio porphyrio* (Linnaeus, 1758)		F	17.5	Resident
77	Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)		R	5	Resident
78	Eurasian Coot	*Fulica atra* (Linnaeus, 1758)		R	5	Winter visitor
	Order 10. Charadriformes					
79	Wood Sandpiper	*Tringa glareola* (Linnaeus, 1758)	37. Scolopacidae	F	10	Winter visitor
80	Common Sandpiper	*Actitis hypoleucos* (Linnaeus, 1758)		F	10	Winter visitor
81	Bronze-winged Jacana	*Metopidius indicus* (Latham, 1790)	38. Jacanidae	UC	30	Resident
82	Grey-headed Lapwing	*Vanellus cinereus* (Blyth, 1842)	39. Charadriidae	F	10	Winter visitor
83	Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)		F	10	Resident
84	Kentish plover	*Charadrius alexandrinus* (Linnaeus, 1758)		R	5	Winter visitor
85	Greater Painted Snipe	*Rostratula benghalensis* (Linnaeus, 1758)	40. Rostratulidae	R	5	Resident
	Order: 11. Anseriformes					
86	Lesser Whistling Duck	*Dendrocygna javanica* (Horsfield, 1821)	41. Anatidae	F	12.5	Resident +Winter visitor
	Order: 12. Apodiformes					
87	Asian Palm Swift	*Cypsiurus balasiensis* (Gray, 1829)	42. Apodidae	R	7.5	Resident
	Order: 13. Strigiformes					
88	Spotted Owlet	*Athene brama* (Temminck, 1821)	43. Strigidae	R	5	Resident
89	Brown Boobook	*Ninox scutulata* (Raffles, 1822)		R	5	Resident
90	Barn Owl	*Tyto alba* (Scopoli, 1769)	44. Tytonidae	R	5	Resident

VC—very common | C—common | UC—uncommon | F—few | R—rare.

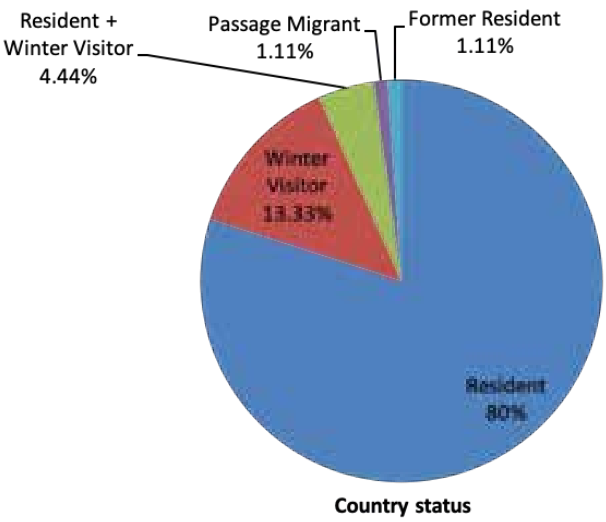

Image 3. Country status of the birds observed in the NSTU campus.

hide, or how to feed in this area. These problems might be affecting the bird species in the study area.

DISCUSSION

The NSTU campus, despite its small area, has a rich avian diversity. The study recorded 90 species, of which 25 species (27.78%) are waterbirds. It indicates that the wetlands of the study area are suitable as a foraging ground for the water birds. Compared to other major university campuses in Bangladesh, NSTU's diversity is competitive given its size. Previous studies have documented varying richness across the country. Rajshahi University campus observed a total of 159 species of birds across 36 families (Reza et al. 2012), whereas Chittagong University (CU) recorded 215 species across 63 families (Kabir et al. 2017). Dhaka University recorded 54 to 70 species recorded in different periods (Banu et al. 2016; Shome et al. 2022), and Jahangirnagar

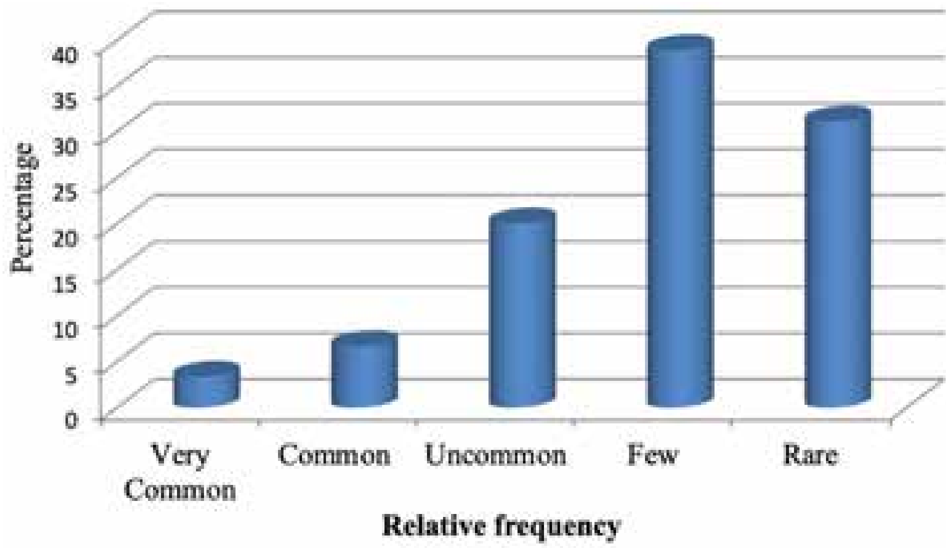

Image 4. Relative frequency of the birds observed in the Noakhali Science and Technology University campus.

University documented 78 species (Chowdhury et al. 2014) and 92 species (Ahsan & Khanom 2005).

Both resident and migratory birds were documented in the study area. Among them, the majority were residents. Brown Crake *Zapornia akool*, a rare bird (Grimmett et al. 2021) reported from the study area, is known as a former resident of Bangladesh (Siddiqui et al. 2008). From the Rajshahi University campus, Reza et al. (2012) observed 121 species of residents and 38 species of migratory birds; whereas Banu et al. (2016) reported 10 (19%) species as migrants and 44 (81%) as residents in the Dhaka University campus. According to Kabir et al. (2017), 74.42% of resident birds and 25.58% of local and seasonal migrants were observed in the Chittagong University Campus. These findings mirror the trends observed in other academic landscapes.

For most of the species, the relative frequency was categorized as few, whereas the least number of species was categorized as very common. In the Rajshahi University campus, Reza et al. (2012) found very common (30 species), common (30 species), fairly common (34 species), few (32 species) and rare (34 species). From the Dhaka University campus, Banu et al. (2016) recorded 14 (26%) species as very common, 7 (13%) species as common, 10 (19%) species as uncommon, and 23 (43%) species as rare; while Kabir et al. (2017) recorded 101 species were very common, 36 species as common, 29 species as uncommon, 22 species as few and 27 as rare from the Chittagong University campus. The smaller size of the study area might have influenced the frequency of observation of the birds on the campus.

Anthropogenic activities refer to the actions or processes originating from human activity that impact the environment, ecosystems or natural resources and destroy biodiversity, including avian populations (Miller & Spoolman 2012; Manigandan et al. 2021). These activities are responsible for excessive habitat degradation, reduce nesting sites, destroy feeding grounds, affect overall activity patterns, and break the migration rhythm of diversified avifauna. The waterbirds belonging to the orders Anseriformes, Pelecaniformes, and Charadriiformes are mostly impacted due to human disturbances (Byju et al. 2025). The present study documented that these disturbances have contributed to the excessive decline of the Lesser Whistling Duck *Dendrocygna javanica* and affected their migration rhythm. Some bird species from the orders Passeriformes, Piciformes, and Columbiformes are also impacted by extreme human intervention.

These findings align with global and local concerns regarding habitat loss as the leading cause of avian extinction (Fahrig 2001). Similar trends of habitat loss due to human activity have been recorded on Hatiya Island (Hossain et al. 2004) and in urban spaces like Ramna Park (Rajia et al. 2015). Without targeted management to mitigate hunting, fishing, and noise pollution, the avian richness of the NSTU campus remains at risk of significant decline.

CONCLUSION

The current study suggests that the NSTU campus possesses a wealth of biodiversity and has the potential to become a habitat for birds. However, anthropogenic threats such as clearing trees, pollution and agricultural intensification in their natural habitat could affect the breeding and other behavioural activities of birds. Restoration of the habitat is necessary to support birds' forage, shelter, and breeding to protect the avifauna of the NSTU campus. Key recommendations include planting fruit-bearing trees to attract several insectivorous and frugivorous birds to reside there. Consequently, in order to maintain the bird species and their population sustainability, awareness should be raised among the university's faculty, staff and students about the need to protect these exquisite creatures.

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COMMUNICATION

Record of the crambid moth *Aethaloessa calidalis* (Guenée, 1854) (Lepidoptera: Crambidae: Spilomelinae) from Chhattisgarh, India

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Abstract: *Aethaloessa calidalis* (Guenée, 1854) is a moth belonging to the family Crambidae, distributed across various states of India, yet it has remained unreported from Chhattisgarh. During a nocturnal light-trap survey at Semra Village, Dhamtari district, Chhattisgarh, one adult of this species was documented and identified using its distinctive orange-yellow wing patches, dark marginal shading, and orange abdomen with a black tip, matching published descriptions and photographic references. This constitutes the first state record of *Aethaloessa calidalis* from Chhattisgarh and extends its known distribution into central India. The finding highlights the value of continued moth monitoring to improve the state's moth inventories.

Keywords: Agroecosystem, biodiversity documentation, central India fauna, Dhamtari District, distribution record, faunal survey, moth fauna, light trap survey, range extension, species distribution.

Editor: Anonymity requested..

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Author contributions: AC: conceptualization, field investigation, species identification, photography, data analysis, literature review, and manuscript preparation. SG: conceptualization, study supervision, manuscript review, and editing.

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INTRODUCTION

Moths belong to the order Lepidoptera of class Insecta. They comprise around 88% of the order Lepidoptera, while remaining 12% comprise of butterflies (Pathania et al. 2021). Crambidae is one of the largest families of moths with 9,655 species described worldwide (Nieukerken et al. 2011). Members of this family show diverse adaptations and behavioural characteristics. Many of its species are serious agricultural pests and are found in and around agricultural fields (Pathania et al. 2021).

Aethaloessa calidalis (Guenée, 1854) is a small, brightly coloured moth belonging to the family Crambidae, subfamily Spilomelinae. It has characteristic orange-yellow wings with dark brown margins and an orange abdomen with dark purplish-brown terminal segment (Walker 1859). It is widely distributed across India, Nepal, Sri Lanka, Myanmar, Bhutan, China, Indonesia, Hong Kong, Africa (Yamanaka 1995; Kendrick 2002, Irungbam et al. 2016) Thailand, Papua New Guinea (Walker 1866), Tahiti (Wallengren 1860), Fiji (Felder et al. 1875), and Singapore (Hampson 1912b). In India, it has been reported from Andhra Pradesh, Tamil Nadu, Meghalaya, West Bengal (Reddy & Murthy 2021), Delhi (Komal et al. 2021), and Kerala (Mahesh et al. 2024). Despite its wide distribution, *Aethaloessa calidalis* has never been recorded from Chhattisgarh. Relevant published literature on the Lepidoptera of Chhattisgarh (Chandra & Nema 2006, 2007 Ramakrishna et al. 2006; Raha et al. 2017, 2018a,b,c,d,e,f,g,h,i,j; Chandrakar et al. 2025) was reviewed to confirm the novelty of the present record.

Therefore, the present observation of *Aethaloessa calidalis* from Semra Village, Dhamtari District, Chhattisgarh, represents the first record of *Aethaloessa calidalis* in the state. This record adds new faunal information to Chhattisgarh and extends the known distribution of the species in central India.

MATERIAL AND METHOD

The present record was made at Semra Village, Dhamtari District, Chhattisgarh, India (20.7377° N, 81.7258° E, 313 m) (Image 1). The village lies close to the Mahanadi River, and the surrounding landscape consists mainly of a mixed agroecosystem. The area is dominated by rice fields, vegetable crops, and pulses, with patches of wild shrubs, herbs, and scattered trees along field margins and uncultivated spaces. This varied vegetation creates suitable conditions for nocturnal moth activity. The region has a typical tropical monsoon climate with hot summers, a rainy season from July to September, and mild winters.

A nocturnal light-trap moth survey was carried out on 28 September 2025 at Semra Village, Dhamtari District, Chhattisgarh (20.737703° N, 81.725808° E, 313 m), comprising a mixed agroecosystem dominated by rice and vegetable fields with adjoining shrubs and scattered trees. A 1,000 W halogen light was used as the light source, positioned in front of a 3 x 3 m^2 white cloth screen and operated from 1830–2230 h to attract moths. All the visiting individuals were photographed using a Canon EOS 1300D DSLR camera equipped with an 18–55 mm kit lens and in-built camera flash.

The recorded specimen of *Aethaloessa calidalis* was identified based on distinct external morphological characters, including wing coloration, wing pattern, and marginal markings, which are diagnostic and allow reliable species-level identification, as described by Guenée (1854), Hampson (1896), and Whalley (1961). The species is distinctive and can be reliably identified using photographic evidence alone. No specimen was collected during the study to follow a non-destructive and ethical sampling approach.

RESULT

A single adult specimen of *Aethaloessa calidalis* was recorded during a nocturnal light-trap survey conducted on 28 September 2025 at Semra Village, Dhamtari District, Chhattisgarh, India (20.7377° N, 81.7258° E, 313 m). The individual was attracted to a halogen light source and photographed in situ (Image 2).

Taxonomy and diagnostic features:
Order: Lepidoptera
Family: Crambidae
Subfamily: Spilomelinae
Genus: *Aethaloessa* Lederer, 1863
Species: *Aethaloessa calidalis* (Guenée, 1854)

Original combination: *Glyphodes calidalis* Guenée, 1854.

Type locality: Coromandel Coast, Tamil Nadu, India.

Synonymy: *Syngamia octavialis* (Walker, 1859), *Syngamia tiphalis* (Walker, 1859), *Hyalea fulvidalis* (Wallengren, 1860), *Syngamia secutalis* (Walker, 1866), *Botys witalis* (Felder, 1875), and *Syngamia aurantiaca* (Hampson, 1912b).

The species was transferred to the genus Aethaloessa

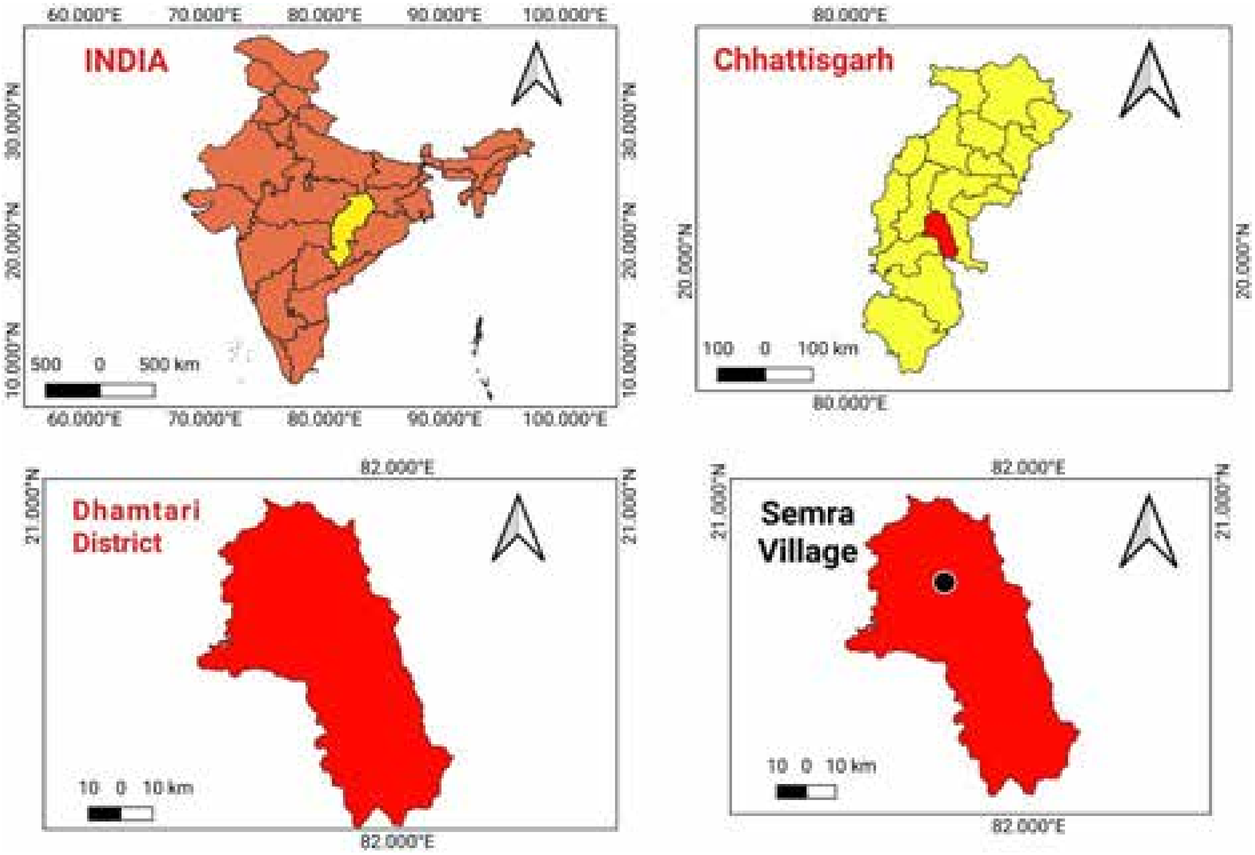

Image 1. Location map showing the study area: Semra Village, Dhamtari District, Chhattisgarh, India. Prepared by the authors using QGIS version 3.22.

by Whalley (1961)

Diagnostic characters: *Aethaloessa calidalis* is a widespread and distinctive species characterized by its bright yellowish-orange and dark brown colour pattern. The forewing length of the observed individual measured approximately 7.0–7.8 mm. The head was orange, the thorax was brown, and the abdomen was orange with a brown basal band and a darkened terminal tip. The forewings bared three large orange areas, sharply defined by a narrow dark brown sub-basal line, a broad brown median fascia, and a broad brown sub-marginal area. The subcostal region was distinctly brown towards the wing base. The hindwing was predominantly orange, with a broad dark brown submarginal band extending from the termen to the postmedial region. These characters were clearly visible in the photographic record and were consistent with published descriptions (Guenée 1854; Hampson 1896; Whalley 1961).

Comparison with other species of *Aethaloessa*

According to Whalley (1961), the genus *Aethaloessa* comprises three species worldwide: *Aethaloessa floridalis* (Zeller, 1852), *Aethaloessa calidalis* (Guenée, 1854), and *Aethaloessa rufula* (Whalley, 1961). *Aethaloessa floridalis* is restricted to Africa and Madagascar, and differs from *Aethaloessa calidalis* primarily in genital morphology and geographic distribution. *Aethaloessa rufula*, occurring in the Solomon Islands and surrounding Australasian-Pacific regions, is externally distinguishable from *Aethaloessa calidalis* by the absence of black scales on the dorsal side of the first abdominal segment, a character emphasized by Whalley (1961). *Aethaloessa tiphalis* (Walker, 1859) is treated by Whalley (1961) as a subspecies of *Aethaloessa calidalis*, distributed from southeastern Asia to Australia, showing only minor variation in wing pattern and colour intensity. The present specimen conforms well to the external morphology and geographic range of *Aethaloessa calidalis*, allowing confident identification based on external characters.

DISCUSSION

Although *Aethaloessa calidalis* is widely distributed across India (Whalley 1961; Komal et al. 2021; Reddy & Murthy 2021; Mahesh et al. 2024), it had not previously

Image 2. *Aethaloessa calidalis* (Guenée, 1854) recorded during a light trap survey in Semra Village, Dhamtari District, Chhattisgarh.

been reported from Chhattisgarh. The species was absent in previous lepidopteran records of the state (Chandra & Nema 2006, 2007; Ramakrishna et al. 2006; Raha et al. 2017, 2018a,b,c,d,e,f,g,h,i,j; Chandrakar et al. 2025). It was even not reported from Chhattisgarh in the Moths of India online database (Anonymous 2025), a well-known citizen-science based unstructured data repository of moths found in India. The present finding, therefore, represents the first record of *Aethaloessa calidalis* from Chhattisgarh, extending its known distribution into central India. This record suggests that several widespread crambid moths may be undocumented in the region due to limited sampling efforts. Continued systematic surveys are thus needed to develop a more complete understanding of the state's moth fauna.

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SHORT COMMUNICATION

First photographic record of the Northern Swamp Deer *Rucervus duvaucelii duvaucelii* in Upper Ganga River Ramsar Site, India

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Abstract: The Swamp Deer is represented by three sub-species, viz., the northern subspecies *Rucervus duvaucelii duvaucelii*, the central Indian subspecies or hardground Barasingha *R. d. branderi*, and the eastern subspecies *R. d. ranjitsinhi* in India. The northern subpopulation is restricted to the Gangetic plains of India and the Terai grasslands of Nepal, which constitute more than 75% of the global population. Previous records of swamp deer along the Ganga River were limited to State Wildlife Barasingha Sanctuary. We recorded a small population of eight swamp deer (two males, three females, and three sub-adults) in a grassland patch along the Ganga River in Narora during the biodiversity survey of the Upper Ganga River Ramsar Site. This is the southernmost extension of the distribution range of swamp deer, around 70 km from the State Wildlife Barasingha Sanctuary.

Keywords: Alluvial grasslands, Barasingha, Gangetic floodplain, irrigation canals, Namami Gange, Lower Ganga Barrage, range extension, threatened, Uttar Pradesh, wildlife sanctuary.

The Barasingha or Swamp Deer *Rucervus duvaucelii* is an endemic deer of the Indian subcontinent (Ellerman & Morrison-Scott 1951; Qureshi et al. 2004). Fewer than 5,000 individuals, restricted to isolated pockets in the Gangetic plains, the Brahmaputra floodplains, the central Indian highlands, and the Terai grasslands of India and Nepal (Pocock 1942; Qureshi et al. 2004) are known. The species is listed as 'Vulnerable' on the IUCN Red List owing to a decline in population across its distribution range (Duckworth et al. 2015). The species *Rucervus duvaucelii* is further represented by three subspecies, viz., the Northern *R. d. duvaucelii* inhabits the swampy grasslands of the Gangetic plains in Uttar Pradesh and Uttarakhand, India, and the Terai grasslands of Nepal. The Central Indian hardground Barasingha *R. d. branderi*, occurs in central India, and the Eastern *R. d. ranjitsinhi* is found in the Brahmaputra floodplains (Gee 1964; Spillet 1966; Schaller 1967; Qureshi et al. 2004).

The Northern *R. d. duvaucelii* is the most abundant of the three subspecies and accounts for more than 75% of the global population (Qureshi et al. 2004). The geographical distribution of the northern subspecies extends from Jhilmil Jheel Conservation Reserve in the north to State Wildlife Barasingha Sanctuary (formerly

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Hastinapur Wildlife Sanctuary) in the south and eastwards to Pilibhit Tiger Reserve, Dudhwa National Park, Kishanpur Wildlife Sanctuary, and Katernaighat Wildlife Sanctuary of India, and Bardiya National Park and Shuklaphanta National Park in Nepal (Qureshi et al. 2004). The subspecies once considered extinct from the Terai grassland was rediscovered in the Jhilmil Jheel Conservation Reserve in 2005 (Sinha & Chandola 2006). Subsequently, a population of *R. d. duvaucelii* was also reported from the Ban Ganga Wetland area of Uttarakhand (Tewari & Rawat 2013). The southernmost limit of the *R. d. duvaucelii* distribution is along the Ganga River up to the State Wildlife Barasingha Sanctuary, approximately 100 km (aerial distance) from Jhilmil Jheel Conservation Reserve (Duckworth et al. 2015).

Surprisingly, in the Gangetic plains, the majority of studies on the status, distribution, habitat use, and threats of the swamp deer are restricted to the landscape between Jhilmil Jheel Conservation Reserve and State Wildlife Barasingha Sanctuary (Sinha & Chandola 2006; Tewari & Rawat 2013; Duckworth et al. 2015; Paul et al. 2018). The status and distribution of swamp deer in the grasslands along the Ganga River downstream of the State Wildlife Barasingha Sanctuary remains unknown. This geographical limitation in research highlights the need for extensive surveys outside the species' reported range in the Gangetic floodplain landscape to achieve a comprehensive understanding of its distribution and population status. Hence, the study was conducted to assess the distribution and status of the swamp deer population in the Upper Ganga River Ramsar Site, India.

Materials and Methods

The survey was conducted along the banks of the Ganga River between Brijghat and Narora (Image 1). The grassland patches and riparian areas were surveyed to assess the presence of *R. d. duvaucelii*. The stretch of the Ganga River between Brijghat and Narora is designated as the Upper Ganga River Ramsar Site (Ramsar site no. 1574). The river stretch has fragmented grassland patches along the banks and on islands (WII-GACMC 2018). The major vegetation of these grassland patches

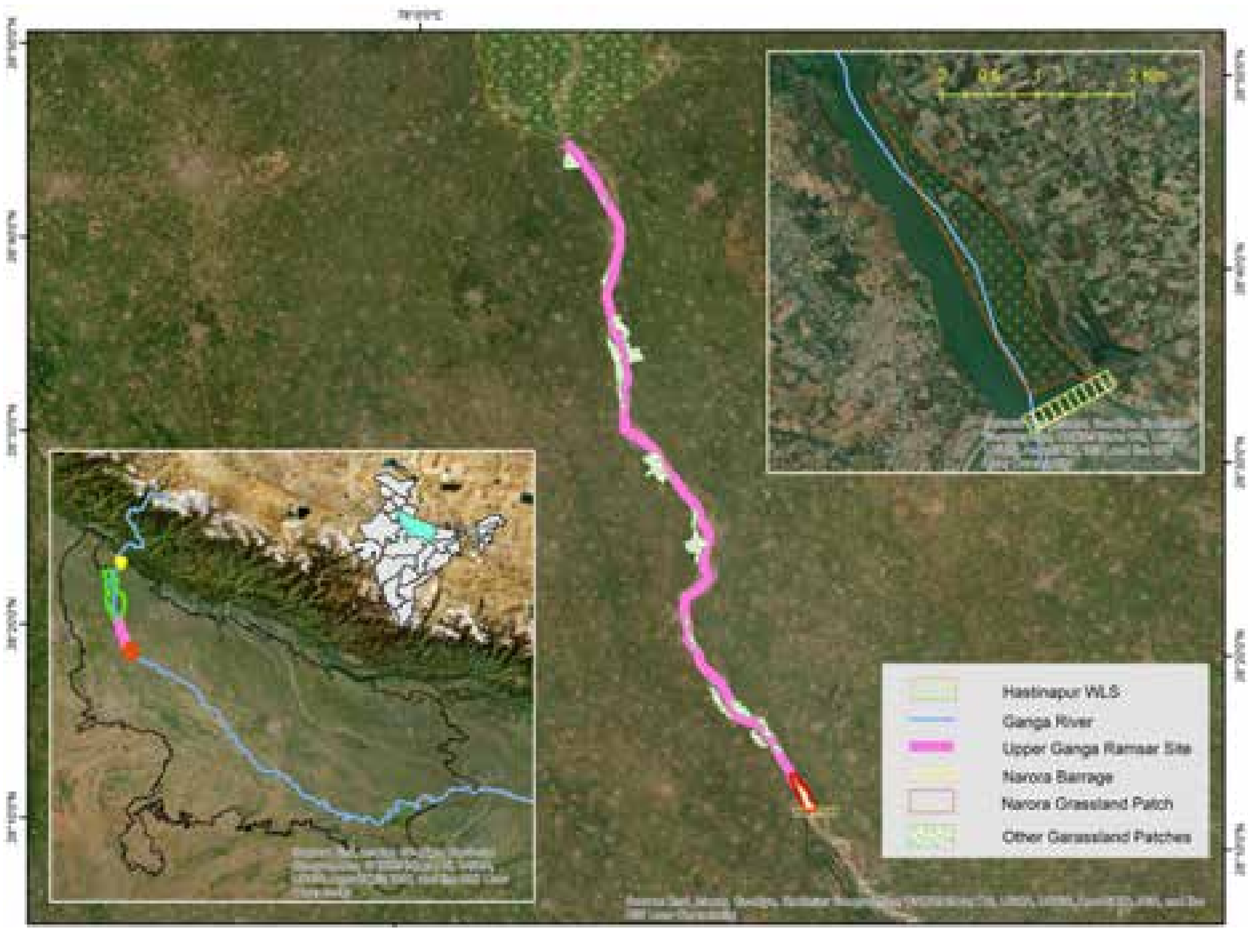

Image 1. The survey area of swamp deer between the Brijghat and Lower Ganga Barrage.

includes *Typha* sp., *Phragmites* sp., *Saccharum* sp., *Eichhornia* sp., etc. This stretch of the river is inhabited by the Gangetic Dolphin *Platanista gangetica*, 76 species of waterbirds, Gharial *Gavialis gangeticus*, Mugger *Crocodylus palustris*, and six species of freshwater turtles (WII-GACMC 2018; Usmani et al. 2025). The major terrestrial species found in this landscape include Sambar *Rusa unicolor*, Hog Deer *Axis porcinus*, Chital *Axis axis*, and Leopard *Panthera pardus* (Usmani 2010).

The study was part of a large-scale Ganga Biodiversity assessment survey conducted in 2021. During the survey, we also gathered information on the presence of the species from locals, especially farmers, cattle herders and fishermen. Photographs of species and their antlers were shown to identify the species. Based on the information collected from local people and identified grassland patches along the Ganga River (Paul et al. 2018), a survey was conducted in selected stretches along the river between May and July 2021. The grassland patches were extensively surveyed on foot, and the riverbank was surveyed by boat for the presence of swamp deer in the identified stretch.

Results

Evidence of swamp deer presence was found only in the Narora grassland patch (Image 2). We located a group of eight individuals, including two males, three females and three sub-adults, during the survey (Images 3 & 4). The individuals were seen in a densely covered grassland patch within Lower Ganga Barrage Reservoir, around one km from Lower Ganga Barrage or Narora Barrage (Image 28.2030° N, 78.3930° E). Local farmers, cattle herders and fishermen have also confirmed the year-round presence of the swamp deer in this area. These people have confirmed the presence of groups of up to 20 individuals in the area. The sighting was outside the protected area, around 70 km (aerial distance) from the State Wildlife Barasingha Sanctuary.

The grassland patch is located within the Lower Ganga Barrage Reservoir, with a deep and fast-flowing channel towards the right bank and a low-depth narrow channel on the left bank. This seasonally flooded grassland habitat is dominated by *Typha* sp., *Phragmites*

Image 2. Grassland patch near Lower Ganga Barrage, Narora.

Image 3. Herd of swamp deer in the grassland patch near Lower Ganga Barrage, Narora.

Image 4. Subadult swamp deer in the grassland patch near Lower Ganga Barrage, Narora.

karka, and *Saccharum spontaneum* and provides an ideal home for the swamp deer. The area also faces a wide range of disturbances, including occasional poaching, intensive grazing, agricultural encroachment, unsustainable extraction of aquatic vegetation, and uncontrolled burning.

Discussion

The survey confirmed the presence of a small number of *R. d. duvaucelii* outside the protected area, around 70 km (aerial distance) south of the State Wildlife Barasingha Sanctuary in Narora. This is the southernmost extended distribution of the swamp deer population along the Ganga River in Uttar Pradesh. Combined with the previously known range extending 100 km (aerial distance) from Jhilmil Jheel Conservation Reserve to State Wildlife Barasingha Sanctuary, the present record extends the total known distribution of *R. d. duvaucelii* to approximately 170 km (aerial distance) along the Ganga River (Qureshi et al. 2004; Sinha & Chandola 2006; Tewari & Rawat 2013; Duckworth et al. 2015; Paul et al. 2018). The swamp deer population in the Narora grassland observed during this study may also be connected to the Northern populations of the State Wildlife Barasingha Sanctuary and, further, to the Jhilmil Jheel Conservation Reserve population through seasonal and flood-driven movement (Martin & Gopal 2015). However, this connectivity may be influenced by anthropogenic barriers including irrigation infrastructure, settlements and transportation infrastructure.

The Narora grassland is threatened by encroachment for agricultural purposes, and illegal burning of grasslands and the swamp deer population is threatened by poaching. The swamp deer population in this area is highly vulnerable and needs dedicated conservation measures supported by strong legislation. Conservation efforts through major government programmes, such as the National Mission for Clean Ganga (NMCG), are also required to extend protection for wetland-dependent species.

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SHORT COMMUNICATION

First image-based evidence of Wroughton's Free-tailed Bat *Otomops wroughtoni* (Thomas, 1913) (Chiroptera: Molossidae) from the Yamuna Floodplain, New Delhi, India

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Abstract: The Wroughton's Free-Tailed Bat *Otomops wroughtoni* is one of the rarest representatives of the family Molossidae globally, presently known from two breeding colonies in the Western Ghats and Meghalaya, and a single individual from Cambodia, and Sri Lanka, each. In this paper, we report the first confirmed record of *O. wroughtoni* from Yamuna Biodiversity Park, New Delhi, on 26 November 2024. This record constitutes a considerable northward range record of the bat species into the Indo-Gangetic Plains. It highlights the role of urban ecological restoration in providing functional habitat for rare fauna, which could help formulate conservation strategies.

Keywords: Additional record, conservation planning, ecological restoration, ecosystem recovery, molossid bat, rare fauna, resilience, urban rewilding, wildlife monitoring, Yamuna Biodiversity Park.

Bats are the only mammals that have evolved and adapted to sustained flight, making them masters of the night sky. Bats occupy a wide variety of feeding guilds, including frugivory, insectivory, and nectarivory, thereby providing an array of ecological services (Ramirez-Francel et al. 2022). Insectivorous bats consume aerial and terrestrial arthropods, thus occupying an important place in the food chain and helping regulate the insect populations. By feeding on nectar and a diversity of fruits, nectarivorous and frugivorous bats act as important pollinators and dispersers (Castillo-Figueroa 2020). Some tropical fruits, such as bananas, agaves, figs, and cashews, are pollinated by bats (Aziz et al. 2021). Consequently, they serve as indicators of general ecosystem health (Vanitharani & Preba 2011).

Despite their ecological importance, bat populations are threatened by rapid urbanization, habitat fragmentation, and degradation. Delhi, the capital of India, is home to around 14 bat species. However, due to extensive habitat alteration and anthropogenic activities, bats are facing population decline and extinction risk. The two natural landscapes of Delhi—the Aravalli Hill ranges and the Yamuna Floodplains—are deteriorating due to extensive mining, pollution, and infrastructure development. Sightings of bats have decreased considerably over the last few decades. To restore the degraded natural landscapes of the river Yamuna Floodplains and Aravalli Hill ranges and bring back the associated faunal diversity, Delhi Development Authority

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(DDA), a local government agency responsible for the development of the city, has established a network of seven biodiversity parks in Delhi in collaboration with Centre for Environmental Management of Degraded Ecosystems (CEMDE), University of Delhi. Yamuna Biodiversity Park (YBP), developed on the floodplain of the river Yamuna, is one of them. The restored wetlands, marshes, floodplain forests, and grasslands of YBP (Niangthianhoi & Khudsar 2015; Khudsar et al. 2025) support a diversity of faunal elements, including eight bat species.

Study Area

The study was conducted at Yamuna Biodiversity Park (28.738° N, 77.212° E) on the floodplains of the Yamuna River in Delhi. Delhi has a semi-arid, subtropical climate with hot, dry summers and cold winters. The mean annual temperature is 25.5 °C, with May and June, the warmest months, and the mean maximum temperature is 39 °C. The area receives an average rainfall of 710 mm, of which 75% occurs during the monsoon season (June–September). The site spans 184 ha of the Yamuna Floodplain in northern Delhi and comprises two distinct phases: Phase I, with restored grasslands, floodplain forest communities, and marshes; and Phase II, with seasonally inundated active floodplain and riparian wetlands, marshes, and grasslands. A 200-m wildlife corridor connects the two phases (Image 1). Over two decades, restoration efforts have re-established the hydrological regime, enhanced native vegetation, and improved habitat quality.

As a result several rare and locally extinct faunal species have reappeared, such as, Hog Deer *Axis porcinus* (Singh et al. 2023), Leopard *Panthera pardus* (Singh et al. 2021), and Seibold's Snake *Ferania sieboldii* (Srivastava et al. 2020). Notable avifauna recorded from the site include crakes (Rallidae), Asian Paradise Flycatcher *Terpsiphone paradisi*, Eurasian Scops Owl *Otus* scops, a breeding population of Oriental Darter *Anhinga melanogaster* (Niangthianhoi & Khudsar 2015), Ferruginous Pochard *Aythya nyroca*, and White-browed Fantail *Rhipidura aureola*.

The present study reports the sighting of a rare bat species *Otomops wroughtonii* in the restored floodplain forest of the YBP, and provides supporting evidence of its occurrence.

Observation

On 26 November 2024, at 1500 h, a team of five researchers observed an individual of *Otomops wroughtoni* roosting on the trunk of a *Holoptelea integrifolia* tree in the restored wildlife corridor of YBP. The tree was approximately 15 m tall, as measured with a range finder (Nikon Laser 550), with GBH of 81 cm and the surrounding canopy cover was estimated to be 70–80 %. The bat was positioned at a height of 3.2 m above ground level, clinging to the exposed trunk (Image 2). The associated tree assemblage comprised of *Gmelina arborea*, *Dalbergia sissoo*, and *Ehretia laevis*. At the same time, the ground layer was dominated by *Phyllanthus reticulata*, *Vitex negundo*, *Chrysopogon zizanioides*, *Panicum antidotale*, and *Saccharum spontaneum*, indicating a grass–shrub dominated understorey typical of semi-arid alluvial systems (Image 2).

The diagnostic traits included a large forearm length and forward-pointing ears joined across the forehead by a thin membranous band. The face was largely naked, with a prominent nostril pad, and the body was covered with short, velvety fur. The dorsal pelage was dark brown across the crown, back, and rump, while a distinct, narrow white border extends along each flank from the axilla to the groin and continues along the forearm membranes. The shoulders and nape exhibit a contrasting pale greyish-white coloration. Ventrally, the fur was dull brown, accentuated by a grey collar that extends onto the chin and upper chest. The tail extended well beyond the posterior margin of the narrow uropatagium—a characteristic feature that gives the group its common name, the free-tailed bats (family Molossidae).

These features correspond to published descriptions of *O. wroughtoni* (Ramakrishna et al. 2003). No attempt was made to capture the bat due to its conservation status. Photographs validate the first authenticated record of the species from Delhi.

Discussion

The species was initially classified as 'Critically Endangered' by the IUCN Red List. However, due to a lack of information regarding its habitat, breeding, diet, distribution, and population, it was moved to the 'Data Deficient' category (Prabhukhanolkar 2016). In India, the species is listed under Schedule I of the Wildlife (Protection) Amendment Act, 2022, indicating its level of protection. This species was described from only one site – Barapede Caves in the Belgaum District of Karnataka, near the Bhimgad Wildlife Sanctuary in India (Thomas 1913). For nearly 88 years, this location has been the sole known habitat, indicating that the species is extremely rare and geographically restricted. However, subsequent records indicate a wider distribution area for *Otomops wroughtoni* (Image 3). For example, the next

Image 1. Google Earth map showing Yamuna Biodiversity Park Phase I, Phase II, and wildlife corridor.

sighting of the species was recorded from Cambodia in March 2001 (Walston & Bates 2001), followed by the Shella region near the Siju caves in Meghalaya (Thabah & Bates 2002). In 2014, several roosting sites were identified in the Jaintia Hills of Meghalaya (Ruedi et al. 2014). Recently, during acoustic and mist-net studies, a colony was observed on open limestone cliffs in the South Garo Hills, rather than in a typical cave habitat (Patel et al. 2024). Acoustic detection from Maharashtra and Srilanka also suggest that the species may have a wider, but still poorly documented, distribution across the Indian subcontinent, although further confirmation is required (Jayakumar & Chakravarty 2025; Kusuminda et al. 2025). The sighting of *O. wroughtoni* in YBP, indicates its northward record into the Indo-Gangetic plains, suggesting the possibility of wider distribution than previously recognised. Although the morphological features confirm the identity of the same species, there is a need for morphometric, molecular, and echolocation studies for authentication.

The Delhi individual may represent a dispersing bat rather than a resident. Nevertheless, the presence within a restored floodplain suggests that such landscapes can serve as foraging or stopover habitats. Restored wetlands, riparian woodlands, and grassland mosaics in YBP likely provide favourable conditions for aerial insectivores such as *O. wroughtoni*.

Whether the sighting in YBP, Delhi reflects vagrancy, exploratory movement, or evidence of an unrecognised northern population remains unclear. However, the accumulation of multiple sightings from different geographical regions indicates the species' broader tolerance and high ecological amplitude is now more evident. However, long-term and systematic monitoring would be necessary to confirm sustained habitat use and ecological significance.

Conservation Implications

The Delhi record further refines the species' distribution, indicating that *O. wroughtoni* may occupy a broader ecological range than previously recognised. The presence of this bat species and several other faunal elements indicates that restored floodplain ecosystems, such as those of Yamuna Biodiversity Park, support rare and specialised fauna and offer resilience to the faunal diversity. As climate pressures and urban expansion intensify, scientifically restored landscapes will serve as places of refuge harbouring native biodiversity, natural habitats connecting with others, and supporting wildlife movement across the larger landscapes. Further, documenting such occurrences is significant for understanding species distribution dynamics and for providing critical inputs to assess extinction risk and inform conservation strategies.

Image 2. A–C—Wroughton's Free-tailed Bat Otomops wroughtoni hanging on the trunk of *Holoptelea integrifolia* | D—restored wildlife corridor in the Yamuna Biodiversity Park. © Mohan Singh, YBP.

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Image 3. Known occurrences of *Otomops wroughtoni*.

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SHORT COMMUNICATION

New distribution record of *Hydrocotyle bonariensis* Lam. (Magnoliopsida: Apiales: Araliaceae) from India

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Abstract: A floristic survey conducted in July 2024 in Aizawl district of Mizoram, led to the collection of unidentified species of *Hydrocotyle*. Detailed morphological examination, comparison with taxonomic literature and consultation of herbarium specimens confirmed its identity as *Hydrocotyle bonariensis* Lam. This is first specimen based, taxonomically confirmed record of *H. bonariensis* from India. This species is a perennial prostate herb widely distributed throughout the tropical and sub-tropical regions. It is well adapted to sandy, moist habitats including coastal dunes, estuaries, and ponds. Herbarium specimens were prepared following standard taxonomic procedures and submitted at the Botanical Survey of India, Eastern Regional Centre, Shillong. Morphological characters, habitat and specimen details are provided to facilitate accurate identification. This discovery highlights the floristic richness of northeast India and reinforces the importance of systematic botanical surveys in underexplored habitats.

Keywords: Aizawl, botanical exploration, conservation, habitat, *Hydrocotyle bonariensis,* Mizoram, protologue, taxonomy.

The genus *Hydrocotyle*, commonly known as pennywort, belongs to the family Araliaceae and was first described by Carl Linnaeus in his Species Plantarum (1753). The name '*Hydrocotyle*' is derived from the Greek words 'hydro' meaning 'water' and 'kotyle', meaning 'dish or plate', referring to the species' aquatic habitat and dish-shaped leaf (Bandara et al. 2011). *Hydrocotyle* is a widespread genus characterized by a rhizomatous perennial creeping growth form with many species occurring in aquatic or moist terrestrial habitats. Currently, the genus comprised of 182 accepted species globally and is widely distributed in Africa, America, Australia, southeastern Asia and some parts of the European Continent (IPNI 2026; POWO 2026). The taxonomic treatment of *Hydrocotyle* in India has undergone several revisions over time. C.B. Clarke (1879) recognized six taxa from India, namely *Hydrocotyle javanica* Thunb., *H. javanica* var. *podantha* Molkenboer, *H. burmanica* Kurz, *H. conferta* Wight, *H. rotundifolia* Roxb., and *H. asiatica* L. Subsequently, Karthikeyan et al. (2009) reported eight species occurring in India: *Hydrocotyle conferta* Wight, *H. hookeri* (C.B. Clarke) Craib, *H. javanica* Thunb., *H. nepalensis* Hook., *H. podantha* Molk., *H. ramiflora* Maxim., *H. siamica* Craib, and *H. sibthorpioides* Lam. Mukherjee et al. (2020) recognized nine species, namely *Hydrocotyle conferta* Wight, *H. himalaica* P.K. Mukh., *H. hookeri* (C.B. Clarke) Craib, *H. javanica* Thunb., *H. kollimalayensis* S. Karup. & A. Ali, *H. ramiflora* Maxim., *H. siamica* Craib, *H. sibthorpioides* Lam., and *H. verticillata* Thunb. *H. sibthorpioides* has maximum 10 cm high, simple and peltate leaves, umbels inflorescence, flat fruit which breaks into two halves during maturity, faint yellow flower with a purple hinge

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(Hazarika et al. 2021). *H. kollimalayensis* has simple and pale green leaves, slender petiole with 2-4 cm long, simple umbel inflorescence, ellipsoid fruit and sub-sessile or very shortly pedicillate flower (Karuppusamy et al. 2014). *H. verticillata* has 3.6 -7 cm length per stolon, simple alternate leaves, smooth green petiole with 8 -14.5 cm, axillary inflorescence with 5.3 - 19 cm long, sub orbicular fruit and small, white, bracteate flowers (Roy & Roy 2024). *H. bonariensis* is a semiaquatic perennial herb with long stolons (runners), from which roots, leaves and inflorescences are produced at nodes The species name *bonariensis* was derived from Buenos Aires, Argentina, where the plant is native and was first identified (Mazumdar et al. 2023). This species typically grows in sandy, moist habitats such as coastal dunes, estuaries, disturbed foreshore sites, ponds and even environments with periodic flooding.

A number of species of this genus are traditionally valued for wound-healing, improving blood circulation, and have effects on lowering blood pressure, tumour reduction and management of depression (Goh 2007). *Hydrocotyle* species contain oleanane-type triterpenes (Barrigenol derivatives) which are recognized for antioxidant, anticancer and anti-inflammatory

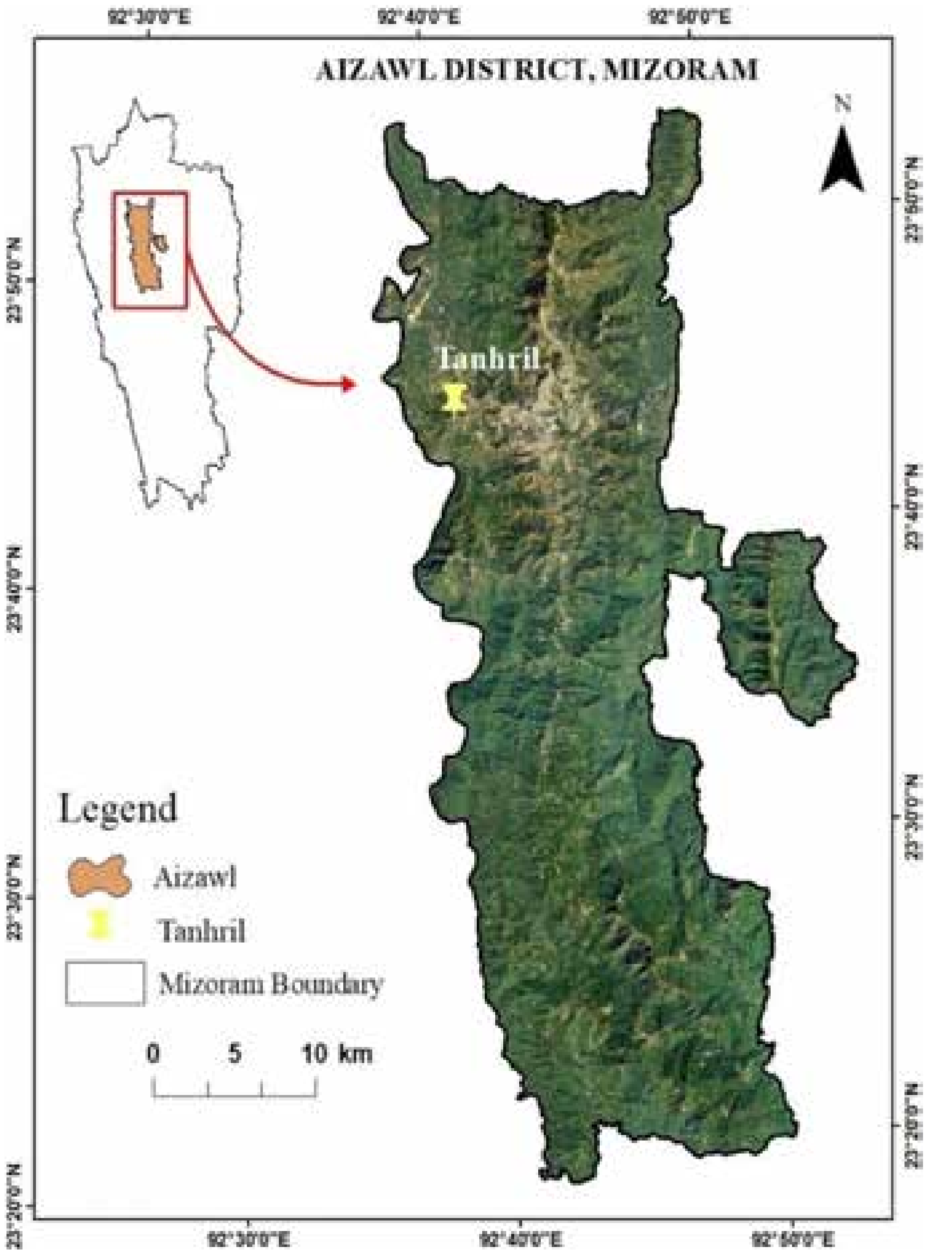

Image 1. The site of collection.

properties (Maulidiani et al. 2014). They are utilized as anti-inflammatory herbs in Taiwanese traditional medicine (Hamdy et al. 2018).

A floristic survey conducted in Tanhril, Aizawl District, Mizoram, in July 2024, one of the authors (Balasiewdor Kharsyntiew) collected an unidentified *Hydrocotyle* specimen. Detailed examination of the specimen, comparison with relevant taxonomic literature (Clarke 1879; Kanjilal et al. 1938; Mukherjee & Constanne, 1993; Singh 2002; Karthikeyan et al. 2009; Mukherjee et al. 2020) and herbarium consultation physically and digitally at ASSAM, CAL and KEW confirmed its identity as *Hydrocotyle bonariensis* Lam., representing the first specimen-based record of the species from India. Although data from the Global Biodiversity Information Facility (GBIF) indicate 16 records of *H. bonariensis* from six localities in southern part of India. However, all of these records are based solely on human observations with no specimen-based records are available in GBIF. Mazumdar et al. (2023) mentioned occurrence of *H. bonariensis* in Asian countries China, Sri Lanka, Indonesia and Malaysia including India, but this review does not provide any reference of published records to verify the presence of this species in India.

Materials and Methods

The plants were collected from Tanhril, Aizawl District of Mizoram, 23.745° N and 92.668° E. A herbarium was prepared and submitted to Botanical Survey of India, Eastern Regional Centre, Shillong (ASSAM). The fresh flowers were also submitted as per proper identification. The flowers were dissected, and detailed morphological study as taxonomic measurements and descriptions of each plant part of the living plant materials was carried out using a stereomicroscope, Magnus MSZ-TR 16G1101. To confirm its distribution, relevant publications and floras were critically studied and compared with related taxonomic literature (Clarke 1879; Kanjilal et al. 1938; Mukherjee & Constanne 1993; Singh, 2002; Karthikeyan et al. 2009; Mukherjee et al. 2020). Further examination of the protologue and a search for type material were conducted in various herbaria, including herbarium specimens housed at the Botanical Survey of India, Eastern Regional Centre, Shillong (ASSAM), and the Central National Herbarium, Howrah (CAL). Collection, pressing and preparation of herbarium voucher specimens were done in accordance with conventional herbarium techniques (Jain & Rao 1976). A voucher specimen of the plant was deposited in the Herbarium of the Botanical Survey of India, Eastern Regional Centre, Shillong (ASSAM).

Taxonomic Treatments

Hydrocotyle bonariensis Lam., Encycl. 3(1): 153. 1789.

Synonyms: *Hydrocotyle petiolaris* DC. in Prodr. 4: 60. 1830.

Herb, 15–40 cm high, creeping, with slender stems, glabrous, rooting at the nodes; stolons pinkish white, cylindrical. Leaves simple, peltate (very rarely with a deep narrow sinus extending to the petiole); petiole 13–21 cm long, terete, glabrous; lamina 2.5–2.8 × 2.5–4.2 cm orbicular, margin often shallowly lobed, the lobes with small secondary crenulations, or sometimes semi-serrate, glabrous beneath, with 12–20 veins radiating from the petiole. Inflorescence arises from stolons, compound umbel; umbel rays 5–7; peduncle up to 32 cm long; flowers bisexual, up to 38 per umbel, white in colour; pedicels 1–20 mm long, slender. Tepals 5, ovate, white; bract ovate, white, papery. Anthers 5 in number; style 2, c. 1 mm long. Fruit laterally flattened.

Flowering & fruiting: May–August

Specimen examined: MZU/HAMP/24/05, 23.745° N 92.668° E, 782 m altitude, Aizawl District, Tanhril, Mizoram, India, coll. Balasiewdor Kharsyntiew.

Distribution: China, India, Sri Lanka, Indonesia, Malaysia, southeastern part of the United States, central America, South America, the Caribbean and sub-Saharan Africa.

Conclusion

This study reports the first record of Hydrocotyle bonariensis Lam. from India, enriching the country's floristic diversity database and listing the distribution of this species in a new geographical region. The finding highlights the importance of continued botanical exploration and taxonomic research, particularly in the under-explored ecosystems of northeast India, where substantial plant diversity remains inadequately documented. It also demonstrates that systematic field surveys in biodiversity-rich regions continue to reveal unrecorded taxa. Continued floristic documentation is therefore essential for monitoring biodiversity, guiding sustainable ecosystem management, and informing conservation initiatives in the face of increasing anthropogenic and climate-driven environmental changes.

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Image 2. ***Hydrocotyle bonariensis***: A—habitat | B—habit | C—inflorescence | D—single flower from herbarium | E—single fresh flower | F—flower bud | G—lower parts from herbarium | H—petals & stamens. © Vijay.

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SHORT COMMUNICATION

Recorded and lost: *Methles indicus* Régimbart, 1899 (Coleoptera: Dytiscidae) a new distribution record from the state of Telangana: a case study on habitat loss due to urban encroachment

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Abstract: Globally, freshwater ecosystems are facing a high level of threat due to rapid development, urbanization, and anthropogenic pressures. Ameenpur Lake, a designated biodiversity heritage site in Hyderabad, Telangana, has significantly supported wide variety of aquatic biodiversity. During field explorations, the aquatic coleopteran species *Methles indicus* Régimbart, 1899, was recorded from banks of this lake and marked as first distributional occurrence from the state. However, subsequent habitat degradation caused by extensive construction and encroachment has led to the apparent local elimination of this species. The study highlights the loss of *Methles indicus* as a sign of declining freshwater habitat health and emphasizes the urgent need for habitat preservation and successful conservation strategies.

Keywords: Ameenpur Lake, anthropogenic pressure, aquatic beetle, biodiversity heritage site, biodiversity loss, Coleoptera, habitat condition, riparian vegetation.

Aquatic coleopterans play an important role in freshwater ecosystems as bioindicators, predators, and scavengers. The presence or absence of aquatic beetles often indicates the habitat condition of wetlands and lakes. The aquatic beetles diversity of India is rich with 902 species (Ghosh & Nilsson 2012; Chandra et al. 2017; Gupta et al. 2024; Shankar et al. 2025); however, numerous species remain understudied and vulnerable to habitat alteration. The predatory water beetle genus *Methles* is associated with small pools, ponds, and streams along with the riparian vegetation. Globally, eight species and one subspecies have been documented within the genus *Methles*: *M. freyi* Guignot, 1953; *M. laevis* Zimmermann, 1933; *M. norberti* Pederzani & Schizerotto, 2014; and *M. punctatissimus* Gschwendtner, 1943, all of which are distributed in the Afrotropical region. *M. rectus* Sharp, 1882 and *M. spinosus* Sharp, 1882 are known from the Palearctic region, whereas *M. cribratellus* (Fairmaire, 1880) has been reported from both the Afrotropical and Palearctic regions. Only one species *M. indicus* is known from India, oriental region and the subspecies *M. cribratellus sparsepunctatus* Guignot, 1956 shows Afrotropical distribution (Régimbart 1889; Vazirani 1970; Shankar et al. 2024).

Ameenpur Lake, situated in Hyderabad, Telangana, is designated as the first biodiversity heritage site within the state due to its high biodiversity, including migratory birds, amphibians, reptiles, aquatic invertebrates, and its support for aquatic vegetation and macroinvertebrate communities. Despite its protected status, in recent years, large portions of the wetland have been encroached upon by construction activities, leading to

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sedimentation, pollution, loss of aquatic vegetation, and alteration of hydrological regimes (Srinidhi et al. 2021, 2022).

Materials and Methods

A common strainer was employed to collect the specimens of *Methles indicus* from the shores of Ameenpur Lake (17.528° N, 78.329° E) biodiversity heritage site, Hyderabad, Telangana (Image 1). The collected specimens of *Methles indicus* were stored in 70% ethanol. Leica EZ4 and Leica M205A microscopes were used for observing and dissecting the specimens. Habitat photographs were captured using a Canon D500 DSLR camera. Species identification was carried out using the standard taxonomic keys provided by Régimbart (1889) and Shankar et al. (2024). Collected specimens were identified, registered, and deposited in the National Zoological Collection of Freshwater Biology Regional Centre, Zoological Survey of India, Hyderabad.

Results and Discussion

Taxonomic treatment
Family: Dytiscidae Sharp, 1882
Genus: *Methles* Sharp, 1882
Methles indicus Régimbart, 1899

Material examined

Two males, three females, Ameenpur Lake, Ranga Reddy, Telangana (17.528° N 78.329° E), 10.ii.2022, Leg.: D. Jaiswal & S. Shankar, Reg. No. FBRC/ZSI/INS/5260.

Distribution

Oriental region (India [Bihar, Jharkhand, Odisha, Telangana, West Bengal]) (Régimbart 1889; Vazirani 1970; Shankar et al. 2024).

Methles indicus originally described from Chota Nagpur Plateau, Jharkhand, later recorded from Kolkata, West Bengal, and most recently it has been documented from Sakti Waterfall, Jeypore, Odisha (Shankar et al.

Image 1. Dorsal and ventral habitus of *Methles indicus*. © Shiva Shankar.

Image 2. Sampling site at Ameenpur Lake: A—Photo was taken during the first field survey (10.ii.2022) | B—Photo taken in recent survey (13.iv.2024). © Shiva Shankar.

2024).

Anthropogenic activity is becoming the foremost threat to aquatic biodiversity (Bashir et al. 2020). The main threat to biodiversity is habitat degradation, changes in land use, fragmentation, and pollution (IUCN 2024). In this current study we highlight the habitat loss and its effects on biodiversity. In the year of 2022, we conducted a first field survey in the banks of Ameenpur Lake to study the aquatic beetle diversity and their distribution. During the field survey to Ameenpur Lake, five individuals of *Methles indicus* were collected from small pools which are part of the lake. Since then, multiple attempts have been made to recollect the species from the banks of this lake but failed, suggesting its local extinction from the habitat. The sampling sites are now encroached and buildings constructed which has resulted in the elimination of small pools and species from the lake (Image 2). However, more survey was undertaken in the banks of adjacent water bodies, i.e., Himayat Sagar Lake (25 km south of Ameenpur Lake), Osman Sagar Lake (24 km south of Ameenpur Lake), RK Puram Cheruvu (28 km east of Ameenpur Lake), Shamirpet Lake (35 km north-east of Ameenpur Lake), and Turkayamjal Masab Cheruvu (48 km south-east of Ameenpur Lake) to know the occurrence of the species but ended up with no collections of the species. The causes of species elimination from its habitat can be attributed to many interrelated factors; first and foremost, habitat destruction or fragmentation, including encroachment and construction has rapidly eliminated shallow littoral zones essential for the beetle's life cycle. Water quality plays a significant role in the aquatic ecosystem; pollution in water that is derived from construction debris, chemicals, and sewage has degraded water quality beyond the tolerance limits of sensitive aquatic beetles (Burghelea 2011). Absence of submerged and emergent floral species has reduced shelter, breeding sites, and food resources to the aquatic beetles. Changes in water flow and depth disrupt the ecological stability required for aquatic beetle populations. The local elimination of *Methles indicus* is not merely the loss of a single species but an indicator of broader ecosystem degradation. Aquatic beetles are key components to freshwater food chain, webs (Dong et al. 2014), and their decline indicates declining water quality and ecosystem resilience (Roth et al. 2020). Such losses may precede further declines in other aquatic organisms, including fish and amphibians. Immediate actions are required at the habitat level to preserve the biodiversity of Ameenpur Lake; strict action should be taken on further encroachment and construction. The biodiversity heritage site authority and the government should take necessary action to restoration of littoral and wetland vegetation. Regular biodiversity monitoring activities, particularly of indicator species need to be undertaken. Awareness among the local community and involvement in lake conservation need to be promoted. Environmental protection laws must be strongly implemented.

The elimination of *Methles indicus* from the banks of Ameenpur Lake highlights the negative impact of unchecked urban development on the banks of freshwater biodiversity and ecosystem. Protecting remaining habitats and restoring degraded wetlands are important to preventing further local extinctions. This case study underscores the urgent need to balance urban growth with ecological sustainability, especially in legally protected biodiversity sites.

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NOTE

Camera-trap record of the Indian Grey Wolf *Canis lupus pallipes* (Sykes, 1831) (Mammalia: Carnivora: Canidae) from Karlapat Wildlife Sanctuary, Odisha, India

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The Indian Grey Wolf *Canis lupus pallipes* (Sykes, 1831) is a medium-sized canid historically widespread across the Indian subcontinent. It is associated with arid and semi-arid open landscapes such as grasslands, scrublands, and sparsely vegetated plains (Jhala & Giles 1991; Jhala 2003; Boitani et al. 2020). However, wolves are also known to utilise heterogeneous and human-modified habitats when suitable prey and denning sites are available. In eastern India, the distribution and ecology of the species remain poorly documented, and existing records indicate the occurrence of small isolated populations (Shahi 1982; Palei et al. 2013, 2019). Therefore, documenting new occurrences is important for improving understanding of the species' distribution in eastern India.

A systematic camera-trap survey was conducted across Karlapat Wildlife Sanctuary between January and February 2026 using 82 paired camera-trap stations, with a total survey effort of 2,050 camera-trap days. Camera-trap locations were selected based on animal signs, existing trails and forest roads. Cameras operated continuously and remained active at each site for approximately 25 days. One paired camera-trap station was placed along a forest road in a Sal-dominated area at an elevation of about 604 m above sea level and approximately 2.5 km from the nearest human habitation. Anthropogenic disturbances, including livestock movement and occasional human presence, were also recorded at the site during the survey. The Indian Grey Wolf was photographed at this station on 26 January 2026 at 0935 h, representing the first photographic evidence of the species from Karlapat Wildlife Sanctuary (Image 1 & 2).

Karlapat Wildlife Sanctuary covers 193.998 km² in the Kalahandi district of Odisha and is characterized by rugged, hilly terrain. There are 19 villages located inside the sanctuary, while 44 villages occur adjacent to its boundary (Palei et al. 2011). The sanctuary consists predominantly of Northern Tropical Dry Deciduous Forest, Dry Peninsular Sal Forest, and moist mixed deciduous forests interspersed with extensive bamboo patches (Champion & Seth 1968). This diverse habitat supports a variety of ungulate prey species, including Sambar *Rusa unicolor*, Barking Deer *Muntiacus muntjak*, and Wild Boar *Sus scrofa*, which are important prey species for sustaining large carnivores.

In Odisha, the Indian Grey Wolf has been recorded from Debrigarh Wildlife Sanctuary, Hadagarh Wildlife

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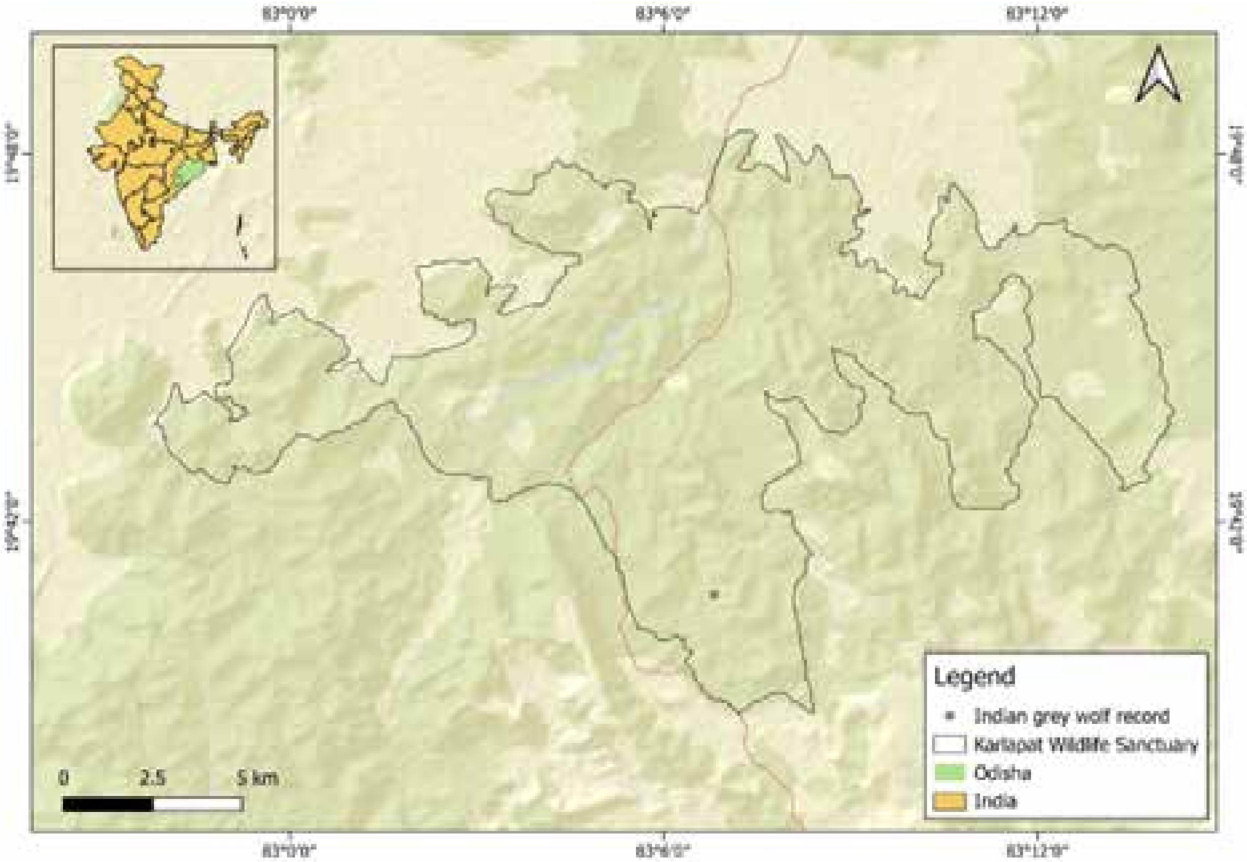

Image 1. Karlapat Wildlife Sanctuary shows the location of the camera trap station where the Indian Grey Wolf was photographed.

Image 2. Indian Grey Wolf recorded on 26 January 2026 in Karlapat Wildlife Sanctuary, Odisha, India

Sanctuary, Sunabeda Wildlife Sanctuary, and Similipal Tiger Reserve, Sundargarh Forest Division (Nair & Panda 2013; Palei et al. 2013, 2023b; Mishra & Bist 2019; Palei et al. 2019, 2020). More recent camera-trap records have also been documented from Badrama Wildlife Sanctuary (Palei et al. 2023a) and Keonjhar Forest Division (Dhanraj et al. 2025), indicating that the species occurs across several parts of the state, although its distribution appears to be fragmented.

The Indian Grey Wolf is listed as a Schedule-I species under the Indian Wildlife (Protection) Act (1972) and is classified as Vulnerable on IUCN Red List, with populations declining due to habitat loss, human disturbance, and other anthropogenic pressures (Hennelly et al. 2025). Continued monitoring and further ecological studies are necessary to better understand the distribution, habitat use, prey availability, connectivity, and potential human–wolf interactions of the species, thereby supporting evidence-based conservation planning and management strategies for the Indian Grey Wolf in eastern India.

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NOTE

Decline in winter visiting Common Kestrel *Falco tinnunculus* (Falconiformes: Falconidae) at Rani, Assam 2011–2024

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The Common Kestrel *Falco tinnunculus*, a raptor with three races known from the Indian subcontinent (Naoroji 2006). The races *interstinctus* and *tinnunculus* are winter visitors (September/October and March/April) throughout the lower hills and plains of the eastern Himalaya, including Garhwal, Assam, and associated northeastern states. It also visits southern India, Andaman Islands, Bangladesh, and Sri Lanka. The species hunts insects, rodents, amphibians, reptiles, and small birds, and inhabits the open grassland and farmlands (Naoroji 2006).

The species was recorded in the Rani block (26.12756^0 N, 91.59464^0 E), Kamrup District, Assam (Image 1). From July to November, the Rani landscape has paddy fields, and after harvest, it becomes a vast open land as a second crop is rarely cultivated (Image 2). The pesticide use is moderate, and the use of tractors over bullocks for ploughing is increasing. The fields are bordered by tall trees, bamboo clumps, beetle nut orchards, and single-storeyed houses. The Common Kestrel takes advantage of electrical poles in the field for perch and from there it pounces on the prey. It has been noted hovering over the harvested fields, for hunting mice, lizards, and insects. Common Kestrels were monitored during the winter season (November–February). The observations were recorded for 14 winter seasons from 2011–12 to 2024–25 (Table 1), on a 5-km road while slowly driving from Bongra–Rani and Jogipara–Rani. The data consisted of 15 transects per month, for 56 months (n = 840) (Archana et al 2024). The species encounter rate was calculated season-wise as: (number of sightings per season) / (transect length (5 km) x number of transects in the season (n = 60)). Out of 422 sightings, on 388 occasions the individuals were sighted singly, while on 34 occasions they were sighted as a pair. The encounter rate was plotted against the time period and showed a decline from 2020 onwards (Image 3). Post 2022–23, no individuals were observed in this area. The absence was confirmed as the same road was traversed almost every day throughout these years, and raptors were recorded opportunistically in Rani block. The raptors generally sighted in the areas are Steppe Eagle *Aquila nipalensis*, Oriental Honey-buzzard *Pernis ptilorhynchus*, Eurasian Marsh Harrier *Circus aeruginosus*, Pied Harrier *Circus melanoleucos*, Black Kite *Milvus migrans*, and Black-shouldered Kite *Elanus caeruleus*.

During 2022–25, the Common Kestrel was observed in other parts of Kamrup District, as well as in Assam (pers. obs.). The eBird data of Assam show the presence of the species from 15 November to 15 February (2008–2022) with a mean relative abundance of 0.09 (Fink et al 2023). Yet, recent absence recorded from this Rani

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Image 1. A Common Kestrel perched on an electric pole, Kamrup District, Assam in 2018. © Sachin Ranade.

Table 1. Sightings of Common Kestrel for 14 seasons (2011–2025).

	Year	Number of sightings
1	2011–12	38
2	2012–13	45
3	2013–14	48
4	2014–15	34
5	2015–16	37
6	2016–17	42
7	2017–18	38
8	2018–19	45
9	2019–20	40
10	2020–21	35
11	2021–22	20
12	2022–23	0
13	2023–24	0
14	2024–25	0
		422

Image 2. Habitat at Rani Block, Kamrup District, Assam, in 2020. © Sachin Ranade.

block evokes a question—whether the birds are pushed away by the urbanization pressure of the expanding Guwahati city or declining in numbers due to any other reason. The population of Common Kestrel is in decline (BirdLife International 2021). Many factors affecting various species of Kestrel populations are known, e.g., pesticides used in agriculture affecting the species (Bird & Bowmen 1987), food shortage affecting both Common Kestrel and Lesser Kestrel *Falco naumanni* (Davis 1975; Aparicio et al. 2022), predation of Common Kestrel by Northern Goshawk *Accipiter gentilis* (Petty et al. 2003) and hatching asynchrony due to climate change affecting the American Kestrels *Falco sparverius* (Callery et al. 2022). As the species is a winter visitor in India, large-

Image 3. Encounter rate of Common Kestrel during winter season, 2011–2024 at Rani, Assam.

scale counts using citizen science, telemetry studies, and intensive studies of feeding habits and habitat would throw some light on this issue.

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NOTE

Coprophagy in Egyptian Vulture *Neophron percnopterus* (Accipitriformes: Accipitridae) at Jorbeer carcass dump, Rajasthan

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Coprophagy is a well-known phenomenon in the animal kingdom, where species consume faecal matter to obtain nutrients that might otherwise be difficult to digest or assimilate. It can be categorized into autocoprophagy, which is feeding on one's own faeces and allocoprophagy, which is feeding on faeces of the conspecific or other species (Hirakawa 2001). Coprophagy benefits the feeding animal by providing partially digested food, including carotenoids and calcium, which otherwise take a longer time to collect, digest, and assimilate (Hirakawa 2001; Ranade & Prakash 2014). It rapidly matures the gut bacteria in Ostriches *Struthio camelus* that increase the growth rate and decrease mortality (Videvall et al. 2023).

Among vultures, a few coprophagous species are recorded from the Old World and the New World: Egyptian Vulture *Neophron percnopterus* and Hooded Vulture *Necrosyrtes monachus*from in the Old World; Black Vulture *Coragyps atratus*, Turkey Vulture *Cathartes aura*, and Andean Condor *Vultur gryphus* in the New World (Blanco et al 2013; Reading et al. 2017; González-Jáuregui et al. 2021; de Moura & de Moura 2023).

Egyptian Vultures (EV) are among the most widespread species in India (Botha et al. 2017). The species is a scavenger but is known to feed on insects, reptiles and birds as well (Hidalgo 2005; Vittorio et al. 2017; Byju & Raveendran 2022). The nutritional benefits of coprophagy include the ingestion of pre-digested nutrients, calcium, and carotenoids, which enhance the yellow pigmentation of their facial skin, a trait associated with mate selection and social hierarchy (Negro et al. 2002; Blanco et al. 2013). This study presents observations of coprophagy in EV at Jorbeer carcass dump, emphasizing its ecological relevance.

The Jorbeer carcass dump (27.9663° N, 73.3769° E) falls within the Jorbeer Conservation Area and is situated on the outskirts of Bikaner City in Rajasthan. The Jorbeer Conservation Reserve covers an area of 57 km^2 with the carcass dump located on its edge spreading over 2.25 km^2 (Image 1). The reserve has a typical desert habitat with sand and scattered xerophytic vegetation, mainly consisting of *Capparis decidua*, *Acacia nilotica*, and *Prosopis cineraria.* It is an authorized municipal dump, and the cattle carcasses from all over the city of Bikaner are dumped here. The Municipality auctions the rights of carcass collection. The carcasses collected by the contractors are dumped here after skinning, the numbers varying 30–100 per day. The dump is frequented by four species of genus *Gyps*—Indian Vulture *Gyps indicus*, White-rumped Vulture *Gyps bengalensis*, Griffon Vulture

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Gyps fulvus, and Himalayan Vulture *Gyps himalayensis*. The other three species sighted are Cinereous Vulture *Aegypius monachus*, Egyptian Vulture, and Red-headed Vulture *Aegypius calvus*. Other facultative scavengers such as Steppe Eagle *Aquila nipalensis*, Tawny Eagle *Aquila rapax*, and Punjab Raven *Corvus corax subcorax* are also common. The stray dog *Canis domesticus* is the commonest mammalian species, followed by the Wild Boar *Sus scrofa* on the feeding ground.

Despite being a carcass dump, Jorbeer functions as part of a dynamic grassland ecosystem. The conservation of this area provides a safe habitat for arid land flora and fauna. The abundant carrion supply sustains a large number of raptors, making Jorbeer a critical foraging ground for resident and migratory scavengers.

We have been studying the EV population and behaviour since 2002, and this note covers the data till 2018 (Table 1). The coprophagy was noted opportunistically and photographed in earlier visits (n = 8) in 2003–05 (Images 2–4). In the photographs, one can see the small flock of EV waiting and feeding immediately on the scat as the dog moves away. During an intensive study at Jorbeer (n = 30 visits) in 2017–18, 10 more incidences were recorded. During all these observations (n = 18), the EV followed the dog, waited for it to excrete and immediately fed on it. On nine occasions, the EV were noted feeding on the dung of Cow *Bos indicus* (Table 1). The dung was from stray cows as well as from the stomach contents of the carcasses. During observations (n = 28), 36% of individuals were *N. p. gingianus* while 64% were *N. p. percnopterus*, as both subspecies are reported here. All of the sightings noted were in broad daylight. No agonistic response took place between the dogs and EV, nor did any other species compete in the coprophagy.

The EVs fulfil their requirement of carotenoids from the faeces of mammals (Negro et al. 2002). The carotenoids provide bright yellow colouration of bare skin on the face and legs in EV. Thus, coprophagy is beneficial for EV in partner selection and, ultimately, for the successful proliferation of the species. The high level of carotenoids in plasma correlated to a more colourful appearance and a higher position in the hierarchy in the Andean Condor as well (Blanco et al. 2013) and

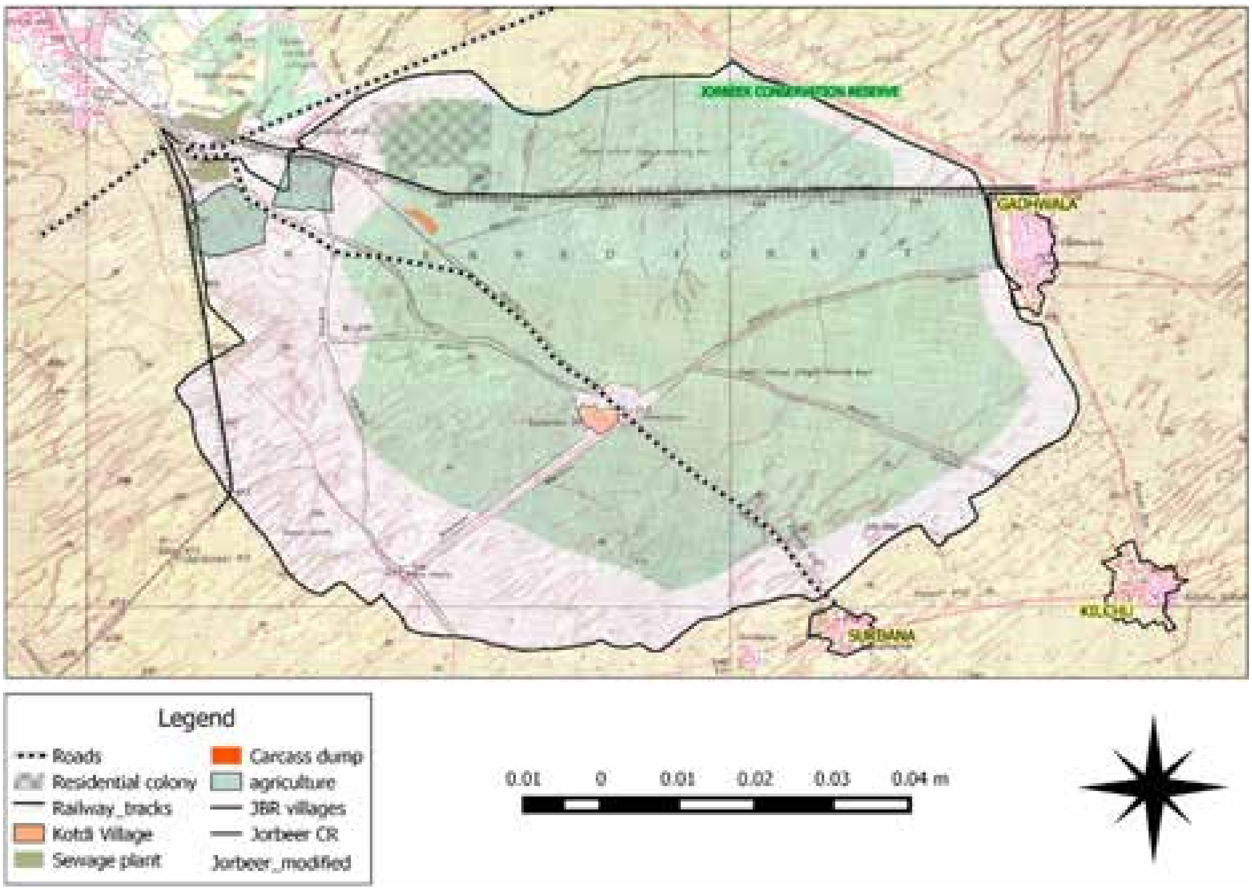

Image 1. Map of Jorbeer Conservation Reserve and it features.

Image 2. The Egyptian Vulture feeding on the scat while the dog defecating (2003). © Sachin Ranade.

Image 3. The flock of Egyptian Vultures waiting next to a defecating dog (2005a). © Sachin Ranade.

Image 4. The flock of Egyptian Vultures feeding on the excreta just after the dog moved away (2005b). © Sachin Ranade.

needs to be confirmed in EV as well. Whitehouse-Tedd et al. (2024) carried out a study on coprophagy by EV, recognizing the dangers of veterinary medicines in the dung, which may pose a future danger, and a similar study needs to be carried out in India to ensure safety in the local species, especially EV.

Table 1. Records of coprophagy by Egyptian Vulture (EV) at Jorbeer carcass dump.

	Date	Time	Feeding on	Number of Egyptian Vulture
1	10.vii.2017	1615	Cow dung	1
2	25.vii.2017	1736	Cow dung	1
3	11.x.2017	1725	Cow dung	3
4	04.xii.2017	1613	Cow dung	2
5	21.i.2018	1115	Cow dung	1
6	29.i.2018	0820	Cow dung	1
1	25.vi.2003	1000	Fresh dog scat	3
2	07.i.2005	1200	Fresh dog scat	5
3	06.iv.2017	0810	Fresh dog scat	2
4	29.iv.2017	0904	Fresh dog scat	1
5	23.x.2017	0955	Fresh dog scat	2
6	20.xii.2017	1000	Fresh dog scat	1
7	13.i.2018	1008	Fresh dog scat	1
8	29.i.2018	1715	Fresh dog scat	1
9	02.iii.2018	1600	Fresh dog scat	1
10	05.iii.2018	0830	Fresh dog scat	1

The EV is known to consume large crickets, termites, frogs, Checkered Keelback *Xenochrophis piscator*, and Ostrich eggs, as well as flamingos' eggs and nestlings. In Israel and Europe, they are known to feed on lizards, skinks, snakes, and rabbits; in Africa, nestlings of pelicans and Rock dove (Hidalgo 2005; Naoroji 2006; Vittorio et al. 2017). The niche-scavenging as well as taking advantage of such a varied diet, must have made this small vulture successful in the competition for survival among the vultures.

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NOTE

New record of cob-web spider species *Steatoda albomaculata* (De Geer, 1778) (Araneae: Theridiidae) from Kachchh, India with detailed distribution of Indian species of *Steatoda* Sundevall, 1833

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Abbreviations: ALE—anterior lateral eye | AME—anterior median eye | PLE—posterior lateral eye | PME—posterior median eye.

The cob-web spider family Theridiidae Sundevall, 1833 is the fourth largest family of the order Araneae Clerck, 1,757 and has 2,624 extant species belonging to 139 genera (WSC 2026), the genus *Steatoda* Sundevall, 1833, is cosmopolitan in distribution. Currently, it consists of 120 extant species, of which six species following, *Steatoda alboclathrata* (Simon, 1897), *Steatoda albomaculata* (De Geer, 1778), *Steatoda cingulata* (Thorell, 1890), *Steatoda erigoniformis* (Pickard-Cambridge, 1872), *Steatoda paykulliana* (Walckenaer, 1806) and *Steatoda rufoannulata* (Simon, 1899) were known from India (Caleb & Sankaran 2026). The known distribution records of these six species in India are compiled (Zamani et al 2022; Tripathi et al 2023; Parmar & Pandya 2025) and illustrated in Figure 1. Among these, a single species *S. erigoniformis* (Pickard-Cambridge, 1872) is reported in Gujarat (Parmar & Pandya 2025). Through recent investigations, we identified an additional species of genus *Steatoda* that has not been documented in Gujarat till date. Thus, this paper presents the new record and documentation of a species *Steatoda albomaculata* (De Geer, 1778), marking its first appearance from Kachchh district of Gujarat, India.

The specimens were hand-collected and studied under a Zeiss SteREO Discovery.V20 stereomicroscope and microphotographic images were taken by a Axiocam 208 colour digital camera attached to the stereomicroscope and enabled with the software Zeiss ZEN 3.3. The epigyne was dissected, soft tissues were cleared using 10% KOH and photographed by placing it in a cavity block filled with 70% ethanol, following Parmar et al (2024). All measurements are in millimetres (mm). The species was identified based on Levy & Amitai (1982) and Tripathi et al (2023). The examined specimens have been deposited in the reference collection of Department of Zoology, R.R. Lalan College,

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Bhuj-Kachchh, Gujarat, India.

Family Theridiidae Sundevall, 1833
Genus *Steatoda* Sundevall, 1833
Type species: *Araneus castaneus* Clerck, 1757

***Steatoda albomaculata* (De Geer, 1778)**
(Images 1–4)
Aranea albo-maculata De Geer, 1778: 257, pl. 15, f. 2–4
Steatoda albomaculata Levi, 1957: 396, f. 56–65

For a complete list of taxonomic references refer WSC (2026).

Materials examined: RRLC-ZC/SP-14, 28.v.2025, 2 female, India, Gujarat, Kachchh, near Lakhadi Village (23.2705^{0} N, 69.3823^{0} E), 216 m, from under stones in arid habitat, leg. S. Parmar.

Diagnosis: The species can be easily distinguished by following characters: female epigyne with sclerotized transverse, elevated bridge centrally and a median furrow bordered by fleshy folds on sides, oval-shaped spermathecae connected to coiled copulatory ducts.

Description: Female (in alcohol) (images 1–4) Body length 3.55. Carapace length 1.50, width 1.11. Abdomen length 2.21, width 1.61. Eye measurements and inter-distances: AME 0.08, ALE 0.08, PME 0.07, PLE 0.08, AME–ALE 0.03, PME–PME 0.05, ALE–ALE 0.32, PME–PLE 0.06, PLE–PLE 0.38, ALE–PME 0.12. legs Measurements: leg I 4.58 [1.37, 0.44, 1.05, 1.13, 0.59], leg II 2.96 [1.17, 0.34, 0.60, 0.48, 0.36], leg III 2.89 [0.97, 0.32, 0.52, 0.66, 0.42], leg IV 4.31 [1.36, 0.50, 1.03, 0.89, 0.52]. Leg formula: 1423. Carapace yellowish-brown, sternum light brown, ocular area black. Abdomen broad, oval-shaped, dorsally covered with white patch and black wavy pattern on lateral sides, ventrally dark brown at middle. Legs yellowish-brown with dark annulations. Epigyne (as in Images 3–4) brownish, large, with centrally elevated, sclerotized transverse bridge, a median furrow present, bordered by fleshy folds on sides (Image 3), spermathecae brown, compact, and oval-shaped connected to long copulatory ducts, coiling underneath (Image 4).

Natural history: *S. albomaculata* was found in the arid habitat of Kachchh, where it prefers dry and open areas with scattered vegetation. The species was encountered on the ground under stones. Two individuals were spotted at the same site at temperatures of 35–40 ^{0}C.

Distribution: North America, Europe, northern Africa, Russia (Europe to Far East), Caucasus, Iran, Kazakhstan, central Asia, western Asia, India, China, Korea, Japan (WSC 2026).

Distribution in India: Rajasthan (Tripathi et al. 2023), Gujarat (New record) (Image 5).

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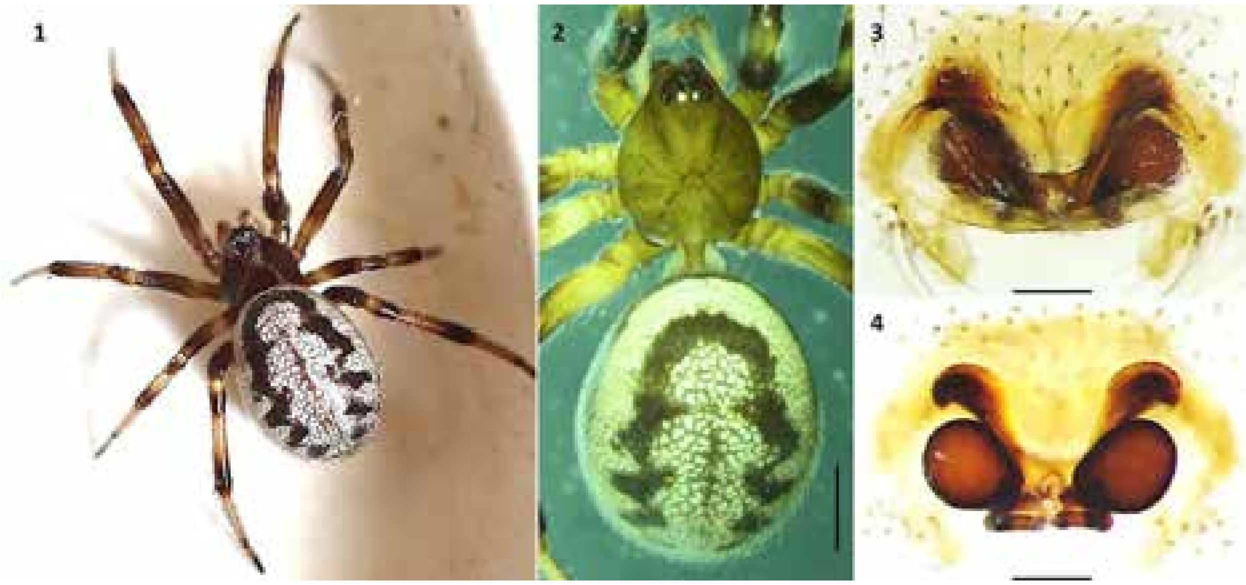

Images 1–4. *Steatoda albomaculata* (De Geer, 1778): 1—female habitus in life, dorsal view l 2—female habitus, dorsal view l 3—epigyne, ventral view l 4—same, dorsal view. Scale bars: 0.5 mm (1) l 0.1 mm (3–4). © Subhash Parmar.

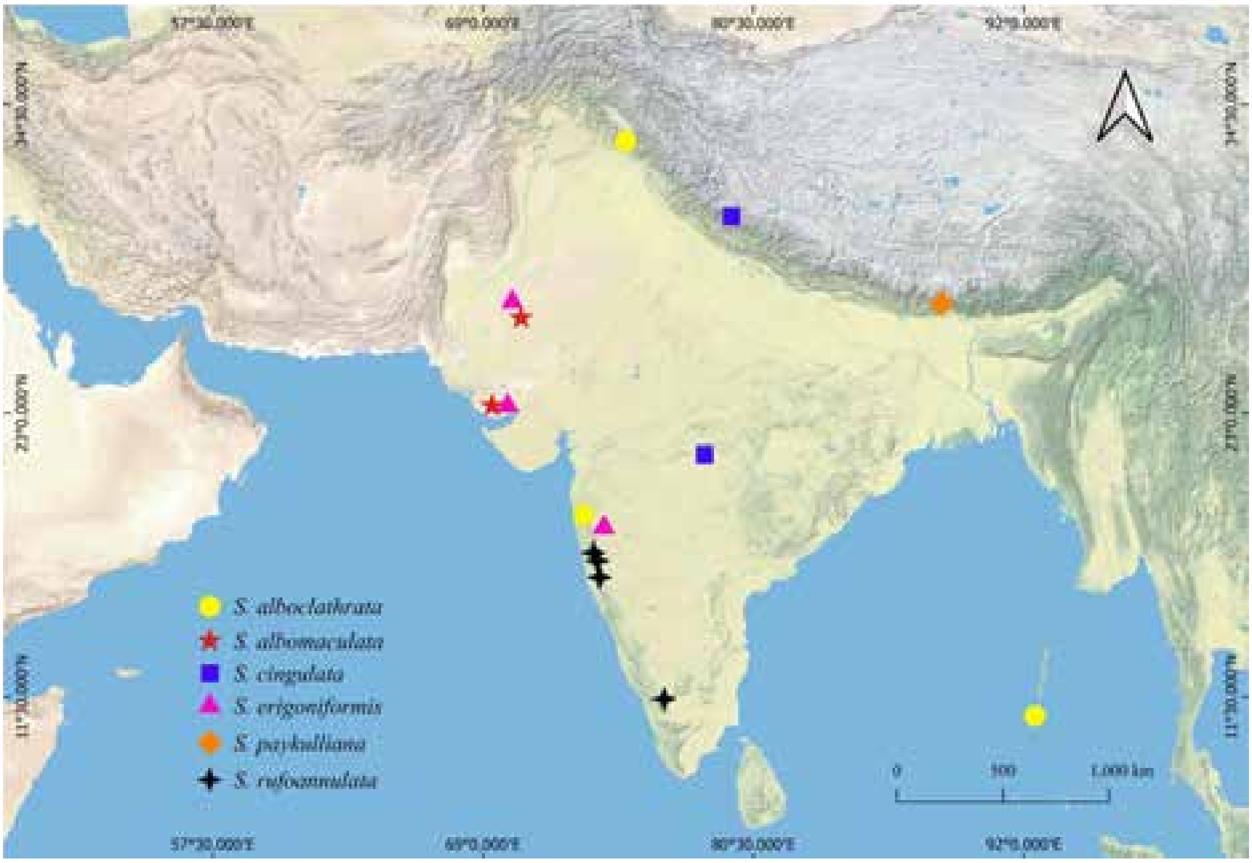

Image 5. Known distribution records of the six species of *Steatoda* Sundevall, 1833 reported from India.

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NOTE

Predation record of the hornet *Vespa basalis* Smith, 1852 (Hymenoptera: Vespidae) by the orb-weaver spider *Nephila pilipes* (Fabricius, 1793) (Araneae: Araneidae)

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Interactions between spiders and wasps represent a classic predator-prey arms race. Numerous hymenopteran lineages are associated with spiders through diverse ecological strategies. While pompilids, several crabronids, and sphecids actively hunt spiders, other families such as Ichneumonidae, Scelionidae, Encyrtidae, Eupelmidae, Eulophidae, and Pteromalidae primarily exploit spiders or their egg sacs as parasitoids or egg predators (Nyffeler & Birkhofer 2017). Conversely, some spiders, including jumping spiders (*Phidippus audax*), tarantulas (*Hysterocrates gigas*), wolf spiders (*Hogna carolinensis*), and orb-weavers (*Araneus trifolium*, *Argiope* spp. and even *Nephila* spp.) are known to opportunistically prey on wasps (Bristowe 1941; Tso et al. 2004; Foelix 2010; Noguchi & Ikeda 2022). Although orb-weaving spiders (Araneidae) occasionally prey upon hymenopterans (Tso et al. 2004), predation on large hornets (Vespinae), among the most formidable Hymenoptera, is exceedingly rare. Noguchi & Ikeda (2022) reported only a few cases involving *Argiope aurantia*, *A. amoena*, *A. bruennichi*, and *A. florida* preying on vespine wasps. In contrast, hornets (*Vespa* spp.) are efficient generalist predators, exploiting a wide range of prey, including other wasps as well (Ojha & Negi 2025). Predation by hornets on orb-weaving spiders, particularly by *Vespa mandarinia*, *V. crabro*, *V. simillima*, *V. analis*, *Vespula vulgaris*, *Ve. flaviceps*, *Ve. consobrina*, *Ve. pensylvanica*, *Ve. germanica*, and others, is frequently reported (Noguchi & Ikeda 2022). Additionally, kleptoparasitic interactions have also been recorded, such as *V. crabro* stealing prey from *Argiope bruennichi* webs (Davis 2011).

Here, we report a rare observation of a Giant Golden Orb Weaver *Nephila pilipes* (Fabricius, 1793) female capturing and immobilizing a Black-bellied Hornet *Vespa basalis* Smith, 1852, at the Dehradun Zoological Park (30.3899° N, 78.0765° E), Uttarakhand, India, on 10 November 2024. The spider was identified as an adult female *Nephila pilipes* (yellow morph) based on its external morphology, including the elongated opisthosoma with a broad yellow dorsal longitudinal band and the characteristic female epigynum with paired lateral indentations and a distinct posterior depression, following Sankaran et al. (2020). The hornet was identified as *Vespa basalis* based on its predominantly dark brown to black metasoma and diagnostic colour pattern, following Smith-Pardo et al. (2020). At 1408 h, a *V. basalis* hornet was observed entangled in the

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upper section of a large female *N. pilipes* web struggling vigorously. The spider cautiously approached the entangled hornet and promptly bit it with its chelicerae while skillfully avoiding the sting by manipulating and orienting the prey with its pedipalps and forelegs (Image 1). Following the initial bite, the spider wrapped the prey in situ before cutting it free from the web, the spider then transported the immobilized prey to the web hub using its chelicerae, where it was suspended within the hub silk (Image 2). The entire interaction lasted approximately 2–3 min (1408–1410 h); however, feeding was not observed because the observation ended shortly after prey immobilization. The observation was made within the Dehradun Zoo campus, a semi-urban green space characterized by mixed vegetation and scattered mature trees. The female *Nephila pilipes* occupied a large vertical orb web measuring approximately 1 m in diameter, suspended between adjacent Sal trees. The spider was estimated to be ≈50 mm in body length, while the captured *Vespa basalis* measured approximately ≈22 mm. Several additional mature female *N. pilipes* occupying large orb webs and free-flying *V. basalis* individuals were also observed in the surrounding area, which indicates that opportunities for such interactions are present within the study area.

Orb-web building spiders utilize a range of tactics to capture insects that are restrained in the web, and the choice of tactic varies among species and with prey type (Robinson & Mirick 1971). Most documented interactions between orb-weavers and vespine wasps involve species of the genus *Argiope* (Noguchi & Ikeda 2022), whereas records involving giant *Nephila* species are exceedingly scarce. This may be linked to the differences in hunting strategies between species of both genus: unlike *Argiope* spp., which typically immobilizes prey by rapidly wrapping before delivering a bite, *Nephila* spp. generally bite prey first and subsequently apply silk (Robinson & Mirick 1971). Such a strategy can be risky as it exposes the spider directly to the prey's defenses, particularly when the prey possesses effective defensive structures such as a sting (Foelix 2010). However, the apparent rarity of such interactions may also reflect limited observational studies rather than their actual frequency in nature.

The present observation therefore provides unique insight into the prey-handling behavior of *Nephila pilipes*, documenting a large female successfully capturing and immobilizing a large vespine hornet. The observed sequence of prey capture closely resembled the long bite and pull-out strategy followed by post-immobilization wrapping (Type I) described by Robinson & Mirick (1971). This observation indicates that large female *N. pilipes* are capable of subduing large vespine wasps despite their well-developed defensive structures. To our

Image 1. Adult female *Nephila pilipes* delivering an initial bite to the entangled *Vespa basalis* at the capture site. © Gautam.

Image 2. Post-immobilization prey handling, during which the spider manipulated the hornet and delivered successive bites before wrapping. Note the disturbance of the web caused by the struggle between predator and prey. © Gautam.

knowledge, this represents the first documented record of an interaction between *N. pilipes* and *Vespa basalis* from India, contributing to our understanding of spider-wasp interactions in the region and demonstrating that *N. pilipes* webs are capable of retaining and facilitating the capture of relatively large hymenopteran prey.

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NOTE

Notes on the occurrence of southeastern Asian taxon *Scopellaria marginata* (Blume) W.J.de Wilde & Duyfjes (Cucurbitaceae) in the Nicobar Islands: a new distribution record in the Indian part of Sundaland

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Abbreviations: NHCP—National Herbarium of Cultivated Plants | NBPGR—National Bureau of Plant Genetic Resources.

The genus *Scopellaria* W.J.de Wilde & Duyfjes, belonging to tribe Benincaseae Ser., is an Old-World genus comprising two species distributed from southern China through Indo-China to west Malesia (Schaefer & Renner 2011). Until two decades back, it was a part of *Zehneria* Endl., and it was de Wilde & Duyfjes (2006a), based on extensive field work and herbarium studies, who had recognised four new genera, namely, *Indomelothria* W.J.de Wilde & Duyfjes, *Neoachmandra* W.J.de Wilde & Duyfjes, *Scopella* W.J.de Wilde & Duyfjes, and *Urceodiscus* W.J.de Wilde & Duyfjes, all from Old-World, citing differences in the type of male inflorescence, the place of insertion of the stamens in corolla lobes, the shape of the anthers, the number of anther thecae, the presence or absence of disc and staminodes, and the shape of the stigma-lobes. Immediately after its publication, the name of the genus *Scopella* was understood as being the illegitimate later homonym of *Scopella* Mains (1939); therefore, a new name, *Scopellaria* W.J. de Wilde & Duyfjes, was validly published (de Wilde & Duyfjes 2006b).

As part of the Sundaland biodiversity hotspot, the flora of the Nicobar Islands closely resembles that of Malesia, and several plant families found in the Nicobar Islands are notably absent from the Andaman Islands (which fall under the Indo-Burma biodiversity hotspot and are primarily characterised by Indochinese elements). The richness of the Sundaland hotspot is witnessed by the presence of over 15,000, 115, and 138 endemic species of plants, mammals, and birds, respectively (Brooks et al. 2002). During the survey and field collection of plant genetic resources on Teressa Island of the Nancowrie group of Islands in the Nicobar Islands, the authors encountered a population of *Zehneria*-like herbaceous creeper-climber, characterised by the absence of probracts, yellow flowers, a long fruiting pedicel, and pitted seeds. After a critical study, and consulting relevant literature and matching digital images of herbarium specimens of Leiden Herbarium (L) and Kew Herbarium (K), the taxon is identified as *Scopellaria marginata* (Blume) W.J.de Wilde & Duyfjes. This genus has not been reported from India to date (vide Chakravarty 1982; Renner & Pandey 2013).

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Scopellaria marginata **(Blume) W.J.de Wilde & Duyfjes** in Blumea 51: 297. 2006; Fl. Thailand 9(4): 493. 2008; Fl. Malesiana 19: 215. 2010; — *Bryonia marginata* Blume, Bijdr. Fl. Ned. Ind. 15: 924. 1826; — *Melothria marginata* (Blume) Cogn. in A.DC. & C.DC., Monogr. Phan. 3: 593. 1881; — *Zehneria marginata* (Blume) Keraudren in Aubrév. & J.-F.Leroy, Fl. Cambodge, Laos & Vietnam 15: 55. 1975, pl. 9: 4; — *Scopella marginata* (Blume) W.J.de Wilde & Duyfjes, Blumea 51: 35. 2006, f. 9, nom. illeg. — Type: Blume 920 (holo L), Java.

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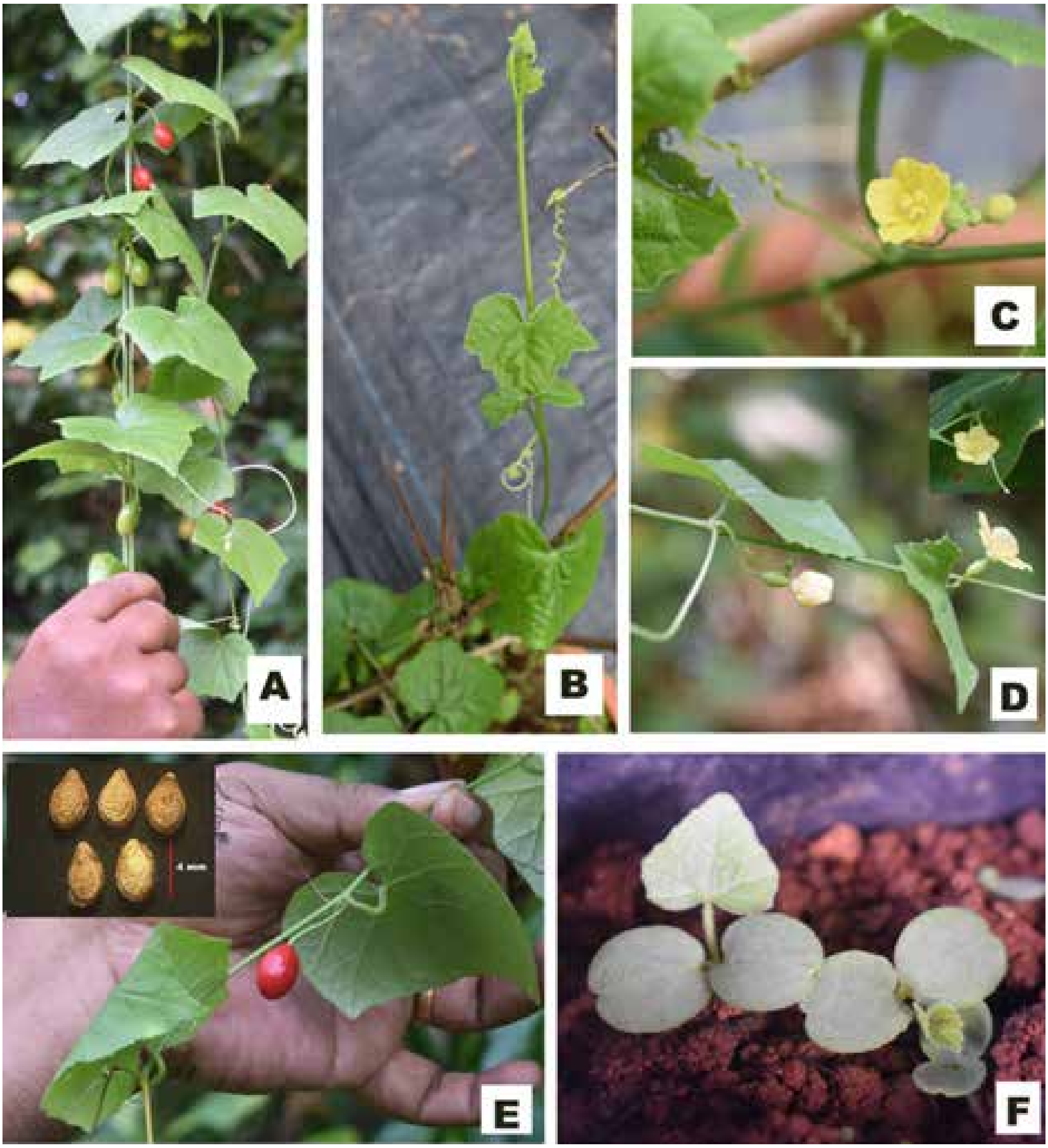

Image 1. *Scopellaria marginata* (Blume) W.J.de Wilde & Duyfjes: A—Habit – A portion of the plant with fruits | B—Young shoot | C—Male inflorescence showing opened flower | D—Solitary female flowers after and during anthesis (from left to right; inset: opened flower in top angle) | E—Fruit with long peduncle (inset: seeds) | F—Seedlings with cotyledonary leaves showing emarginate apex. © K. Pradheep.

Annual, herbaceous, monoecious climber or creeper, up to 5 m long; stems angular-sulcate, glabrescent, 1.5–2 mm diam.; probracts absent; tendrils simple, slender, white-hairy throughout. Leaves petioles 3–5 cm long, hairs soft, short, white; blades unlobed, initially broad cordiform, later subangulate, 3-angled, green above and pale green below, 5.5–9.0 x 3.5–6.0 cm, adaxially short-hairy, scabrous (due to cystoliths), abaxially coarsely short-hairy on the veins, base rounded or deeply cordate, margins coarsely dentate. Male inflorescences occasionally coaxillary with earlier developed female flower, 5–8 flowered in a 3–5 cm long raceme, glabrescent; bracts absent; peduncle c. 2 cm long; flowers crowded at the apex. Staminate flowers pedicel 5–6 mm long; receptacle tube campanulate, c. 1.5 mm diam., coarsely hairy outside; sepals ovate-triangular, patent, c. 1 mm long; petals imbricate, yellow, obovate, apex rounded, c. 3 x 2.5 mm, papillose; stamens 3, inserted in the throat of receptacle, filaments c. 1 mm long, slender, anthers ellipsoid, exserted, 2-thecous, anther thecae lateral, straight, c. 1 mm long; disc subglobose. Pistillate flowers solitary, pedicel 2–2.5 cm long; ovary ellipsoid, with sparse hairs, subglabrescent; receptacle tubes shallow; sepals as in male flower; petals obovate, apex rounded or subobtuse, 3–4 cm long, papillose; styles short, stigmas enlarged, constitute 3 feather-like arms, each 2-lobed, fringed on margin; staminodes linear, c. 1 mm long; disc rudimentary. Fruits pedicels 2.3–3 cm long; pepos ellipsoid, glabrous, 1–1.5 x 0.6–0.7 cm, red upon ripening, exocarp leathery, ripe fruits juicy. Seeds 15–23 per fruit, pale yellow to whitish, ovate, compressed, 4–4.2 x 2.6–2.7 x c. 1 mm, distinctly square-margined, faces coarsely scrobiculate. Seedlings cotyledonary leaves subrotund, short-hairy, emarginate at apex (Image 1 & 3).

Flowering & Fruiting: July–February & August–April.

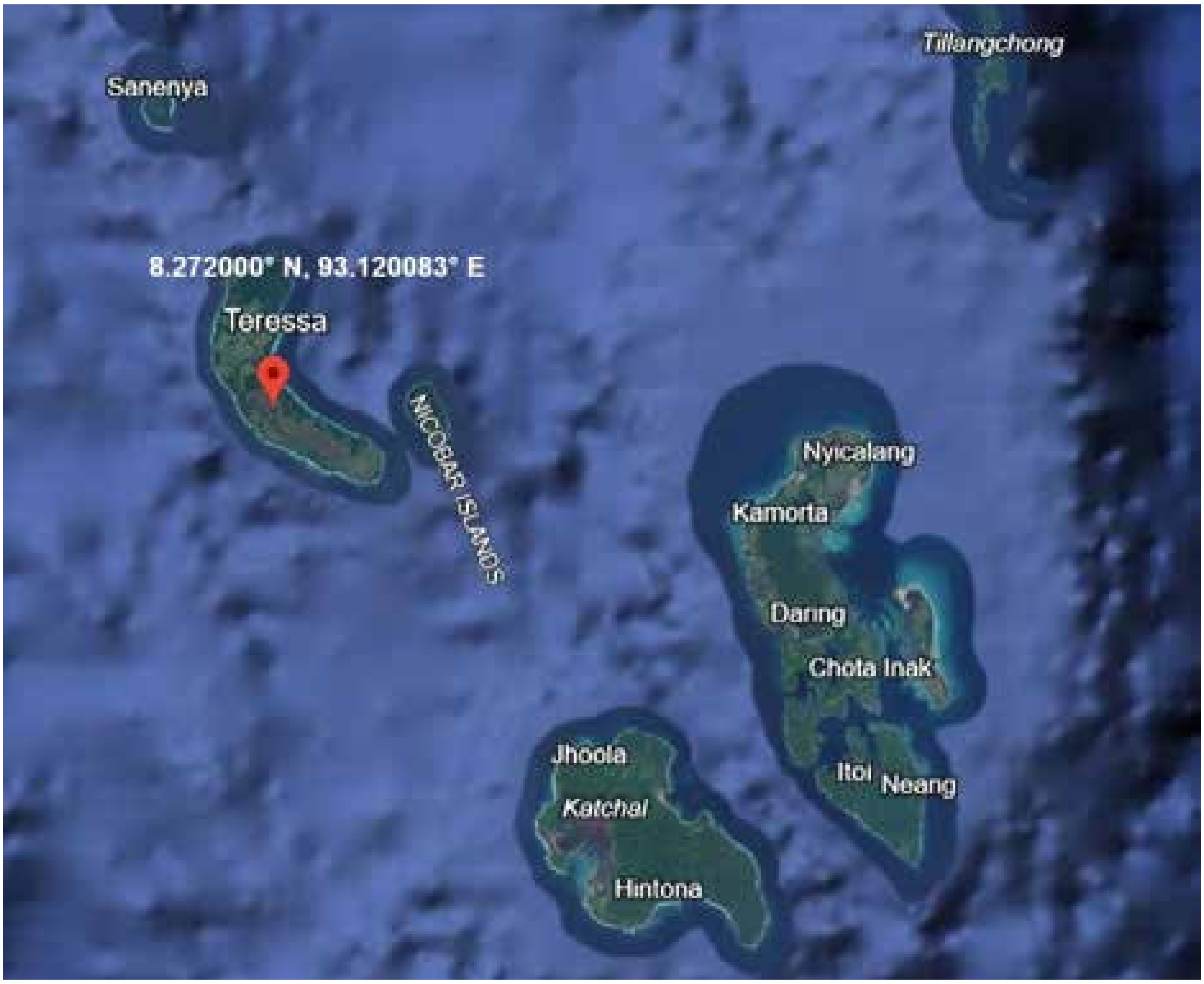

Image 2. Collection site (indicated by a red peg) of *Scopellaria marginata* in Teressa Island of the Nancowrie group of Islands in the Nicobar District, Andaman & Nicobar Islands. Source: Google Earth, https://earth.google.com/web/.

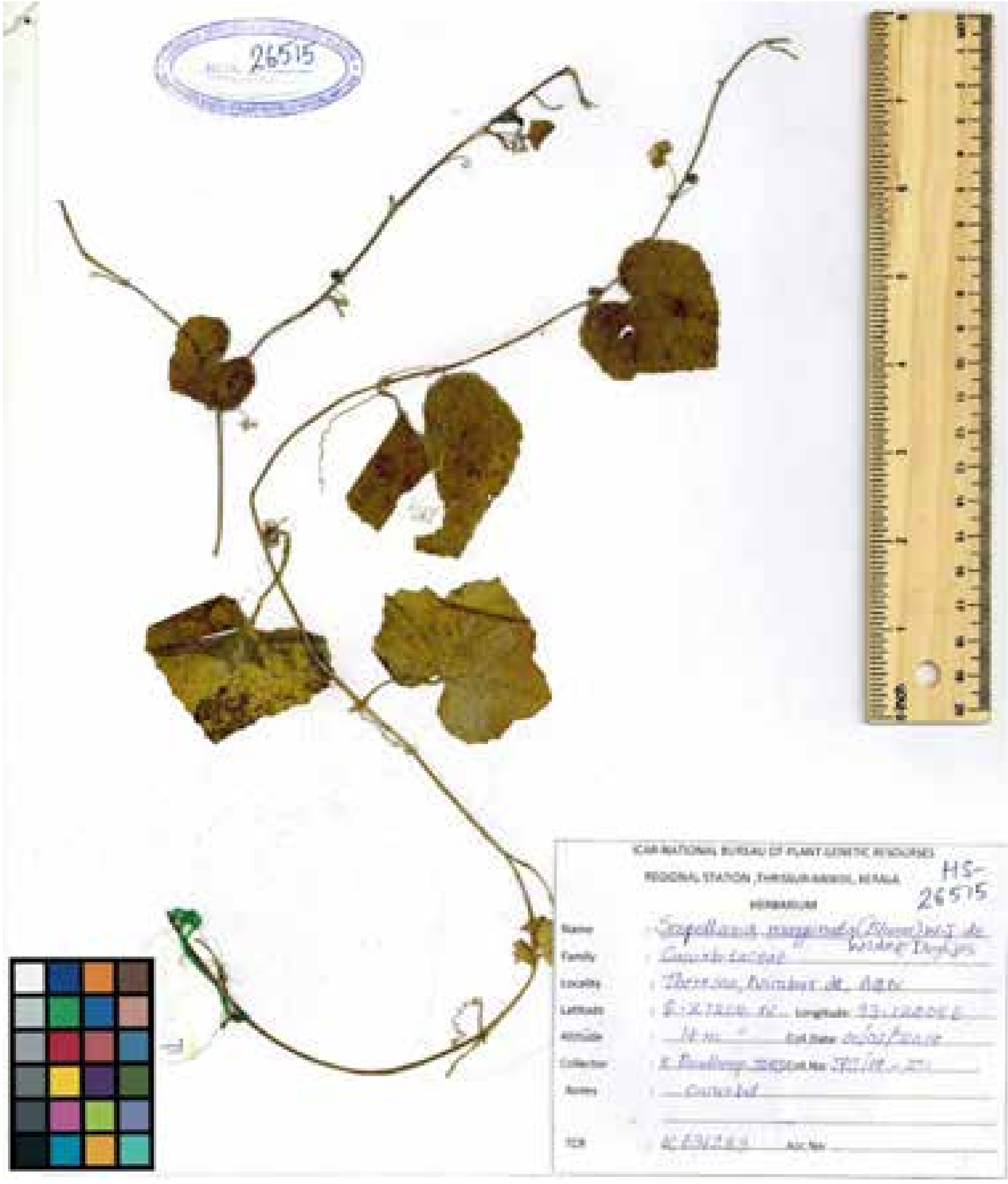

Image 3. Herbarium of *Scopellaria marginata* deposited in NHCP, New Delhi.

Ecology: In thickets along forest edges and roadsides, at altitudes of 14 m. Associated species are *Macaranga nicobarica* N.P.Balakr. & Chakr., *Stephanotis floribunda* (L.f.) S.Reuss, Liede & Meve, *Terminalia citrina* (Gaertn.) Roxb., *Cissus* sp., *Stephania* sp., and *Sterculia* sp.

Distribution: Myanmar (East), China (South-central), Thailand, Laos, Cambodia, Vietnam, Malaysia (Peninsular Malaysia, Sabah, Sarawak), Indonesia (Java, Kalimantan, Sumatra, Sulawesi), Philippines (POWO 2025; de Wilde & Duyfjes 2010), and India (Nicobar Islands).

Specimens collected: K Pradheep 3183 [NHCP26515], 02 February 2019, 8.2720° N, 93.1200° E, elevation at 14 m, 1 km before Minyuk from Haonin, Teressa Island, Nicobar District, Andaman & Nicobar Islands, India (Image 2). The specimen was originally prepared from ICAR-NBPGR Regional Station, Thrissur, and was deposited in NHCP, NBPGR, New Delhi (Image 3). Seed material (JPJ/19-271; IC631283) has been conserved with the National Genebank, ICAR-NBPGR, New Delhi.

Population: The authors could observe only about 10 plants at the site. It remains unclear whether this disjunct distribution is the result of long-distance dispersal or historical vicariance. In general, the dispersal of small-fruited wild cucurbits with red skin is mediated by birds, which might have led to the spread of this species from neighbouring territories of Thailand

and Indonesia (Sumatra). Enquiry with villagers revealed their unawareness about this plant, indicating its rare nature or recent occurrence. Future molecular studies could help resolve these alternative explanations and provide insights into the biogeographic history of the species.

Notes: Reported to be highly variable with leaf lobing nature, fruit shape and length of fruiting pedicel; however, the population in Teressa Island has ellipsoid-shaped fruits and unlobed leaves with cordate outline. Cotyledonary leaf characters of this species are described for the first time. Jansen et al. (1991) mentioned that its fruits are edible and are employed as a remedy against coughs. Though reported (de Wilde & Duyfjes 2006a, 2008, 2010), we refrain from further classifying the variability within *S. marginata*; as the two varieties (var. *marginata* and var. *penangense* W.J.de Wilde & Duyfjes) have overlapping distribution patterns and no good characters to distinguish them. Nevertheless, our collection matches more closely with var. *penangense* due to its unlobed leaf blades, short ellipsoid fruits and seed length exceeding 4 mm.

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