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Cover Image: Adult Spot-billed Pelican (*Pelecanus philippensis*) perched atop a tamarind tree (*Tamarindus indica*) at Kokkare-Bellur Community Reserve, Karnataka, India, displaying its distinctive spotted bill and breeding plumage. © Manjunathan Jayaseelan

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Content

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TYPE Review Article

Dark side of the development: A Review on Road Mortality of Wildlife in the Western Ghats Biodiversity Hotspot

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Abstract

Road mortality of wild animals has been documented across the Western Ghats biodiversity hotspot. However, a comprehensive review of these studies is lacking, which is imperative for the implementation of mitigation measures. In this context, this study presents a systematic review of peer-reviewed articles on road mortality of wild animals in the Western Ghats to identify species most vulnerable to roadkill, assess mortality rates across taxa, and highlight research gaps. We analysed 32 research articles, including six short communications and 26 full-length articles published from 1997 to 2023. The results reveal a geographical bias in the available road mortality data, with most studies conducted on the eastern slopes of the southern Western Ghats. Across the reviewed literature, 166 vertebrate species (21 amphibians, 74 reptiles, 40 birds and 31 mammals) and 73 invertebrate species (excluding unidentified species) were documented as roadkill. Among them, 51 vertebrate species were endemic to the Western Ghats. Reptiles constituted the highest proportion of species killed, with snakes facing most of the mortality cases (43% of snakes endemic to the Western Ghats). Overall, 4,960 vertebrate individuals were recorded as roadkill, with amphibians constituting the majority (52% of total vertebrate mortality), followed by reptiles (30%). Notably, nearly 53% of the recorded vertebrate mortalities were not identified to the species level. The overall estimated mortality rate was 0.014 kills per kilometre, with a wide variation among the studies: 0.72–137.3 kills/km for invertebrates and 0.006–40 kills/km for vertebrates. The mortality rate reported for amphibians was relatively higher in the wet-zone sites of the Western Ghats compared to the dry-zone sites. We discuss these results in detail, emphasising research gaps and biases in road mortality studies alongside future research directions and mitigative measures in the Western Ghats.

Keywords: Amphibian, biodiversity hotspot, endemic species, reptile, road ecology, south India, wildlife roadkill.

Introduction

Globally, road networks spanning 64 million kilometres have been established (CIA, 2024), facilitating human mobility and the transportation of goods (van der Ree *et al.,* 2015). A recent meta-analysis reveals a concerning trend: nearly 80% of the world's roadless areas are highly fragmented, consisting of almost 6,00,000 distinct patches, half of which are smaller than 1 km^2 (Ibisch *et al.,* 2016). Projections indicate road and rail networks will expand over 60% between 2010 and 2050 (Dulac, 2013; Laurance *et al.,* 2014), with significant growth expected in biodiversity-rich developing countries. Roads often lead to contagious development, *i.e.*, the establishment of new settlements and habitat conversion for agriculture. The environmental impacts of roads are profound, encompassing both direct and indirect effects, immediate and long-term. These include habitat loss and fragmentation, changes in microclimate, increased windthrow, heightened wildfire risks, animal injuries and mortality, changes in animal behaviour, population isolation, increased pressures from tourism and hunting, and elevated levels of pollution (Spellerberg, 2002; see examples in van der Ree *et al.,* 2015). Among these, road mortality remains the most detrimental and severe threat to wildlife (Trombulak & Frissell, 2000). Therefore, understanding vulnerable species and road mortality rates across sites and species is crucial for informing road policies, and management practices, and mitigating adverse effects on biodiversity.

Wildlife-vehicle collisions, or road mortality or roadkill, refer to any case where animals are killed or injured to death by vehicles (ranging from motorcycles to heavy trucks). The estimated/actual roadkill values globally reveal alarming figures: annual bird mortality is 340 million in the USA, 194 million in Europe, and 138 million in Canada (Calvert *et al.,* 2013; Loss *et al.,* 2014; Grilo *et al.,* 2020); mammal mortality in Europe is 29 million (Grilo *et al.,* 2020), and vertebrate deaths in China average 6.35 individuals per 100 km per day. A recent consortium on Global Roadkill Data (Grilo *et al.,* 2025) compiled nearly 2,00,000 observations across 54 countries, revealing that mammals account for the highest road kills (61%), followed by amphibians (21%) and reptiles (10%). Although some species may experience low road mortality rates, species already threatened by other factors and with slow reproductive rates may find it challenging to recover from the losses, increasing the risk of local extinctions (Quintana *et al.,* 2022; Grilo *et al.,* 2025).

India has the second longest road network in the world, spanning approximately 63,45,403 km, which includes over 1,46,145 km of National Highways (NH), about 1,79,535 km of State Highways (SH), and about 60,19,723 km of other roads (MoRTH, 2024). In the Western Ghats region, around 26,482 km of roads have already been constructed, including 7,182 km of NH, 8,122 km of SH, and the remaining being other roads. The Western Ghats is one of the biodiversity hotspots in the world (Myers *et al.,* 2000; Mittermeier *et al.,* 2011), and it is globally recognised for its rich biodiversity and high degree of vertebrate endemism (Myers *et al.,* 2000; Gunawardene *et al.,* 2007). For instance, 91% of the amphibian species found here are endemic (Dahanukar & Molur, 2020), and 73% of reptile species found in the region are endemic to India (9% are endemic to the Western Ghats; Srinivasulu *et al.,* 2021). Despite this rich biodiversity and endemism, large stretches of natural forests in the Western Ghats have seen conversion for monoculture and economically-important/cash crops (*e.g.*, tea, coffee) over different time periods (Menon & Bawa, 1998; Jha *et al.,* 2000). To support these plantations, human settlements were established in various parts of the Ghats (Gadgil, 1979). In later years, these high-elevation regions were exploited for tourism-related activities, including pilgrimages (Seshadri & Ganesh, 2015), following the implementation of land transformation policies. This increased the necessity for several roads along the Western Ghats to facilitate the movement of people and goods. Many of these roads connect important tourist destinations, major cities or pilgrimage sites in the Western Ghats (Baskaran & Boominathan, 2010; Bhupathy *et al.,* 2011; Seshadri & Ganesh, 2011; Seshadri & Ganesh, 2015; Jeganathan *et al.,* 2018a), carrying heavy vehicular traffic through ecologically fragile landscapes, including tiger reserves and wildlife sanctuaries, leading to enormous wildlife road mortalities (*e.g.* Mudumalai Tiger Reserve – Baskaran & Boominathan, 2010; Kalakkad-Mundanthurai Tiger Reserve – Seshadri & Ganesh, 2011).

While several studies have documented road mortality in the Western Ghats, few have evaluated the effectiveness of mitigation strategies, with a few initiatives where mitigation measures were implemented for reducing roadkill (*e.g.*, the canopy bridge for arboreal mammals in Valparai – Jeganathan *et al.,* 2018b). However, such measures rarely address the mortality of smaller vertebrates or invertebrates. To initiate effective mitigation measures for these taxa, it is important to identify vulnerable species and mortality rates across taxa and sites for the Western Ghats. The existing literature on road mortality studies in the Western Ghats is fragmented, impeding an understanding of the overall picture of this understudied yet critically important conservation issue. In this context, we attempted to collate published works on road mortality of wild animals in the Western Ghats to identify vulnerable species, mortality rates of various taxa, and bias in road mortality studies.

Methods

To investigate the patterns of road mortality among wildlife (both invertebrates and vertebrates) in the Western Ghats, we conducted a systematic literature survey of all published articles (including short communications and research articles) using three academic search engines: Google Scholar, ResearchGate, and Web of Science. The search employed the following combinations of keywords: "Roadkill+Western+Ghats"; "Road+mortality+Western+Ghats"; "Road-kill+Western+Ghats"; "Vehicle+traffic+mortality+Western+Ghats". From this search, we collated 42 publications addressing road mortality studies in the Western Ghats, encompassing a wide array of taxonomic groups from invertebrates to higher vertebrates. In the first level of filtering, we omitted articles published in predatory journals (n=8) as well as theses, dissertations, and reports, to include only peer-reviewed articles. Such literature was also excluded because of its limited accessibility and uncertain availability. Data presented in predatory journal publications were excluded due to the lack of a peer-review process (journals listed at https://www.predatoryjournals.org/the-list/journals) and the lack of DOI numbers. In the second level of screening, we excluded duplicate publications that contained the same data appearing in multiple sources, and retained only one version for our analysis (n=2). Thus, this review focused exclusively on articles published in peer-reviewed journals, with non-repetitive information (Supplementary 1).

From the selected articles, we extracted all available data to create a comprehensive database of roadkill information. This database includes critical information such as locations (GPS coordinates, state, and district-level information), year and month of data collection, habitat types examined (as specified in the article), lengths of the road surveyed (in km), number of replications, species and number of individuals killed (including unidentified species), and publication details (author, year and journal). In addition to this data, we compiled species-wise conservation status (based on the IUCN Red List category (www.iucnredlist.org/)), classifications under the Schedule of the Indian's Wild Life (Protection) Act, 1972, as amended in 2022, habit, venomous/non-venomous (in the case of snakes), taxonomic classifications (order, family, and scientific and common names) and endemicity status pertaining to all recorded instances of road mortality (Dahanukar, 2020; Srinivasulu *et al.,* 2021; Nameer, 2020). We plotted study locations and checked for geographical patterns among the publications using QGIS version 3.14 (QGIS Development Team, 2020). We calculated the mean road mortality rate for species (hereafter "mortality rate") by dividing the number of recorded kills by the total survey effort (*i.e.*, kilometres surveyed multiplied by the number of replicates) from studies that reported this information.

Result

As a result of the filtering process, we retained 32 publications – including 26 research articles and six short communications – covering four states for this study (Figure 1 and Supplementary 1). The total surveyed road length across the 32 studies was 511.81 km.

Spatial distribution of road mortality studies:
The spatial analysis of the locations of road mortality studies across the Western Ghats revealed that a large proportion of studies were conducted in the southern Western Ghats (n=27), particularly within the Nilgiris (n=17) and Anamalai (n=6) landscapes. In contrast, fewer studies were conducted in the central (n=3) and northern (n=2) Western Ghats (Figure 1). Most studies focused on selected taxa or multiple vertebrates (n=23), with a few studies collecting information on invertebrates as well (n= 8). The studies spanned across various seasons – dry, *i.e.*, March to June (n=2), wet, *i.e.*, June to December (n=15), dry and wet seasons (n=12) – and habitats – from dry thorn forests to high-elevation evergreen forests and plantations. A majority of the studies were conducted during the wet season and in dry forests (n=9), and agricultural areas and plantations (n=10).

Diversity of fauna in road mortality studies

Species inventory:
Altogether, 6,507 individuals of various taxa (1,547 individuals of invertebrates and 4,960 individuals of vertebrates), including

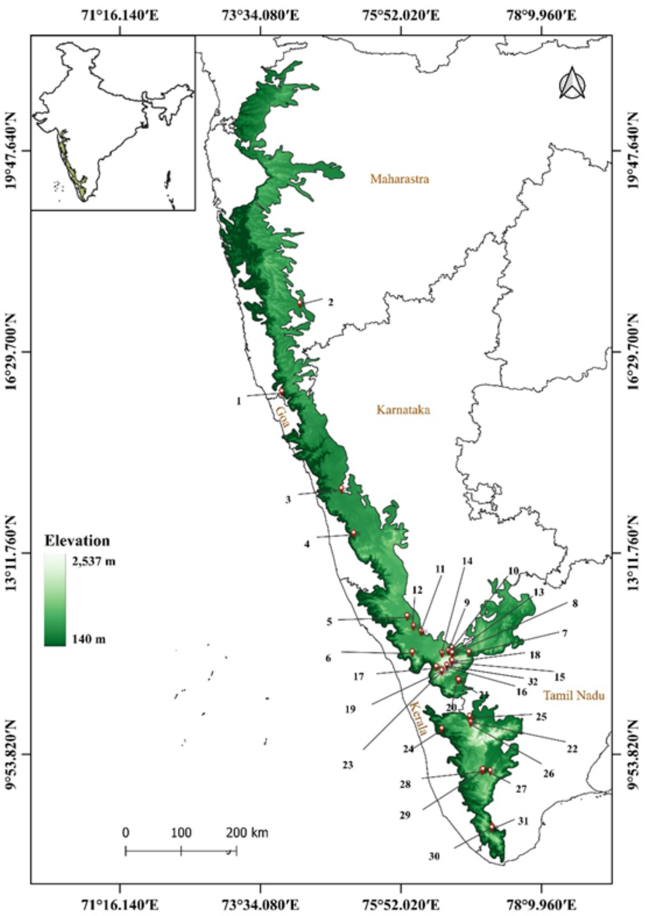

Figure 1. Spatial distribution of road mortality studies across the Western Ghats.
Note: 1 - Gaitonde *et al.,* (2016); 2 - Kumbar & Lad, (2017); 3 - Seshadri *et al.,* (2009); 4 - Correa *et al.,* (2023); 5 - Bansal, (2020); 6 - Roshnath & Cyriac, (2013); 7 - Deb & Sengupta, (2020); 8 - Samson *et al.,* (2020); 9 - Samson *et al.,* (2016); 10 - Khanduri *et al.,* (2022); 11 - Rao & Girish, (2007); 12 - Selvan *et al.,* (2012); 13 - Gokula, (1997); 14 - Baskaran & Boominathan, (2010); 15 - Santhoshkumar & Kannan, (2017); 16 - Santhoshkumar *et al.,* (2016); 17 - Kannan, (2007); 18 - Santhoshkumar *et al.,* (2017); 19 - Vadivalagan *et al.,* (2012); 20 - Prakash & Karthik, (2021); 21 - Sony & Arun, (2015); 22 - Kumara *et al.,* (2000); 23 - Balakrishnan, (2007); 24 - Yadav *et al.,* (2022); 25 - Jeganathan *et al.,* (2018a); 26 - Vijayakumar *et al.,* (2001); 27 - Ganesh & Chandramouli, (2020); 28 - Bhupathy *et al.,* (2011); 29 - Selvan, (2011); 30 - Narayanan, (2015); 31 - Seshadri & Ganesh, (2011); 32 – Samson & Princy, (2023).

unidentified species, were killed. Out of 6,507 individuals, only 2,820 (43%) individuals of 235 species were identified up to species level, *i.e.*, nearly 57% of the mortalities were unidentified (Figure 2). Among higher vertebrates, species-level identification was available for only 47% of the mortalities, while the remaining 53% could not be identified up to species level.

Between 1997 and 2023, studies reported 239 species of invertebrates and vertebrates belonging to 70 families as road kill along the sampled roads of the Western Ghats. Of these, 73 species were invertebrates belonging to eight families (one wasp, three dragonflies, and four butterfly families). The remaining 166 species, which accounted for 14% of the total vertebrate diversity of the Western Ghats, consisted of 74 reptiles (18 families), 40 birds (22 families), 31 mammals (16 families) and 21 amphibians (six families) (Supplementaries 2–6). Excluding unidentified species, road mortality affected 28% of reptiles (15 lizard species, 42 snake species, 14 worm snake and shieldtail species, three turtle and tortoise species), 25.6% of mammals (four primate species, nine rodent species, eight carnivore species, six ungulate species, one hare species, one shrew species, one bat species, domestic dog), 8% of

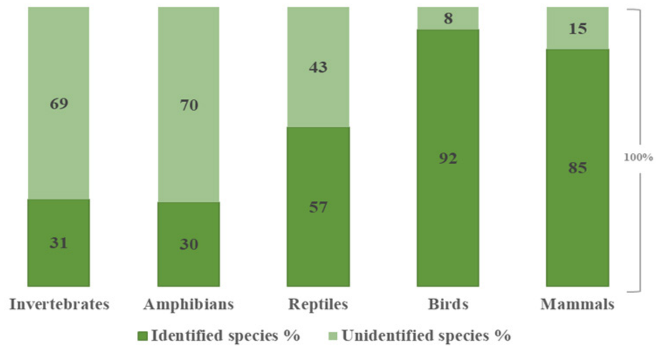

Figure 2. Percentage of kills identified up to species level across taxa in the Western Ghats.

Table 1. Number of higher vertebrate species affected due to vehicular movement in the Western Ghats

Taxa	No. of species in the Western Ghats	No. of families in the Western Ghats	No. of species killed (%)	No. of families killed (%)	Source
Amphibians	252	11	21 (8.3%)	6 (54.5%)	Dahanukar & Molur, 2020
Reptiles	264	24	74 (28%)	18 (75%)	Srinivasulu *et al.,* 2021
Birds	529	85	40 (7.6%)	22 (25.9%)	Minsa, 2018
Mammals	121	31	31 (25.6%)	16 (51.6%)	Nameer, 2020

amphibians (two toad species, 18 frog species, one caecilian species), and 7.6% of bird species found in the Western Ghats (Table 1 and Supplementaries 2-6).

Endemicity:
Out of 446 endemic vertebrates (excluding fishes) in the Western Ghats, nearly 51 (n = 682; 13.79%) endemic vertebrates were reported as road fatalities, including 31 reptile species, 14 amphibian species and six mammal species. Endemic vertebrates that were recorded as road kills included *Uropeltis ocellatus*, *Uropeltis ceylanica*, *Minervarya nilagirica*, *Uperodon triangularis*, *Salea horsfieldii*, *Xylophis perroteti*, *Plectrurus perroteti*, *Beduka amboli*, and *Hylarana spp.* (Supplementaries 2-6).

Conservation status of roadkilled species:
Of the 166 vertebrate species, 18 (n = 122; 2.47%) species were listed under one of the IUCN threatened categories (CR, EN, and VU). This included seven mammal species (five Vulnerable and two Endangered), eight reptile species (six Vulnerable and two Endangered), and three amphibian species (all Endangered; Supplementaries 2–6). Among Endangered vertebrates, lion-tailed macaque *Macaca silenus*, Nilgiri tahr *Nilgiritragus hylocrius*, red-spotted earth snake *Uropeltis rubromaculata*, Travancore shieldtail *Rhinophis travancoricus*, Boulenger's bubble-nest frog *Raorchestes signatus*, spotted bush frog *Raorchestes tinniens*, and Amboli rock toad *Xanthophryne tigerina* were reported in the studies. Some of the Vulnerable species reported were bonnet macaque *Macaca radiata*, leopard *Panthera pardus*, spiny tree mouse *Platacanthomys lasiurus*, nilgiri langur *Semnopithecus johnii*, sambar Deer *Rusa unicolor*, Indian star tortoise *Geochelone elegans*, Indian flap-shell turtle *Lissemys punctata*,

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Western Ghats king cobra *Ophiophagus kaalinga*, Phipson's shieldtail *Uropeltis phipsonii*, two-lined black earth snake *Melanophidium bilineatum* and shorthead kukri snake *Oligodon brevicauda*. Out of the 239 species, 103 were listed under different schedules of India's Wild Life (Protection) Act, 1972, as amended in 2022. Twenty-three species were under Schedule I, which included two birds, 13 mammals, and eight reptiles; 43 species were under Schedule II, which included 31 birds, eight mammals, and four reptiles; one species of mammal under Schedule III, and 36 species under Schedule IV, which included two mammalian and 34 reptilian species (Supplementary 2-6). In addition, 682 individuals (13.79%) of endemic vertebrates and 122 individuals (2.47%) of globally threatened vertebrates were reported in road mortalities.

Most frequently killed species:

The species most affected by road mortality in terms of the number of road-killed individuals found varied between sites and studies. However, common Asian toad *Duttaphrynus melanostictus*, Oriental garden lizard *Calotes versicolor*, *Uropeltis spp.*, and *Ahaetulla spp.* were reported to be killed most frequently across the study locations (Table 2).

Road mortality rate

Among vertebrate road kills, amphibians (52.16%) were more abundant than reptiles (30.15%), mammals (15.96%), and birds (1.73%).

We calculated mortality rates using information from the 18 studies that mentioned survey effort and total mortalities. The overall mortality rate for animals across these study sites ranged from 0.006 to 137.3 kills/km. Mortality rates for invertebrates and vertebrates varied widely between the studies, ranging from 0.72 to 137.3 kills/km for invertebrates and 0.006 to 40 kills/km for vertebrates. Wayanad had the highest mortality rates for invertebrates, while Sharavati had the highest rates for vertebrates (Figure 3). The mortality rate for amphibians across the studies ranged from 0.02 to 2.0 kills/km, except in Sharavati (40 kills/km) and Kalakad Mundanthurai Tiger Reserve (KMTR) (31.7 kills/km), where the highest road mortality was reported. Amphibian road mortality rates were relatively lower in Mudumalai and Bandipur Tiger Reserves, compared to Mukthikulam and Sharavati. Reptile mortality rates were also relatively higher in KMTR and Anamalai Tiger Reserve (Figure 3). In contrast, birds and mammals exhibited relatively lower mortality rates across most sites, except in KMTR, where a maximum of 0.79 kills/km was reported for mammals. In terms of species' habit, terrestrial and semi-aquatic amphibian species were more vulnerable to roadkill (Figure 4), whereas arboreal and fossorial species showed greater vulnerability among reptiles (Figure 5).

Discussion

Our review of wildlife road mortality studies in the Western Ghats biodiversity hotspot revealed that invertebrates, amphibians, and reptiles are more vulnerable to vehicle-induced mortality, both in terms of the number of species and individuals killed. We found that mortality rates for these taxa were relatively higher in sites such as Mukthikulam and Shravati, which are high-rainfall (wet) zones of the Western Ghats, which can be attributed to prolonged breeding and hydroperiod-mediated migration. Furthermore, our results suggest that current roadkill assessments across the Western Ghats have not been adequately covered in terms of taxa (*e.g.*, invertebrates), spatial and temporal scope, and that several methodological artefacts exist.

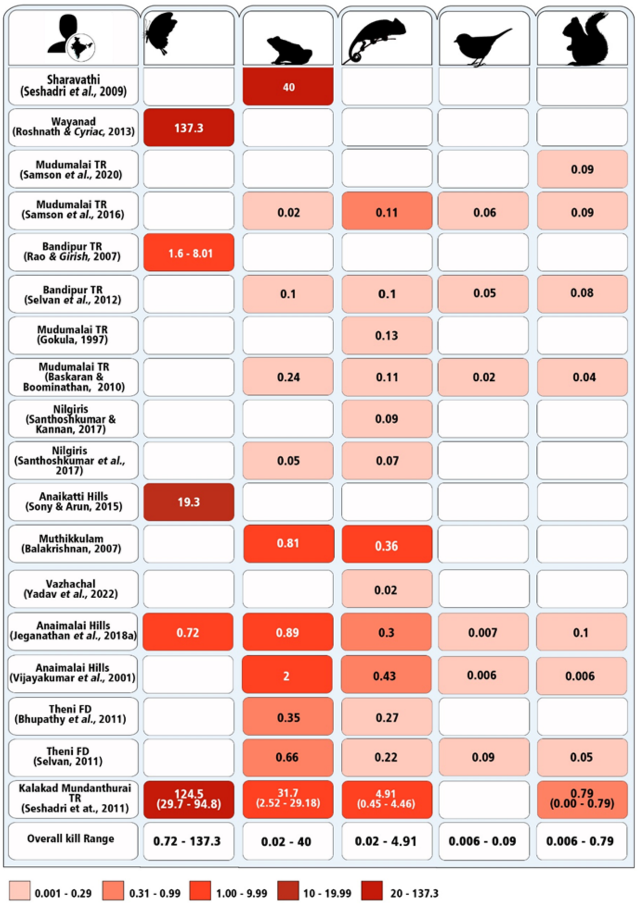

Figure 3. Road mortality rate (Number of kills/km/visit) of invertebrates and vertebrates (including unidentified species) in various studies along the Western Ghats between 1997 and 2023 (Kalakad Mundanthurai TR (Seshadri *et al.,* 2011) – Overall mortality rate/km/visit (Before and During religious tourism season).

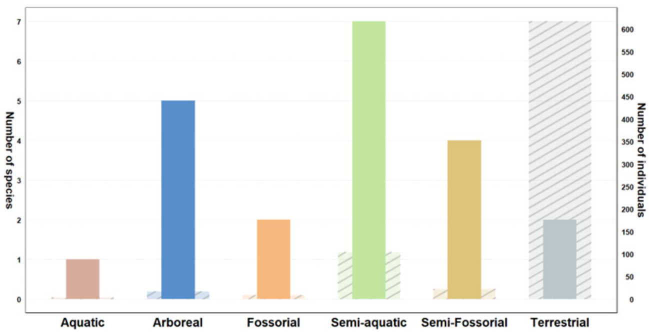

Figure 4. Number of amphibian species and individuals killed across different habits in the Western Ghats. Dark colour was number of species and light shade was number of individuals.

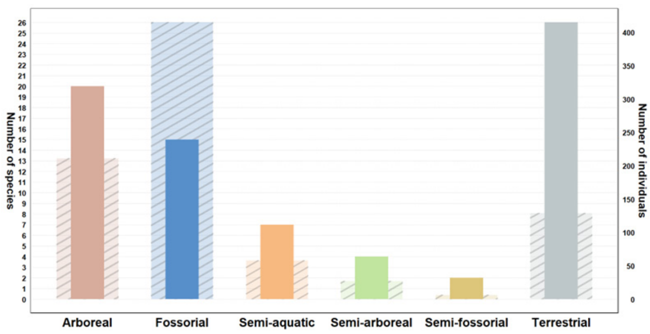

Figure 5. Number of reptile species and individuals killed across different habits in the Western Ghats. Dark colour was number of species and light shade was number of individuals.

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Table 2. Site-specific vulnerable invertebrate and vertebrate species affected by vehicular traffic in the Western Ghats (*values in parentheses indicate the mortality rate of the species)

Source	Location & State	Invertebrate*	Vertebrate*
Gaitonde *et al.,* (2016)	Amboli		*Xanthophryne tigerina*
Kumbar & Lad, (2017)	Sangli		*Duttaphrynus melanostictus*
Seshadri *et al.,* (2009)	Sharavathi		*Fejervarya sp.* (1.5/km)
Correa *et al.,* (2023)	Agumbe		*Chrysopelea ornata*
Bansal, (2020)	Kodagu	Arachnid	*Hypnale hypnale* (0.05/km)
Prakash & Karthik, (2021)	Anaikatty	Butterflies	Lizards
Roshnath & Cyriac, (2013)	Wayanad	*Tirumala septentrionis* (118.6/km)	
Deb & Sengupta, (2020)	Sathyamangalam		*Calotes versicolor*
Samson *et al.,* (2020)	Mudumalai Tiger Reserve		*Funambulus palmarum* (0.09/km)
Samson *et al.,* (2016)	Mudumalai Tiger Reserve		*Calotes versicolor* (0.07)
Khanduri *et al.,* (2022)	Nilgiris		*Calotes versicolor*
Samson & Princy, (2023)	Nilgiris		*Bandicota indica*
Rao & Girish, (2007)	Bandipur Tiger Reserve	Dragonflies	
Selvan *et al.,* (2012)	Bandipur Tiger Reserve		Snakes
Gokula, (1997)	Mudumalai Tiger Reserve		*Ahaetulla sp.* (0.22/km)
Baskaran & Boominathan, (2010)	Mudumalai Tiger Reserve		*Duttaphrynus melanostictus* (0.38/km)
Santhoshkumar & Kannan, (2017)	Nilgiris		*Xylophis perroteti* (0.09/km)
Santhoshkumar *et al.,* (2016)	Nilgiri		*Plectrurus perroteti*i
Kannan, (2007)	Mudumalai Tiger Reserve		*Ahaetulla sp.*
Santhoshkumar *et al.,* (2017)	Nilgiri		*Xylophis perroteti* (0.02/km)
Vadivalagan *et al.,* (2012)	Nilgiri	*Pachliopta aristolochiae*	
Sony & Arun, (2015)	Anaikatti Hills	*Tirumala septentrionis* (11.71/km)	
Kumara *et al.,* (2000)	Anaimalai Hills		*Uropeltis ceylanicus*
Balakrishnan, (2007)	Muthikkulam		*Uropeltis sp.* (0.23/km)
Yadav *et al.,* (2022)	Vazhachal		*Dendrelaphis tristis* (0.002/km)
Jeganathan *et al.,* (2018a)	Anaimalai Hills	Snail (0.23/km)	Frog (0.5/km)
Vijayakumar *et al.,* (2001)	Anaimalai Hills		*Duttaphrynus melanostictus* (0.227/km)
Ganesh & Chandramouli, (2020)	Megamalai Hills		*Calotes grandisquamis*
Bhupathy *et al.,* (2011)	Theni Forest Division		*Duttaphrynus melanostictus* (0.14/km)
Selvan, (2011)	Theni Forest Division		*Duttaphrynus melanostictus* (0.12/km)
Narayanan, (2015)	Tirunelveli Hills		*Gongylosoma calamaria*
Seshadri *et al.,* (2011)	Kalakad Mundanthurai Tiger Reserve	*Mellipede sp.* (48.28/km)	*Clinotarsus curtipes*(21.3/km)

Comparisons of mortality rates across the reviewed articles in the Western Ghats were not possible due to substantial methodological variations between the studies: (1) differential sampling effort (season covered, mode of survey-walk or vehicle, number of observers); (2) variations in topography and habitat matrix along the surveyed roads (habitat and elevation gradients) and (3) variations in species reporting (order, family, genus and species levels). Therefore, we only identified vulnerable species and high mortality-prone zones based on the available information in select articles to prioritise the conservation interventions.

Spatial distribution of road mortality studies:
Compared to the southern Western Ghats, road mortality studies in the northern and central regions of the Western Ghats are limited, despite the presence of extensive road networks and ongoing

development. Even within the southern Western Ghats, there is a notable lack of studies on the western slopes (the rain-fed areas of the southern Western Ghats), as compared to the eastern slopes (the rain-shadow regions). The western slopes receive relatively higher rainfall during the southwest monsoon and have one of the longest road networks with a high human density. Therefore, it is expected that road mortality rates for invertebrates and lesser vertebrates would be higher in these areas.

Taxa- specific road mortality

Amphibians:
Among the amphibians, widespread terrestrial *Duttaphrynus melanostictus* and other semi-aquatic and semi-fossorial species such as *Hylarana spp.*, *Uperodon triangularis*, *Microhyla ornata*, and *Minervarya nilagirica* are more vulnerable to road kills. Due to their slow movement, most of the terrestrial toads (*e.g.*, *Duttaphrynus melanostictus*) were killed when they tried to cross the road. In the Western Ghats, the highest road mortality was reported for amphibians, particularly during the wet seasons (*e.g.*, Vijayakumar *et al.,* 2001 & Bhupathy *et al.,* 2011). During this time, amphibians move in large numbers to congregate in pools and streams for breeding, becoming vulnerable to road kills. It is evident that roads near waterbodies or parallel to streams have higher mortality rates, as reported in Baskaran & Boominathan, (2010), and Rajvanshi *et al.,* (2013). Furthermore, factors such as traffic intensity, road structural characteristics, and road density significantly increase the likelihood of road kills (van der Ree *et al.,* 2015). The higher mortality rates of herpetofauna in the rainfed areas of the Western Ghats are likely due to extended rainy days, which prolong breeding-related movements in amphibians and lead to relatively enhanced road kills compared to rain-shadow regions.

Reptiles:
The second most affected vertebrate group was reptiles, with 74 species, including 31 species endemic to the Western Ghats. The overall mortality rate ranged from 0.07 to 0.43 individuals/km, except in the KMTR, where the highest road mortality of reptiles (4.91 kills/km) was reported. Other than the widespread Oriental garden lizard, uncommon and rare species like common skink *Eutropis carinata*, Indian chameleon *Chamaeleo zeylanicus*, brahminy blind snake *Indotyphlops braminus*, Indian rock python *Python molurus*, common kukri snake *Oligodon arnensis*, common wolf snake *Lycodon aulicus*, common bronzeback tree snake *Dendrelaphis tristis*, Oriental rat snake *Ptyas mucosa*, slender-nosed vine snake *Ahaetulla oxyrhyncha*, green keelback *Rhabdophis plumbicolor*, checkered keelback *Fowlea unicolor*, common krait *Bungarus caeruleus* and Russell's viper *Daboia russelii* were also recorded as road kills (Figure6). Among reptiles, nearly 56 snake species (*i.e.*, 46% of the snake species known from Western Ghats) were recorded as roadkill, including individuals from *Uropeltidae* and *Typhlopidae* families. The frequency of occurrence of snakes roadkill was notably high in all parts of the Western Ghats. The higher snake mortality rates have been attributed to thermoregulation behaviour (Vijayakumar *et al.,* 2001; Bhupathy *et al.,* 2011) as tarred roads retain daytime heat and provide an optimal environment for thermoregulation during the night. This explanation may be appropriate in temperate regions, where temperature fluctuations are significant during night hours. However, in tropical areas like the Western Ghats, temperature fluctuations are not extreme. So, animals may not require a hot surface like roads for thermoregulation. This is also partially supported by the studies on the Indian rock python in Sathyamangalam Tiger Reserve in the Western Ghats, and water python in Australia, which state that pythons are active throughout the year (Vishnu *et al.,* 2023; Shine & Madsen, 1996). Rajvanshi *et al.,* (2013) suggested a design to reduce road mortality of snakes by creating artificial thermoregulation structures on both sides of the road to facilitate snake thermoregulation, reducing roadkill in the vicinity. This approach needs to be evaluated through experimental field studies on snakes in the Western Ghats.

Potential reasons for the higher frequency of snake road mortality in the Western Ghats could be: ***1) Body shape-*** Snakes have long and slender bodies when compared to other lesser vertebrates and reptiles, which enhances their chances of being struck by moving vehicles (Hughes, 2025), regardless of tyre width and weight of the vehicle. ***2) Scavenging behaviour-*** Observations indicate that Indian snakes, including banded krait *Bungarus caeruleus* (Dabholkar & Sagar, 2024), spectacled cobra *Naja naja* (Patel *et al.,* 2018), and checkered keelback *Fowlea unicolor* (Wewhare & Pandey, 2021) scavenge on crushed animal carcasses. ***3) Dilution of vehicle-*** induced vibrations- Snake road mortality rates are relatively higher during the monsoon season (Pragatheesh & Rajvanshi, 2013; Santhoshkumar & Kannan, 2017). We believe that this might be due to rain induced vibration on tarred road, which could hinder the ability of snakes to recognise the vibration of a speeding vehicle (*e.g.* Hartline, 1971). ***4) Road as barrier-*** The obstruction of water courses, soil, and vegetation forces various species like water snakes (*e.g.*, *Natricidae*), fossorial snakes (*e.g.*, *Typhlopidae* & *Boidae*), and arboreal snakes (*e.g.*, *Ahetulla spp.*) to cross roads, which are not adept at moving on tarred surfaces (Figure 5); and ***5) Predator vigilance-*** Although species like rat snakes are fast movers, they are also being killed at several locations. This may be due to predator vigilance and smoother surfaces (*e.g.*, Bhupathy *et al.,* 2011). When they enter open places like roads, they move slowly, looking for predators (Waring *et al.,* 1991). Further research should focus on these aspects to elucidate the possible reasons for high snake mortality rates in the Western Ghats. Such studies would also assist managers and the public works department in designing roads in the region to mitigate road mortality in the future.

Birds & Mammals:
Higher bird mortalities among the reviewed studies involved shrub-dwelling, low-flight, and open habitat preferring families such as *Columbidae* (5 species of doves and pigeons), *Cuculidae* (5 species of cuckoos), *Pycnonotidae* (3 species of bulbuls), and *Corvidae* (2 species of crows). Foraging and scavenging for food grains or insects on or near the road surface could increase the probability of birds like doves, mynas, crows, and bulbuls being hit by vehicles (*e.g.*, Husby, 2016). Further, the species reported frequently as roadkill were most abundant along the roads (Santos *et al.,* 2016). During our endemic bird survey in Nilgiris, we also observed the road mortalities of endemic birds of the Western Ghats, such as Nilgiri sholakili *Sholicola major* and Nilgiri laughingthrush *Montecincla cachinnans* (unpublished data, S.Babu), although existing literature has not reported road fatalities of these bird species.

The mortality rates of birds were lower than those of other vertebrates in the Western Ghats. This can be attributed to road structural characteristics (narrow width, sharp curvature, and elevation), and slow vehicle speeds that reduce collisions with flying birds owing to quick evasive responses of birds. However, the influence of breeding and moulting seasonality on roadkill susceptibility of birds remains understudied and warrants further examination.

Mammals:
Among mammals, arboreal and commensal species, such as bonnet macaque, grey langur, three-striped palm squirrel *Funambulus palmarum*, and herbivores such as sambar deer and Indian chevrotain *Moschiola indica* were frequently killed on roads. One of the major reasons for the road mortality of arboreal mammals was anthropogenic food supplies or garbage dumped along the tourism/pilgrimage-dominated roads (*e.g.*, Nilgiris), and lack of canopy contiguity. In some cases, over-speeding vehicles hit large-bodied mammals like sambar deer and Nilgiri tahr (Jeganathan *et al.,* 2018a), contributing to their deaths. Most rodent (rats and shrews) kills could not be identified to the species level.

From our review, we conclude that the survey efforts to monitor bird and mammal road mortality require broader spatial coverage, rather than intensive searches limited to a few kilometres. A broad spatial coverage would likely capture a greater variety of species, including endemic and range-restricted bird species, than what is currently documented.

Mortality vs vehicle intensity:
A few studies were conducted to illustrate the relationship between vehicular traffic and road mortality rates for vertebrates and invertebrates, revealing differential patterns: some showed linear relationships (Rajvanshi *et al.,* 2013; Sheshadri & Ganesh, 2011), while others indicated non-linear relationships (Sheshadri & Ganesh, 2011) and no relationship (Bhupathy *et al.,* 2011; Santhoshkumar & Kannan, 2017). A non-linear relationship suggests that while road mortality for wild animals increases with higher vehicle density, it may decline after reaching a certain threshold (particularly for nocturnal and vertebrate species; Sheshadri & Ganesh, 2011).

Mortality rate of wildlife

The length of the road network in the Western Ghats is 26,482 km, which includes national highways, state highways, and rural roads. Based on the published road mortality rates, we calculated a conservative estimate of daily roadkill of wild animal individuals (kills/visit) for the entire road network in the Western Ghats: 19,067 - 36,35,979 (invertebrates); 530 – 10,59,280 (amphibians); 530 - 1,30,026 (reptiles), 159 - 2383 (birds), and 159 to 20,920 (mammals). Even when considering the lowest mortality rates (kills) for each taxon, the annual estimates of the roadkill (for 365 days) for vertebrates (amphibians: 1,93,450; reptiles: 1,93,450; birds: 58,035; and mammals: 58,035) in the Western Ghats is alarmingly high. This estimate raises significant concerns as it appears to be a primary anthropogenic reason for the amphibian and reptile population decline in the Western Ghats. This review underscores the need for collaborative efforts among researchers, policymakers, and conservationists to develop wildlife-friendly road infrastructure in this ecologically sensitive region.

Survey bias in road mortality studies
Though only about 14% of total Western Ghats vertebrate diversity (166 vertebrate species) have been reported as dying due to vehicular collisions, the actual number of species affected and individuals killed would be much higher than that reported. Roadkills often go undetected due to several reasons, such as- ***1)*** Carcasses are often consumed by scavenging birds (crows and kites), mammals (mongooses and civets), and free-ranging animals such as dogs and cats (Santos *et al.,* 2011; Teixeira *et al.,* 2013). ***2)*** Animals with injuries may retreat to nearby forest patches and may subsequently die there. Such kills are unreported or undocumented (Raman, 2011). ***3)*** Roadkill of smooth-skinned, and soft, small-bodied (*e.g.*, caecilians, anurans, shieldtail, geckos, and rodents) animals can become unidentifiable after being run over repeatedly by vehicles, and washed off the roads during peak monsoon. Because of these reasons, more than 70% of road mortalities of amphibians, and several species of *Uropeltidae* and *Typhlopidae* families reported from the Western Ghats were not identified to the species level. In contrast, despite their slow movement, species of the genus Bufo (with their rough skin) could remain identifiable for longer periods (for more than 7 days; personal observation in Anaikatty hills) despite heavy vehicle traffic and less abundance in forest floors (*e.g.*, Vijayakumar *et al.,* 2001). This species is frequently reported across multiple studies in the Western Ghats. ***4)*** Observer's expertise in identifying road mortalities up to species level. Although these factors have been addressed in several studies across the globe (Santos *et al.,* 2011; Santos *et al.,* 2016), we find that these aspects have not been included as part of studies in the Indian context.

Mitigative measures
Given the higher road mortality rates of vertebrates, characterised by both the number of kills and species affected, it is essential to implement mitigative measures targeting these taxa. For this, data on the spatial and temporal distribution of road kills across the country would be required (Saxena *et al.,* 2019). However, it is impractical to collect such voluminous data through a single study. A solution to this issue is to use citizen science data through established mobile applications (*e.g.*, roadkillmonitoring.in), combined with an intensive outreach programme to collect roadkill data across the country (Pawgi *et al.,* 2024). Hotspots of roadkill generated from citizen science data would further help prioritise sites requiring conservation interventions. Site-and species-specific mitigative measures should be developed to reduce wildlife mortality. Our review strongly indicates that amphibians and reptiles are more vulnerable to roadkill in the Western Ghats. Although limited attention has been given to herpetofauna conservation in the country, a few conservation measures, such as the construction of herpetofaunal passages, and the use of drift fences near canals, streams and rivers can be attempted (Ward *et al.,* 2015). However, the effectiveness of such measures should be tested frequently.

Figure 6. Road kills of some uncommon species in the Western Ghats. 1. *Uropeltis bhupathyi* – Fossorial ©Arjun Viswa S; 2. *Ahaetulla sp.* – Arboreal © S. Babu; 3. *Rhabdophis plumbicolor* – Semi-aquatic ©Arjun Viswa S; 4. *Loris lydekkerianus malabaricus* – Arboreal © Kishore Muthu.

Way Ahead

To address and control road mortality of wild animals in the Western Ghats and other key biodiversity-rich regions of the country, we suggest that further studies are required in the following areas: ***(1)*** Since 57% of roadkill remains unidentified, it is important to apply cost-effective molecular-based species identification for small, soft-bodied vertebrates (*e.g.*, caecilians, bush frogs, shieldtail); ***(2)*** Standardisation of survey protocols for road mortality studies and the correction of mortality rates for carcass persistence is essential; ***(3)*** An assessment of the impact of road characteristics, vegetation structure, species-specific traits and hydrological parameters on vertebrate mortality patterns is needed, and ***(4)*** Research and development focusing on drift fences and culverts (both dry and wet), amphibian tunnels, underpasses and overpasses in the Indian context should be conducted.

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CONFLICT OF INTEREST

Dr P. R. Arun is an academic editor at the Journal of Wildlife Science. However, he did not participate in the peer review process of this article except as an author. The authors declare no other conflict of interest.

DATA AVAILABILITY

Data is available from the corresponding author on request.

AUTHOR CONTRIBUTIONS

SB conceived the idea, design and analysis. AVS collated the review, compiled, curated the data and did descriptive analysis. Both AVS and SB wrote the first draft and finalized the manuscript. MM and PRA contributed through mentorship to AVS throughout the dissertation periods.

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Economic valuation of ecosystem services in the Kole wetlands, A Ramsar site in Kerala, India

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Abstract

Wetlands are widely acknowledged as ecologically rich and highly productive ecosystems, on par with tropical evergreen forests, and are integral to long-term ecological sustainability. The present study undertook a comprehensive economic valuation of ecosystem services rendered by the Kole wetlands, a Ramsar-designated site located in Kerala, South India. Regarded as the "rice bowl of Kerala," the Kole Wetlands offer a diverse array of provisioning, regulating, and cultural services that support the livelihoods of surrounding communities. A two-stage random sampling design was employed to select respondents for a household-level survey, administered using a semi-structured questionnaire. The valuation incorporated multiple methodologies, including the market price method, travel cost method, replacement cost approach, benefit transfer method, and contingent valuation technique. The assessment utilized the Total Economic Value (TEV) framework, which captures direct use, indirect use, and non-use values. The TEV of the Kole Wetlands was estimated at approximately USD 54.24 million (417.3 INR Crores), with flood regulation services contributing USD 25.3 million and paddy cultivation generating an annual value of USD 19 million. The findings underscore the critical ecological and economic roles of the Kole Wetlands, highlighting their function in biodiversity conservation and the socio-economic reliance of local populations on their ecosystem services.

Keywords: Contingent valuation method, ecosystem service valuation, flood regulation, sustainable livelihoods, total economic value (TEV), wetland management

Introduction

Wetlands are among the most productive ecosystems on earth and are often referred to as "the kidneys of the landscape" due to critical functions they perform in hydrological and chemical cycles. They are also described as "biological supermarkets" for their extensive food webs and rich biodiversity (Mitsch & Gosselink, 2015). Globally, wetlands are considered some of the most diverse and life-supporting ecosystems, covering approximately 5–10% of the earth's land surface and serving as highly productive transitional zones that support a wide range of aquatic and terrestrial species (Mitsch *et al.*, 2009). For millennia, human societies have cultivated fertile riverine wetlands, benefiting from their natural sedimentation and water availability. However, large-scale wetland reclamation for agricultural purposes has significantly reduced biodiversity and impaired critical ecosystem functions beyond mere crop production (Hassan *et al.*, 2005).

The global significance of wetlands was first formally recognized through the Ramsar Convention on Wetlands, held in the Iranian city of Ramsar and signed on 2 February 1971. As of today, India hosts 96 designated Ramsar sites. Wetlands provide a wide range of ecosystem services, including provisioning services such as timber, food, and fiber (Berg *et al.*, 2017), as well as regulating, supporting, and cultural services, including groundwater recharge and flood mitigation (Roebeling *et al.*, 2016). Their ecological and economic importance is well-documented, given the multitude of goods and services they deliver (MEA, 2005). These ecosystems contribute significantly to human well-being by supplying essential resources—such as food, medicinal plants, and construction materials—while also offering critical services including flood regulation, climate moderation, water purification, and biodiversity conservation. Wetlands also play a vital role in mitigating environmental challenges, particularly those related to climate change and extreme weather events, by regulating atmospheric conditions, filtering pollutants, and buffering communities against floods and storm surges.

Despite their increasing ecological and economic significance, wetlands continue to degrade globally (Deane *et al.*, 2017), with nearly 50% of wetland loss occurring since 1900—most notably in Asia (Hu *et al.*, 2017). This widespread degradation has led to significant adverse impacts on ecosystem services, biodiversity, and human livelihoods (Costanza *et al.*, 2014; Hu *et al.*, 2017). Between 1997 and 2011 alone, global ecosystem services experienced an estimated annual loss of USD 4.3 trillion due to land-use changes (Costanza *et al.*, 2014). Such persistent exploitation threatens the well-being of future generations and disproportionately affects vulnerable populations (De Groot *et al.*, 2012). It is widely acknowledged that the true economic value of wetlands is frequently underestimated, as valuation efforts tend to emphasize tangible outputs such as agricultural and fishery resources, leading to systemic undervaluation (Turpie, 2010). Assigning economic value to ecosystem services offers a pathway to reframe societal interactions with natural systems (De Groot *et al.*, 2012). Monetizing these services serves various policy and management functions, including the assessment of ecosystem restoration initiatives, the determination of access fees for protected areas, and the evaluation of conservation-related policy alternatives (Perez-Verdin *et al.*, 2016). Robust valuation methodologies are also essential for informing biodiversity markets and supporting complex conservation decision-making processes (Engel *et al.*, 2008).

This study aims to assess the economic value of the Kole wetlands, located in the Thrissur and Malappuram districts of Kerala, India. Designated as a Ramsar site, the Kole wetlands play a crucial role in Kerala's rice production and support a wide range of migratory bird species (Sivaperuman & Jayson, 2000). However, increasing anthropogenic pressures—particularly land encroachment—have posed serious threats to the wetland ecosystem, leading to biodiversity loss, declining agricultural productivity, water scarcity, disrupted flood regimes, and a reduction in aesthetic and recreational value (Jyothi & Sureshkumar, 2014). Traditionally, the Kole wetlands have sustained agriculture, recharged groundwater, and supported dry-season cropping. In addition to these services, they offer essential resources such as fish, food, fodder, timber, and medicinal plants, while also serving as important habitats for wildlife, especially migratory birds (Mori *et al.*, 2017). Ecosystem service valuation has emerged as a strategic approach to integrate natural capital into the framework of economic development and to inform policy agendas (Munda, 2003).

The limited availability of comprehensive research on the Kole wetlands, particularly in relation to their ecosystem services and economic valuation, constitutes a significant knowledge gap. This study addresses that gap by providing a holistic assessment of the economic value of wetlands, incorporating provisioning, regulating, supporting, and cultural ecosystem services through the application of an integrated and robust methodological framework.

Materials and methods

The Total Economic Valuation (TEV) framework is widely used to assess the full range of ecological services provided by ecosystem (Nitanan *et al.*, 2020; Loomis *et al.*, 2019; Saunders *et al.*, 2010; Ledoux & Turner, 2002). TEV categorizes ecosystem values into use and non-use values, based on the nature of the goods and services derived (Chee, 2004). In the case of the Kole wetlands, nine key ecosystem services—spanning various TEV categories—were identified and included in the study. These services were selected through consultations with domain experts and local stakeholders, including farmers and residents of the region. The interrelationships among various ecosystem services within the TEV framework are illustrated in figure 1.

Study Area

The Kole wetlands have been designated as a Ramsar Site since 2002 and recognized as an Important Bird Area (IBA) since 2004 (Ramsar Convention, 2021; Rahmani *et al.*, 2004). Additionally, the Government of India classified it as a High-Value Biodiversity Area in 2009. Covering an area of 13,632 hectares, the Kole wetlands extend across the Thrissur and Malappuram districts of Kerala, India, and are geographically situated between

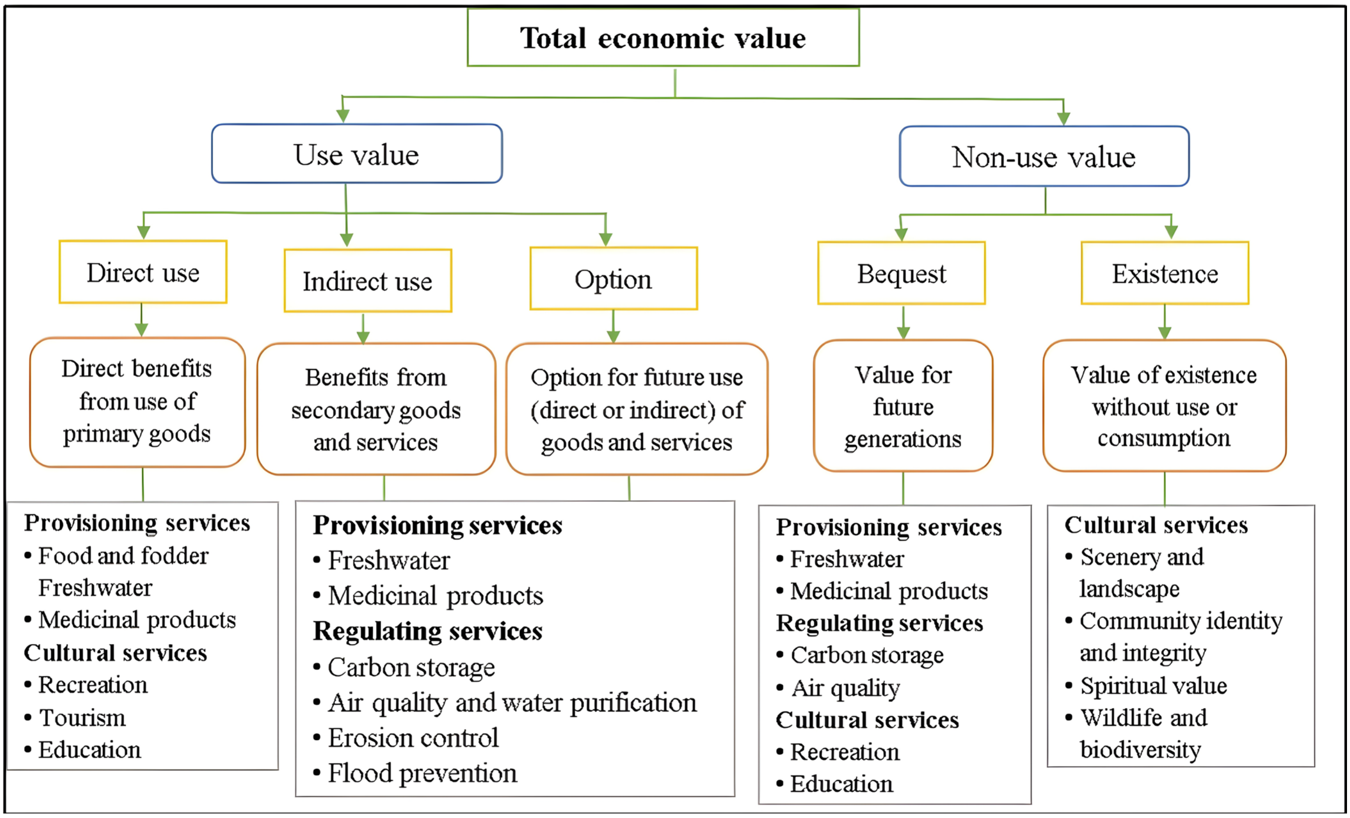

Figure 1. Total Economic Valuation (TEV) Framework for ecosystem services valuation adopted for the study

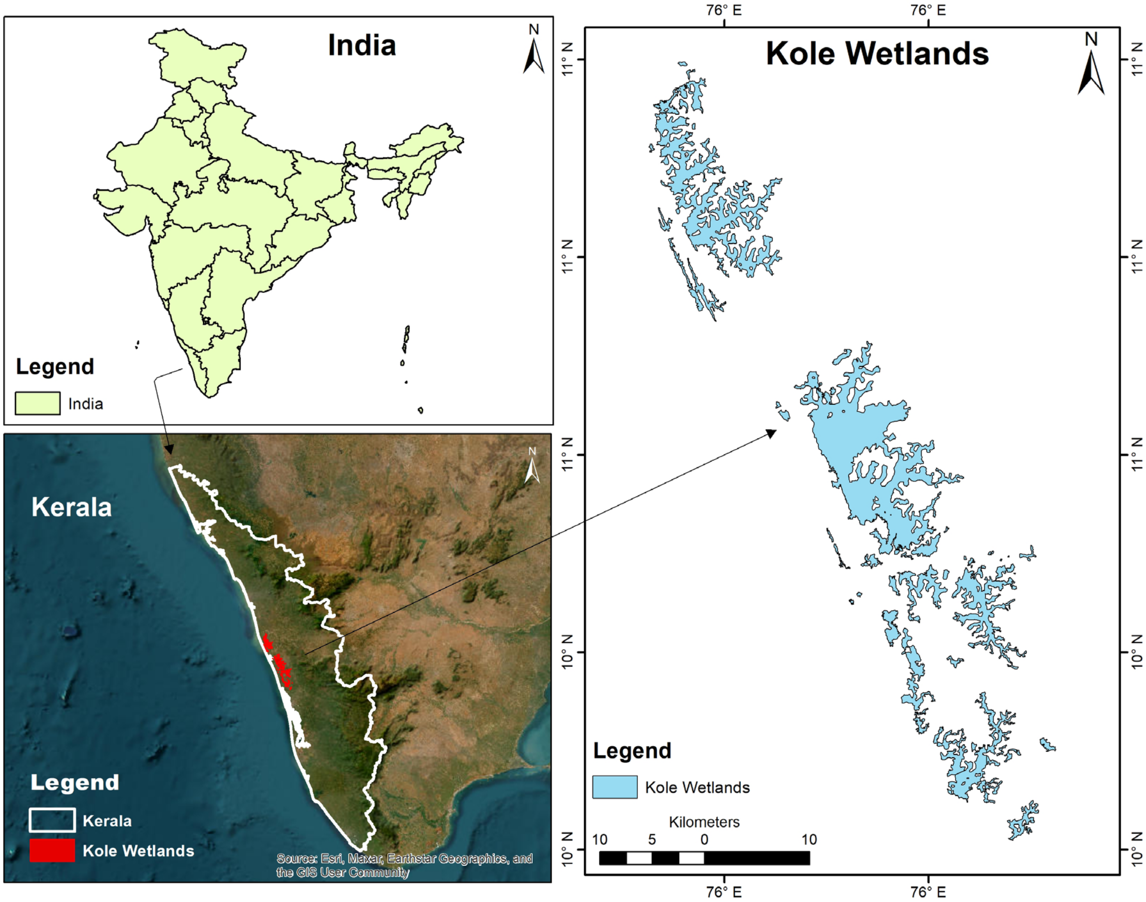

Figure 2. Location of the Kole wetlands, Kerala, India.

latitudes 10°20'–10°40'N and longitudes 75°58'–76°11'E (see Figure 2).

Study design and data collection

The study was based on both primary and secondary data. The study was conducted over a 13-month period, from November 2020 to December 2021. Nine key ecosystem services were selected for Total Economic Valuation (TEV), following the Millennium Ecosystem Assessment framework (MEA, 2005). A combination of Participatory Rural Appraisal (PRA) tools, including Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), and Household Surveys, was employed to collect primary data (Table 1, see Supplementary 1 for methodological details). The conversion from INR to USD was calculated using the 2021 exchange rate, where 1 USD was equivalent to ₹74.2. A two-stage sampling design was employed for data collection. At the initial stage, seven villages within the Thrissur Kole wetlands – Thommana, Enamav, Kanjani, Pulazhi, Nedupuzha, Aranattukkara and Kodannur were randomly selected. In the second stage, the lists of farmers from these villages were obtained from the respective Padasekharam Samiti, and 10 farmers from each village (Total = 70) were randomly chosen. Among them, respondents who were also engaged in natural fishing or pisciculture before rice cultivation (N=40) and who leased their land for duck rearing (N= 40), were interviewed to collect information on pre-cultivation fisheries and duck rearing activity. All available lotus cultivators were interviewed, as very few people are engaged in lotus farming. Tourists visiting the wetland for recreation were sampled randomly, with 40 individuals interviewed at key tourism sites (Vilangan hills and Pullu 2021). To represent community-level perceptions and non-use values, 30 residents from the selected villages (directly dependent on Kole wetlands for ecosystem services) and 30 residents living approximately 10 km outside the Kole area (indirectly dependent on Kole wetlands from Vellanikkara, Pandiparamb, Chirakkekod, and Thanikudam) were randomly selected and surveyed using the Contingent Valuation Method (CVM). Thus, the overall sampling strategy combined random sampling (farmers, residents, tourists, and off-site respondents) with purposive sampling (lotus farmers and duck-rearing lessors) to ensure adequate representation of all stakeholder groups.

Two structured questionnaires were used:

1. a direct-use questionnaire for farmers, fishermen, and local residents;
2. a tourist questionnaire focusing on recreational benefits

The questionnaires included demographic and socio-economic details, followed by questions on ecosystem service use, perceived benefits, travel cost method, and willingness to pay (WTP) for conservation and management.

Statistical Analysis of Survey and Demographic Data

Descriptive statistics and cross-tabulation analyses were performed using SPSS to explore relationships and evaluate the survey data (Table 2). To examine relationships among key demographic variables, cross-tabulations were performed, and chi-square tests of independence was used to assess the statistical significance of observed associations. A p-value of less than 0.05 was considered statistically significant. All assumptions underlying the chi-square test, including minimum expected cell counts, were verified prior to interpretation.

The study considered two main sub-populations:
(i) respondents residing within the Kole wetlands who were interviewed to collect information on direct ecosystem services received, and

(ii) tourists, who are non-residents and therefore treated as a separate sub-population.

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Table 1. Various approaches used to analyse ecosystem services of the Kole wetlands, Kerala, India.

Ecosystem service	Valuation approach	References
Paddy cultivation	Market Value method	Legesse *et al.*, 2022; Harrison *et al.*, 2018; Zou & Zhao, 2014; Badola *et al.*, 2010
Fishing and Fish farming		
Lotus farming		
Duck rearing		
Tourism	Travel Cost Method	Legesse *et al.*, 2022; Badola *et al.*, 2017; Turpie & Joubert, 2001; Willis & Garrod, 1991
Flood storage function	Replacement Cost Method	Droste & Bartkowski, 2018; Barbier, 2007
Carbon sequestration	Benefit transfer method	Kumara *et al.*, 2024; Legesse *et al.*, 2022; Harrison *et al.*, 2018; Baral *et al.*, 2016
Groundwater Recharge	Alternative/substitute method	Droste & Bartkowski, 2018; Zhou *et al.*, 2018; Barbier, 2007
Non-use value	Contingent Valuation Method	Legesse *et al.*, 2022; Lee & Heo, 2016; Constanza *et al.*, 1997

Table 2. Details and characterisation of the respondents evaluating non-use value of the Kole wetlands, Kerala, India.

Respondents residing in the Kole wetland:								
Particulars	**Age**		**Family size**		**Homestead area (cents)**		**Wetland area (acre)**	
	Mean	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
Paddy farms	57.5	9.6	4.3	1.7	40	60	3.5	5.8
Farmers engaged in fishing and aquaculture	48.53	7.32	5.02	1.3	22	21	3.2	3.5
Other occupation	47.5	13.61	4.4	1.1	20	10	1.2	3.2
Tourist respondents:								
Particulars	**Age**		**Family size**		**Average distance from Kole wetlands**			
	Mean	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**		**Std. Dev**	
Tourists	33	10	4.6	1.46	12.9		10.8	

The results revealed statistically significant associations of annual income with homestead area, wetland holdings, and occupation, and between occupation and homestead area (Table 3). These findings suggest a strong dependence of household income on the extent of agricultural landholdings, highlighting the critical role of land access in shaping economic outcomes for local residents.

Results

The study offers key insights into the ecosystem valuation of the Kole wetland through the application of the Total Economic Valuation (TEV) framework, which classifies value into direct use, indirect use, and non-use values.

The direct use value of Kole wetlands:
Provisioning services in the Kole Wetlands encompass paddy cultivation, fishing activities , lotus farming, and land leasing for duck rearing. Paddy farming was the dominant activity, with an average yield of 5,114 kg per hectare. The market price of paddy averaged USD 0.37 per kilogram, although this varies based on quality, market fluctuations, and seasonal conditions. The production cost was approximately USD 679.88 per hectare, while paddy straw contributed an additional USD 162.48 per hectare. This results in an average net return of USD 1,419.19 per hectare. With 10,974 hectares under paddy cultivation, the total annual economic value was estimated at USD 15 million, with upper-end projections suggesting it may reach up to USD 19 million.

In addition to paddy farming, aquaculture is a significant livelihood activity, particularly during the monsoon season. Following the paddy harvest, the flooded fields are repurposed for fish farming, with harvesting completed at least 10 days before the next cultivation cycle begins (Srinivasan, 2010). Fish farming involves both leased and self-managed operations, with species such as catla (*Labeo catla*), rohu (*Labeo rohita*), and common carp (*Cyprinus carpio*) being most commonly cultivated (Srinivasan, 2010). The average income from aquaculture was USD 133.91 per hectare. With 291 hectares currently under fish farming, the total economic value was approximately USD 1.6 million per year.

Lotus (*Nelumbo nucifera*) cultivation represents another valuable provisioning service. Currently, 6.8 hectares in the Kole wetlands are devoted to lotus farming. Laborers harvested approximately 145 flowers per acre on alternate days, using small boats. With strong cultural and religious demand, particularly for temple offerings and Hindu ceremonies, the yield averaged 100,000 flowers per hectare annually. The net return from lotus farming was estimated at USD 2,964.22 per hectare, yielding a total annual value of approximately USD 20,156.74.

Duck rearing is also a notable seasonal activity. Following the paddy harvest, ducks from Tamil Nadu, Karnataka, and various regions of Kerala are brought to graze in the fields, feeding on leftover grains, weed seeds, and vegetation. Farmers leased their land for this purpose at an average rate of USD 9.10 per hectare. With around 461 hectares used for duck rearing, the estimated annual economic value was approximately USD 0.1 million.

The scenic Kole wetlands, located in the Thrissur and Malappuram districts of Kerala, possess significant ecotourism potential due to their picturesque landscape and rich biodiversity. Tourist surveys conducted during the study period revealed that the

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Table 3. Cross-tabulation of the demographic variables and corresponding chi-square test values to understand their associations at the Kole wetlands, Kerala, India.

Cross tabulation of demographic variables (Respondents)			
Variable A	Variable B	χ^2 (Chi-square)	Significance
Annual income	Gender	0.61	Not significant
Annual income	Age	2.03	Not significant
Annual income	Family size	1.97	Not significant
Annual income	Homestead area	14.65	Significant at 1 percent level
Annual income	Wetland holding	18.46	Significant at 1 percent level
Occupation	Homestead area category	18.21	Significant at 1 percent level
Occupation	Gender	0.94	Not significant
Occupation	Homestead area	87.92	Significant at 1 percent level
Occupation	Wetland holding	89.15	Significant at 1 percent level
Cross tabulation of demographic variables (Tourists)			
Number of visits	Age	4.32	Not significant
Number of visits	Gender	1.4	Not significant
Number of visits	Family size	0.61	Not significant
Time spent on site	Age	6.28	Not significant
Time spent on site	Gender	4.92	Not significant
Time spent on site	Income	10.42	Significance at 5 percent level
Time spent on site	Opportunity cost	67.5	Significant at 1 percent level
Purpose of visit	Gender	0.34	Not significant
Purpose of visit	Age	3.58	Not significant
Purpose of visit	Income	0.16	Not significant
Purpose of visit	Opportunity cost	1.62	Not significant

average opportunity cost per visitor in 2021 was USD 3.31, while the average expenditure per visit was USD 1.20, resulting in a total per-visitor cost of approximately USD 4.50. An estimated 81,810 tourists visited parts of the Kole Wetlands during the study period, contributing to an annual recreational economic value of approximately USD 1.2 million.

Indirect Ecosystem Services of the Kole wetlands

The Kole wetlands provide critical indirect ecosystem services, including flood storage, carbon sequestration, and groundwater recharge.

Flood Storage:

Functioning as a natural buffer between the Western Ghats and the Arabian Sea, the Kole Wetlands serve as a vital flood storage zone. Spanning 13,632 hectares with an average water depth of 2 meters, the wetlands are capable of storing approximately 272.64 billion liters (or 8.5 TMC) of water annually. This makes flood mitigation one of their most essential ecological functions. For comparison, the proposed reservoir at Kannankottai and Thervaikandigai in Tamil Nadu, designed to support Chennai's drinking water supply, has a storage capacity of only 1 TMC and an estimated project cost of ₹330 crores (approximately USD 3.91 million) (Veerappan & Lakshmipathy, 2018). Assuming a reservoir lifespan of 15 years, the annualized cost of providing an equivalent flood storage service *via* engineered infrastructure significantly exceeds that of the natural system. Accordingly, the flood storage function of the Kole wetlands is valued at approximately USD 25.3 million per year.

Carbon Sequestration:

Wetlands play an essential role in climate regulation through carbon sequestration—the long-term capture and storage of atmospheric carbon dioxide (CO_2). Based on the benefit transfer method, the average carbon sequestration rate for tropical wetlands is 1.29 tonnes of carbon per hectare per year (Mitsch *et al.*, 2013). Given that one tonne of carbon equals 3.67 tonnes of CO_2 (Baral *et al.*, 2016), and with a total area of 13,632 hectares, the Kole Wetlands sequester approximately 64,786 tonnes of CO_2 annually. Using India's estimated social cost of carbon at USD 86.25 per tonne (Ricke *et al.*, 2018), the economic value of carbon sequestration in the Kole wetlands was approximately USD 5.5 million per year.

Groundwater Recharge:

The wetlands also play a key role in maintaining groundwater levels by influencing the hydraulic head and supporting both recharge and discharge processes. Factors such as soil type, vegetation cover, site conditions, perimeter-to-volume ratio, and the water table gradient affect the recharge potential. Based on data collected in the current study, the average daily water requirement per individual in the Kole region was 206.5 litres—higher than the 197.7 litres required by individuals living outside the area. Assuming an average household size of four persons, the daily water requirement per household was approximately 824 liters. With 345,673 households in and around the Kole wetlands (Census of India, 2011), the total groundwater recharge service was valued at approximately USD 1.3 million annually.

Non-Use Value of the Kole wetlands

Non-use ecosystem services refer to the values derived from natural ecosystems that are neither directly consumed nor indirectly utilized by individuals, yet hold substantial significance. These include the intrinsic value of biodiversity, the existence value of the wetland, and the bequest value associated with preserving the ecosystem for future generations. To estimate the non-use value of the Kole Wetlands, respondents were presented with hypothetical conservation scenarios and asked about their annual willingness to pay (WTP) for wetland

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preservation. The initial bid was set at INR 50, with respondents allowed to provide open-ended responses. The bid values (₹ 50, ₹100, ₹ 200, ₹ 500, ₹ 1000) used in the contingent valuation survey were selected based on a preliminary discussion with local stakeholders, which indicated that these values represent a realistic and affordable contribution range for households in the study site. The bid range also aligneds with the typical WTP intervals (Rs. 50 - Rs. 500) used in CVM studies in India (Payal *et al.*, 2024) and conforms to the guidelines of the National Oceanic and Atmospheric Administration (NOAA) Panel, USA (Arrow *et al.*, 1993). Approximately 66% of participants expressed a willingness to contribute financially toward wetland conservation.

The majority indicated a WTP of INR 100, while a smaller, highly motivated subset offered contributions ranging from INR 1,000 to INR 2,000. On average, the WTP was calculated at USD 2.52 per person annually. With a total population of 345,673 residents in the Kole Wetlands region, the estimated economic value of non-use ecosystem services amounted to approximately USD 0.9 million per year.

Total estimated economic value of ecosystem services of Kole wetland:
The total estimated economic value of the Kole wetlands including direct use, indirect use, and non-use values was approximately USD 54.24 million (Table 4, see Supplementary 1 – Tables S1 to S8 - for details on calculations).

Discussion

Economic contribution of provisioning services
Coastal wetlands that support rice cultivation are a major asset of South Indian states. Provisioning services constitute a major economic pillar of the Kole wetlands, with paddy farming as the a significant contributor. The current study estimated that paddy cultivation generates an annual economic value of approximately USD 15-19 million, highlighting its main role is sustaining local livelihoods and regional food security. Despite rising input costs and increasing climate variability, rice farming remains economically viable, yielding an average net return of over USD 1,400 per hectare. The findings align closely with reported values from similar agro-wetland systems in eastern India, where the ecosystem value of rice fields considering other ecosystem services was estimated to range between USD 1,238 and 1,668 per hectare per year using similar methodologies (Nayak *et al.*, 2019). This result highlights the wetland-based rice agroecosystems in supporting rural economies across India. Fisheries contributed approximately USD 1.6 million per year in the Kole wetland, reflecting both its economic role and its adaptive integration with paddy farming in a seasonally dynamic landscape. This system is comparable to floodplain aquaculture systems where agriculture and fishery integration has supported income diversification and resilience (Ramachandran *et al.*, 2023; Arunat & Sereenonchai, 2022; Dey *et al.*, 2005). Lotus cultivation, though occupying only 6.8 hectares, delivered high per-hectare returns due to strong cultural and religious demand; however, its overall expansion remains limited because it conflicts with paddy farming. The present study suggests that high-value, culturally important crops like lotus could still offer opportunities for sustainable livelihood diversification. Duck rearing, while generating a modest USD 0.1 million annually, added post-harvest value with minimal input, highlighting the multifunctional nature of the wetland landscape.

Ecotourism and cultural value
Tourism contributed an additional USD 1.2 million annually to the local economy of the wetland. The Kole Wetlands' aesthetic appeal and rich biodiversity present great potential for ecotourism development. The recent studies from Kerala support the viability of valuing cultural ecosystem services in wetland-like systems, for instance, Meharoof *et al.*, (2024) applied the same Travel Cost Method to the Peechi Reservoir and estimated substantial consumer surplus from visitor recreation. Kaur *et al.* (2023) estimated the recreational value of Harike Wetland at USD 1.19 million annually, aligning closely with the Kole Wetlands. In contrast, Periyar Tiger Reserve was valued at USD 15 billion (Bulow & Lundgren, 2007), owing to its more extensive ecotourism offerings such as safaris and trekking-opportunities that remain underdeveloped in Kole. Enhancing infrastructure and visitor experience while ensuring environmental sustainability could significantly boost both conservation and economic returns from such ecosystems (Baloch *et al.*,2023).

Non-use and Willingness-to-Pay (WTP) assessments
Non-use values, such as existence and bequest values, are increasingly recognized as crucial to conservation planning. The present study considered respondents from both groups- those directly dependent on the wetlands and those indirectly dependent to capture the full spectrum of non-use values, including bequest value from dependent users and existence value from non-dependent users. In the present study, 66% of respondents expressed a willingness to pay (WTP) for wetland conservation, with an average contribution of USD 2.51 (₹ 197.42) per household annually. These values are quite similar to the values reported by Rose & Prema (2024), in the same study site, which documented a mean WTP of ₹ 211.

Table 4. Total Economic Value of all direct use, indirect use and non-use values of the Kole wetlands, Kerala, India.

Values	Ecosystem services	Estimated Economic value per year (INR)	USD (Million)	INR (Crore)
Direct use value	1. Paddy cultivation	1,47,63,23,637	19	147.6
	2. Farmers engaged in fishing activities	11,96,35,964	1.6	11.9
	3. Lotus farming	14,90,390	0.02	0.14
	4.Farmers leasing land for duck rearing	73,95,378	0.1	0.73
	5.Tourism	9,49,69,970	1.2	9.4
Total direct use value		**1,69,98,15,339**	**22.2**	**169.9**
Indirect use value	6.Flood storage	1,87,73,33,333	25.3	187.7
	7.Carbon sequestration	42,43,86,221	5.7	42.4
	8.Groundwater recharge function	9,90,35,314	1.3	9.9
Total Indirect use value		**2,40,07,54,868**	**31.5**	**240.07**
Non- use value	9. Non-use value	7,32,82,676	0.9	7.3
Estimated total economic value (Rs)		**4,17,38,52,883**	**54.24**	**417.3**

Note: INR values were converted to USD at the exchange rate in the year 2021, during the time of the survey: 1 USD = ₹74.2.

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Binilkumar (2010) reported, the willingness to pay per person as USD 5.24 (~₹ 240) at the Kole wetlands. The increase in exchange rates from 2010 to 2021 suggests that the WTP values from both years, though expressed differently, remain comparable, indicating consistency in perceived economic value over time. Another study from the Kole wetlands reported a maximum WTP of USD 4.91 (Aravindh *et al.*, 2019). Together, these findings demonstrate that despite variations in monetary estimates over time, studies using similar methodologies consistently reveal strong public support for conservation of the Kole wetlands.

Total economic value and regional comparisons

This study estimated the total economic value of the Kole Wetlands at approximately USD 54.24 million per year, incorporating direct use, indirect use, and non-use values. The global value of wetland ecosystem services has been estimated at approximately USD 47.4 trillion per year (Costanza *et al.*, 2014). However, this figure likely underrepresents their true worth due to the lack of precise and comprehensive valuation methodologies.

Comparable studies in South Asia, which support these findings, are Sharma *et al.* (2015), who evaluated Koshi Tappu Wildlife Sanctuary at USD 13 million, focusing only on provisioning services. Baral *et al.* (2016) assessed Jagadishpur Reservoir at ₹ 94.5 million annually, identifying option and existence values as the highest contributors. Similarly, Singha *et al.*, (2024) estimated the TEV of Sone Beel (Assam, India) at USD 6.77 million per year, using a combined similar methodology as used in the current study, such as the market price method, TCM, CVM, etc. By integrating direct, indirect, and non-use values, this study offers a comprehensive estimate of the worth of wetland- an approach rarely applied in India, providing a useful baseline for future research. Despite methodological limitations, it presents a holistic picture of the economic significance of the Kole wetlands.

Socioeconomic inequities in wetland access

Our analysis revealed significant relationships between household income and factors such as homestead size, wetland holdings, and farming category. These findings suggest that wealthier households tend to control larger wetland areas and derive greater benefits, raising concerns about equitable access. Such inequalities may marginalize vulnerable groups and hinder inclusive development. Policy measures should therefore, promote transparency in land leasing, encourage cooperative farming and community aquaculture, and support smallholder participation in ecosystem service-based livelihoods.

Policy implications and integration in planning

The substantial economic value of the Kole Wetlands must be recognized in local development planning, climate adaptation strategies, and payment for ecosystem services (PES) schemes. Ecosystem services like flood mitigation and carbon sequestration should be integrated into disaster risk reduction plans, climate-resilient infrastructure planning, and local government budgeting frameworks. Incentivizing practices such as organic agriculture, biodiversity conservation, and regulated tourism can further strengthen community resilience and ecological sustainability.

Study limitations and future research

Despite its robust valuation framework, this study has the following limitations. The estimates for services like carbon sequestration and flood control rely on benefit transfer methods and secondary data, which may not reflect site-specific variations. The contingent valuation results may be influenced by hypothetical bias and starting-point bias. Hence, we suggest that future studies should adopt long-term, interdisciplinary approaches that combine, ecological modeling, primary biophysical measurements, and advanced economic valuation tools. Such efforts will provide more accurate estimations, establish ecological baselines, and guide sustainable development of the wetland ecosystems.

Conclusion

The Kole wetlands in Kerala hold substantial ecological and economic importance, offering a wide array of goods and services that directly support local communities. This study assessed both use and non-use values, with particular emphasis on direct-use services such as paddy cultivation, fishery, lotus farming, and duck rearing—activities vital for livelihood sustenance and income generation. The total estimated annual economic value of the wetlands was USD 54.24 million (INR 417.3 Crore), underscoring their significant contribution to regional well-being and natural capital.

Among the components of value assessed, indirect use services emerged as the largest contributor to the total economic value, followed by direct use and non-use values. This finding emphasizes the critical yet often overlooked role of regulating and supporting services such as flood control, groundwater recharge, and carbon sequestration which are typically excluded from conventional market assessments. The results of this study underscore the urgent need for comprehensive conservation strategies. Local governments and stakeholders must prioritize restoration efforts and explore sustainable financing mechanisms, such as ecotourism development and payment for ecosystem services (PES), to ensure the long-term ecological integrity of the Kole Wwetlands. Fostering community participation and integrating ecosystem valuation into policy planning will be essential for achieving sustainable management and resilience of this vital Ramsar site.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY

Data is available from the corresponding author on request.

AUTHOR CONTRIBUTIONS

Ms. Neha Vidyadhar Tamhankar: Conceptualization, methodology design, data collection, analysis, and manuscript drafting.
Dr. P.O. Nameer: Conceptualization, supervision, interpretation of results, and critical revision of the manuscript, and final approval of the manuscript for submission.
Dr. M. Krishnadas: Conceptualization, methodology design, supervision, interpretation of results of original dissertation.
Mr. K.C. Ayyoob: Conceptualization, methodology design, supervision, interpretation of results, statistical analysis of original dissertation.
Dr. M. Shaji: Methodology design, review and editing of original dissertation.

ETHICAL STATEMENT

The authors declare that the research was conducted in accordance with all applicable ethical standards. Fieldwork and data collection were conducted with appropriate permissions from relevant authorities. Informed consent was obtained from all participants prior to participation in any surveys or interviews. No endangered species were harmed during research. The authors also confirm that the manuscript is original, has not been published elsewhere, and is not under consideration by any other journal.

ORIGINALITY STATEMENT

We, the authors, declare that this manuscript is our original work and has not been published previously in any form, nor is it under consideration for publication elsewhere. All sources of information used have been appropriately acknowledged and referenced. We confirm that there is no plagiarism or duplication, and the work complies with the ethical standards of research and publishing. Both the authors have read and approved the final version of the manuscript and agree to its submission to the Journal of Wildlife Science.

AI USE DECLARATION

The authors acknowledge the use of artificial intelligence (AI) tools for improving language. All scientific content, analysis, and interpretations are the original work of the authors. The authors take full responsibility for the accuracy, integrity and originality of all content presented.

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Post-release dispersal, space use, and breeding integration of rescued adult and juvenile spot-billed pelicans tracked using GPS telemetry

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Abstract

We tracked two rescued spot-billed pelicans, *Pelecanus philippensis*, a hand-raised juvenile and a rehabilitated adult, using GPS telemetry for approximately two years after release from Kokkare-Bellur Community Reserve, southern India. Dynamic Brownian Bridge Movement Models revealed distinct age-dependent utilization distribution strategies. The juvenile exhibited progressive spatial expansion, from localized movements in the first year to distant wetlands in the second year. The adult dispersed immediately and remained largely within the Bengaluru–Mysuru corridor, with daily distance traveled increasing during the breeding season. Results demonstrate successful post-release dispersal and landscape use, highlighting the importance of wetland network connectivity for the conservation of the pelican.

Keywords: Dynamic Brownian Bridge Movement Model (dBBMM), *Pelecanus philippensis*, rehabilitation, space use, southern India, wetland connectivity.

Introduction

Wildlife rescue and rehabilitation are widely applied conservation interventions for injured, orphaned, or displaced birds, yet their effectiveness is rarely evaluated beyond short-term survival (Pyke *et al.*, 2018; Hernandez, 2019). In this context, post-release monitoring is a powerful approach for assessing the functional outcomes of rehabilitation, including dispersal behavior, space use, and landscape integration (Bernardo *et al.*, 2011; Raine *et al.*, 2020; Rozsypalová *et al.*, 2025). GPS telemetry studies on rehabilitated pelicans following oil spills have demonstrated altered movement strategies, increased dispersion, and reduced breeding investment relative to non-rehabilitated individuals, highlighting the need for long-term behavioural assessment of released birds (Lamb *et al.*, 2018; Fiorello *et al.*, 2021).

Pelicans are large, colonial, piscivorous waterbirds that function as top predators in aquatic ecosystems and are widely regarded as indicators of wetland health due to their sensitivity to changes in water quality, fish availability, and disturbance to breeding sites (del Hoyo *et al.*, 1992; Amat & Green, 2009). Among the eight extant pelican species, the spot-billed pelican (*Pelecanus philippensis*), a tree-nesting species distributed across South and Southeast Asia, remains poorly studied (Kannan & Pandiyan, 2013; BirdLife International, 2017). In India, the species breeds at approximately 20 sites, primarily in southern states, and is classified as Near Threatened (BirdLife International, 2017) due to the loss of wetlands, human disturbance, and emerging disease threats (Kannan & Pandiyan, 2013). Despite its conservation importance, empirical information on its current population status and movements is limited, and more specifically, survival following rescue or rehabilitation efforts remains unknown.

Kokkare-Bellur Community Reserve represents one of the oldest and most important breeding sites for the spot-billed pelican in southern India. Alarmingly, between 2017 and 2018, this site experienced a mass mortality event involving more than 50 adult pelicans, later attributed to heavy gastrointestinal nematode infestations associated with degraded wetland conditions (Kumar *et al.*, 2019). Similar mortality events linked to *Contracaecum* spp. infestations have since been reported from other pelican breeding and foraging sites in southern India (Durairajan, 2023; Mathews *et al.*, 2025), underscoring growing concerns regarding adult survival and exposure to environmental stressors. These events prompted tracking fine-scale movements of rescued pelicans to understand their ranging behavior, wetland use, and evaluate the overall success of rehabilitation efforts.

Here, we present a case report of documenting spatio-temporal movements of two rescued spot-billed pelicans, a hand-raised juvenile and a rehabilitated adult, tracked for approximately two years using GPS telemetry following their release from Kokkare-Bellur site. This study offers a rare, detailed look into the individual-level movement ecology of this species, providing valuable data for future conservation and reintroduction programs.

Methods

This study was conducted as part of a five-year monitoring program of spot-billed pelican breeding ecology at Kokkare-Bellur Community Reserve, Karnataka. The site exemplifies a unique conservation model, wherein colonial waterbirds, primarily spot-billed pelicans and painted storks Mycteria leucocephala, nest within a human-inhabited village landscape. Nesting trees are distributed in scattered patches throughout residential areas, agricultural lands, and temple grounds rather than in an isolated tree patch in a wetland.

During monitoring, natural falls of pelican chicks and adults from nests were documented, attributed to sibling competition, adverse weather, fledging attempts, and illness. During the 2022–23 breeding season, a total of 13 chicks and two adults were rescued and rehabilitated, of which two individuals were selected for GPS tagging based on health status and growth parameters. A chick rescued at four days old on 16 January 2022 was hand-raised and released on 9 November 2022 (named Shimsha; body mass at tagging = 4865 g), while an adult pelican rescued in a dehydrated condition on 21 December 2022 received veterinary treatment and was released on 4 February 2023 (named Aadi; body mass at tagging = 4480g). Both pelicans were released near the village in proximity to the Shimsha River and were fitted with 33 g solar-powered GPS-GSM patagial transmitters (OrniTrack P33, Ornitela, Lithuania). Transmitters were programmed to record GPS locations at 10-minute intervals and transmit the data daily once. Movement data were collected from September 10, 2022, to August 31, 2024, for Shimsha (722 days) and from February 4, 2023, to February 28, 2025, for Aadi (755 days). For Shimsha, GPS data collection ended prematurely on August 31, 2024, after the transmitter detached and fell into the river; however, subsequent field observations confirmed that the bird retained the patagial tag and was repeatedly recorded flying, foraging, and hunting fishes, indicating normal movement and an apparently healthy condition.

For Shimsha, the data were partitioned into Year 1 (November 9, 2022, to November 9, 2023) and Year 2 (November 10, 2023, to August 31, 2024). The data were treated separately for each year to quantify annual changes in space use. For Aadi, data were partitioned into breeding and non-breeding seasons across two cycles. Breeding seasons were defined as October 2023 to April 2024 (Year 1) and October 2024 to February 2025 (Year 2) based on observed nesting activity and colony monitoring. Non-breeding seasons comprised the remaining months (February 2023 to September 2023 and May 2024 to September 2024).

Data were processed in R version 4.3.1 (R Core Team, 2024) using packages move (Kranstauber *et al.*, 2024), raster (Hijmans *et al.*, 2025), sp, (Pebesma *et al.*, 2025a), and sf (Pebesma *et al.*, 2025b). Prior to analysis, all GPS locations were imported into QGIS 3.28 and visually inspected for spatial outliers and implausible fixes. One erroneous outlier location was identified and removed from the dataset. There were no missing GPS fixes in the dataset. The daily distance traveled was calculated by summing the distances between consecutive locations within each 24-hour period. The daily distance travel data were summarized using median and range. For a visual representation, the daily distances traveled were plotted using a LOESS regression.

To quantify space use and identify core areas, we employed the Dynamic Brownian Bridge Movement Model (dBBMM), which estimates an animal's probability of occurrence by incorporating the time and distance between consecutive locations and the animal's movement variance (Kranstauber *et al.*, 2012). The dBBMM was computed using the 'brownian.bridge.dyn' function in the package 'move' with a window size of 31 and a margin of 11 fixes to capture temporal variations in movement behavior. A location error of 20 m was specified, and a high-resolution grid (dimSize = 600) was used to ensure detailed contouring. From the resulting Utilization Distribution (UD) raster, we extracted isopleths for the 50% (core use area), 75% (primary use area), and 99% (overall utilization distribution) contours to quantify annual and seasonal differences in space use for each individual. Seasonal dBBMMs enabled the quantification of reproductive versus non-reproductive space-use patterns. Spatial outputs were visualized in QGIS 3.28, utilizing satellite imagery, to identify core wetlands and map movement patterns.

Results

Juvenile pelican (Shimsha) movement patterns

Shimsha was tracked for 722 days post-release, generating 104,112 GPS locations. Movement patterns were predominantly concentrated around the release location along the Shimsha River, with opportunistic exploratory movements to neighboring inland wetlands. A single long-distance movement to Mysuru (approximately 80 km from the release site) was also recorded, during which Shimsha visited multiple wetlands before returning to the core area.

During the first year (November 2022 to November 2023), Shimsha's movements remained highly localized. The 50% core utilization area was very small (less than 1 km^2). The 75% UD encompassed 1 km^2, whilst the 99% UD covered 32 km^2, capturing the full extent of exploratory movements along sections of the Shimsha River within 10 km of the release location and two neighbouring lakes.

In the second year (November 2023 to November 2024), Shimsha's core areas shifted spatially and expanded substantially. The 50% UD covered 1 km^2, encompassing sections of the Shimsha River and more distant lakes, including Maddur Lake and BV Halli Kere, located farther from the release location. Relative to the first year, the 75% UD expanded to 3 km^2 (a 200% increase from Year 1), while the 99% UD showed the most substantial expansion, reaching up to 86 km^2 (a 169% increase), reflecting increased ranging behavior and the utilization of more distant wetland networks (Figure 1).

Adult pelican (Aadi) movement patterns

Aadi was tracked for 756 days, providing 108,864 GPS locations. Immediately after release, Aadi moved away from the release site, first travelling to lakes in Bengaluru (approximately 100 km from the release location), and then to Mysuru (approximately 80 km from the release location). Throughout the tracking period, all movements remained within the Bengaluru–Mysuru geographical belt, demonstrating spatial fidelity to this corridor.

During the first non-breeding season (February to September 2023), Aadi's movements were broadly distributed across the Bengaluru–Mysuru belt. A few concentrated 50% core areas were evident (less than 1 km^2), indicating spatially diffuse foraging patterns. The 75% UD encompassed 1 km^2, centered on Kudlur Lake in a neighboring district, while the 99% UD extended to 907 km^2, incorporating multiple urban lakes in both the Bengaluru and Mysuru regions. In the second non-breeding season (May to September 2024), ranging patterns contracted substantially. The 50% core area was recorded to be 2 km^2, concentrated within a 10 km radius of Ranganathittu Bird Sanctuary in Mysuru and Karanji Lake. The 75% UD reduced to 1 km^2 (no change in absolute area but representing refined spatial concentration), and the 99% UD contracted to 152 km^2, showing an 83% reduction compared to the first non-breeding season (Figure 2).

During the first breeding season (October 2023 to April 2024), Aadi attempted breeding twice. The initial attempt at the release location (Kokkare Bellur) failed after one month of nesting. Following this failure, Aadi moved to Ranganathittu Bird Sanctuary and initiated a second nesting attempt, successfully producing one fledgling, as confirmed through photographic evidence by forest staff (pers. comm.). The 50% core area encompassed 8 km^2, including both breeding sites and

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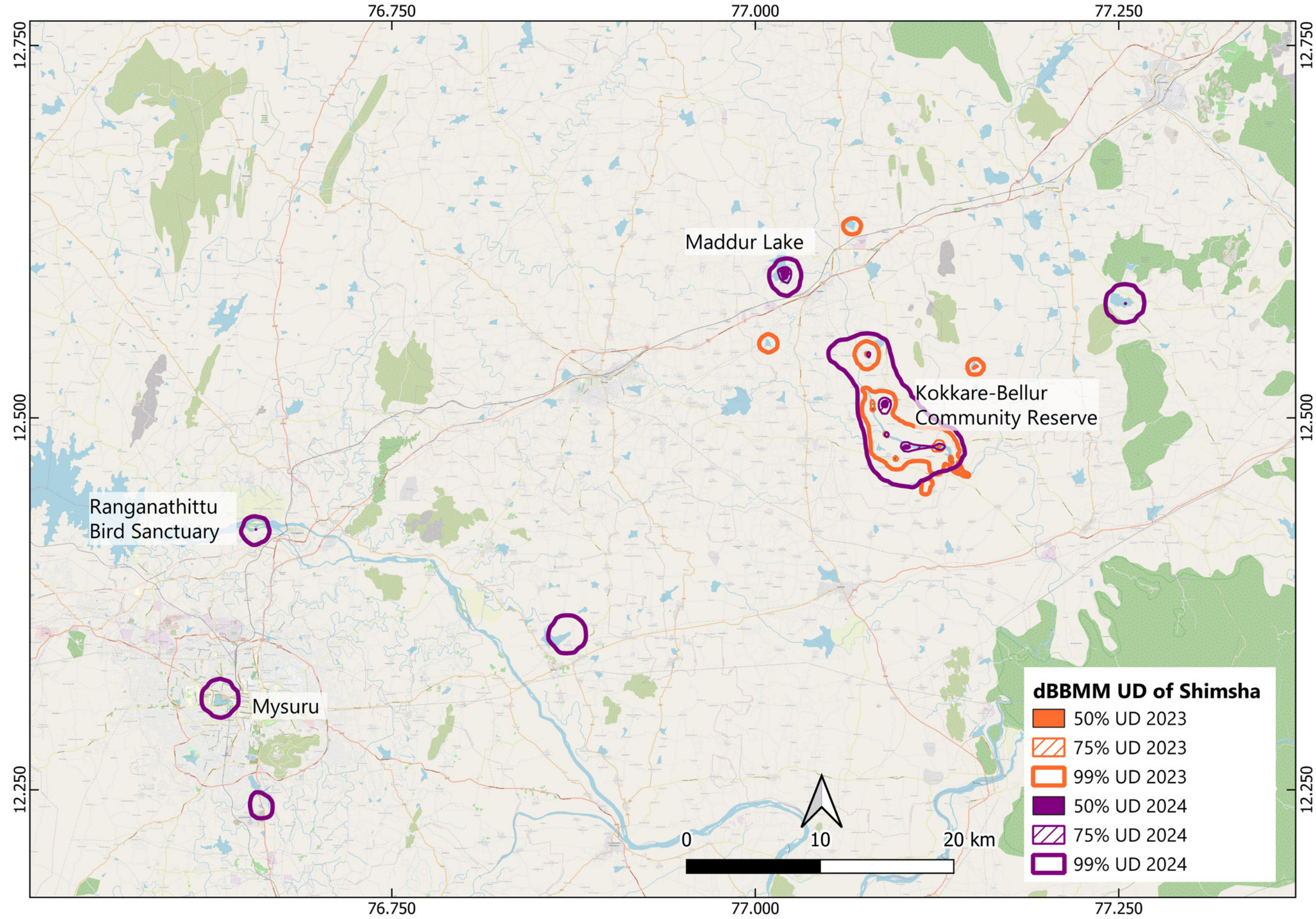

Figure 1. Utilization distributions (UD) of the juvenile spot-billed pelican (Shimsha) derived from Dynamic Brownian Bridge Movement Models (dBBMM). The maps show the 50% (core), 75% (moderate), and 99% (overall) UDs for the bird-year 2023 (November 2022–November 2023) and the bird-year 2024 (November 2023–November 2024), illustrating spatial expansion over time. Basemap data: © OSM Standard, rendered in QGIS 3.28.

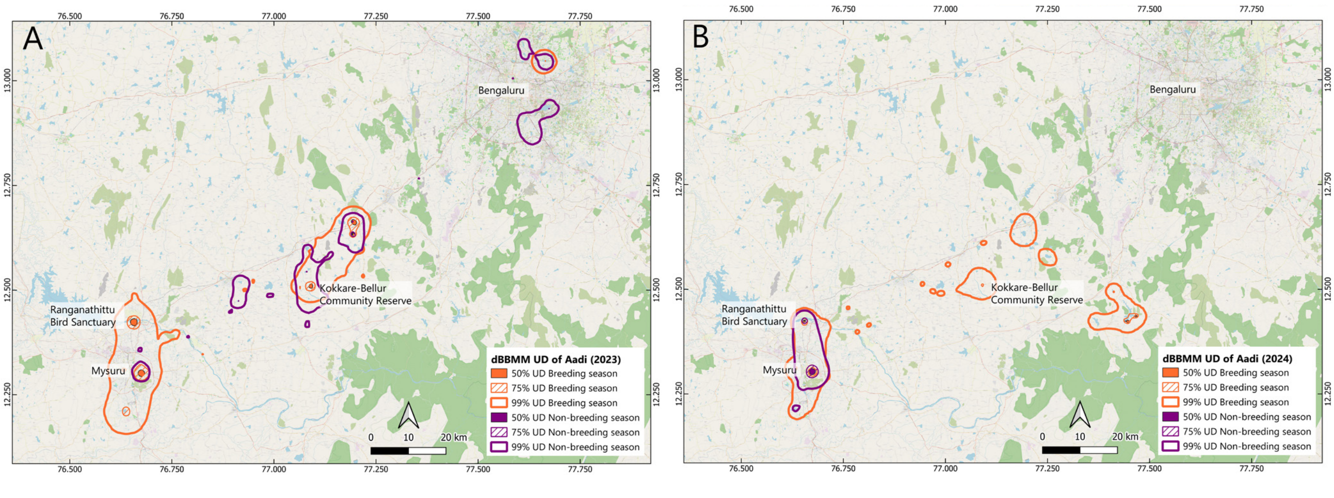

Figure 2. Inter-annual comparison of breeding and non-breeding season space use of the adult spot-billed pelican (Aadi) derived from Dynamic Brownian Bridge Movement Models (dBBMM). Panels represent (A) bird-year 2023, showing the non-breeding season (February–September 2023) followed by the breeding season (October 2023–April 2024) and (B) bird-year 2024, showing the non-breeding season (May–September 2024) followed by the breeding season (October 2024–February 2025). The maps depict the 50% (core), 75% (moderate), and 99% (overall) utilization distributions (UDs) for each season. Basemap data: © OSM Standard, rendered in QGIS 3.28.

neighboring lakes, which represented foraging grounds. The 75% UD extended to 43 km^2, whilst the 99% UD covered 703 km^2, capturing movements between failed and successful breeding attempts and associated foraging areas. In the second breeding season (October 2024 to February 2025), Aadi bred only once at Ranganathittu. The 50% core area was reduced to 2 km^2 (a 75% reduction), encompassing Ranganathittu, a neighboring lake, and a distant reservoir located approximately 120 km from Ranganathittu. The 75% UD contracted to 12 km^2 (a 72% reduction), and the 99% UD decreased to 471 km^2 (a 33% reduction) (Figure 2).

Daily distance travelled (DDT) differed markedly between the adult (Aadi) and juvenile (Shimsha) and varied across seasons and years. For the adult pelican, Aadi, median daily distance travelled (DDT) increased consistently during breeding seasons relative to the preceding non-breeding periods. In 2023, the median DDT during the non-breeding season was 5.55 km (range: 1.96–99.2 km), increasing to 24.7 km (range: 1.56–151 km) during the 2023 breeding season. Similarly, in 2024, the median DDT increased from 1.39 km (range: 0.41–66.7 km) in the non-breeding period to 3.54 km (range: 0.39–73.3 km) during the breeding season. The juvenile pelican, Shimsha, showed consistent daily movement patterns across years, with comparatively narrower seasonal variation. During the first- year post-release (2022–2023), the median DDT was 8.8 km, with values ranging from 1.47 km to 68.7 km. In the second year (2023–2024), the median DDT increased to 10.9 km, while the overall range remained similar (0.41–67.6 km). Compared to the adult, Shimsha displayed higher median DDT values than Aadi during non-breeding periods, but lower maximum DDT than those recorded by the adult during breeding (Figure 3).

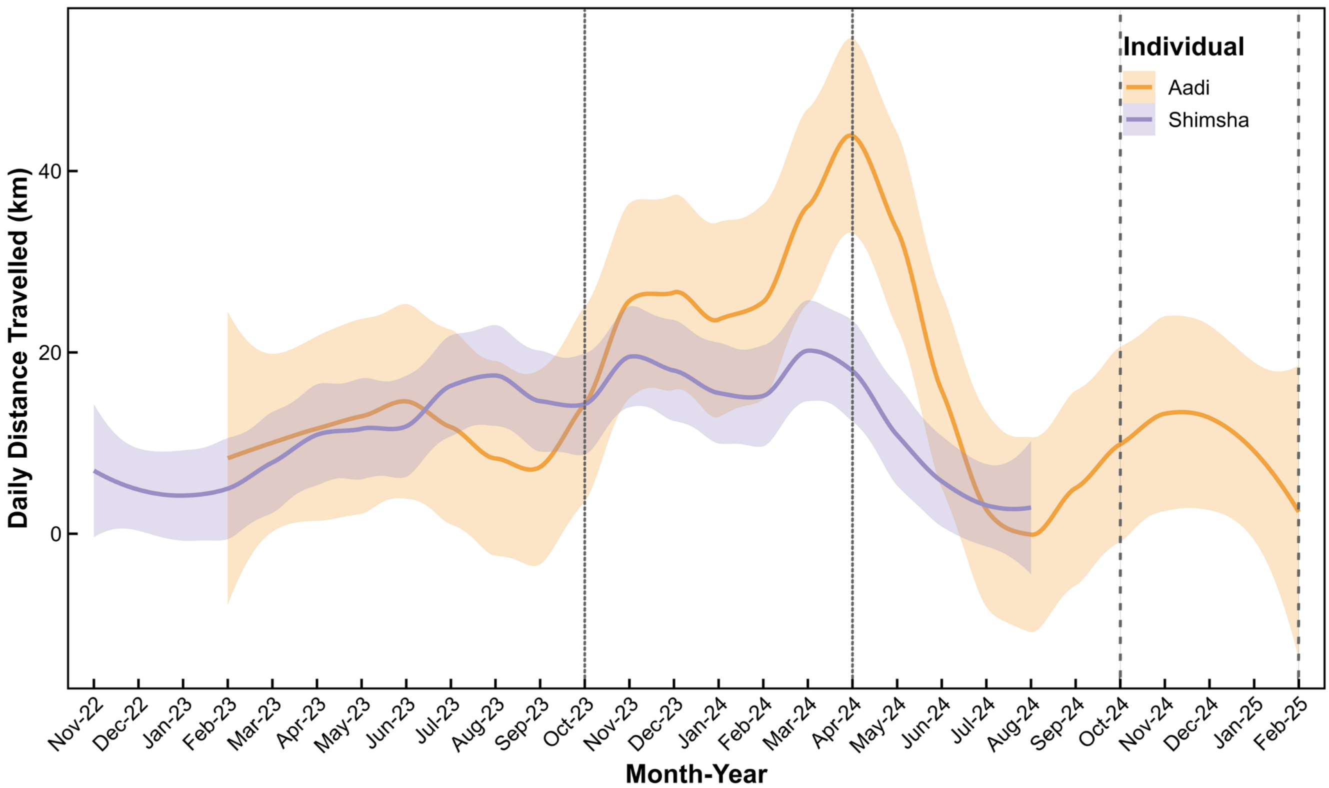

Figure 3. Comparison of age-dependent movement patterns in two spot-billed pelicans tracked using GPS telemetry. The juvenile (Shimsha) shows a progressive increase in daily distance travelled over time, whereas the adult (Aadi) exhibits a cyclical movement pattern with pronounced peaks in daily travel during breeding seasons, consistent with central-place foraging behaviour. Vertical dashed lines indicate the onset and termination of Aadi's breeding periods (October 2023–April 2024 and October 2024–February 2025). Lines represent LOESS-smoothed mean daily distance travelled, with shaded bands indicating 95% confidence intervals.

Discussion

This study provides novel insights into the post-release movement ecology of rescued spot-billed pelicans, revealing distinct ranging strategies between a hand-raised juvenile and a rehabilitated adult. The application of GPS telemetry, coupled with dBBMM analysis, enabled the precise quantification of utilization distributions and temporal dynamics in space use, contributing to an understanding of individual-level variation in this Near Threatened species.

The movement patterns of Shimsha and Aadi reflect fundamental differences in life-history stage and prior experience. Shimsha's gradual spatial expansion and increasing daily distances traveled align with the ontogenetic development of foraging skills and spatial knowledge acquisition in juvenile waterbirds (Mendez *et al.*, 2017). The progressive shift from localized movements near the release site to exploration of more distant wetlands suggests increasing independence and competence in identifying foraging opportunities. Hand-raised waterbirds often exhibit protracted development of optimal foraging behaviors compared to wild-reared conspecifics (Delord *et al.*, 2024), and the gradual increase observed here suggests Shimsha acquired foraging skills over an extended period post-release. By Year 2, daily distances approached those of the adult during non-breeding periods, indicating functional integration into wild foraging patterns.

In contrast, Aadi's immediate long-distance departure from the release site and rapid establishment of movements within the Bengaluru–Mysuru corridor indicate retention of spatial memory and navigational abilities despite rehabilitation. This behavioral pattern suggests that adult individuals possess prior knowledge of regional wetland networks, enabling them to navigate efficiently to known foraging and breeding areas (Baert *et al.*, 2022). The restriction of movements to this corridor throughout the tracking period demonstrates spatial fidelity, a common trait among adult waterbirds with established home ranges.

Aadi's evident seasonal variation in space use, with contracted core areas during the second year, reflects habitat familiarity and optimized resource use. The dramatic reduction in UD size during the non-breeding season in Year 2, with movements restricted to the vicinity of Ranganathittu and Karanji Lake, suggests a refinement of foraging strategies and the identification of productive, reliable wetlands. Such spatial optimization has been documented in other colonial waterbirds, where experienced individuals concentrate their foraging effort in familiar, high-quality habitats rather than engaging in exploratory movements (Geary *et al.*, 2020).

The breeding season patterns of Aadi reveal reproductive site fidelity and flexible nesting strategies. The dual breeding attempts in Year 1, including a failed attempt followed by successful breeding at an alternative site, demonstrate behavioral plasticity in response to initial failure. Site-switching following breeding failure is an adaptive strategy in colonial waterbirds, enabling relocation to sites with higher success probability (Danchin *et al.*, 1998; Wilkinson & Jodice, 2022). The subsequent concentration of breeding activity at Ranganathittu in Year 2, reflected by a reduced UD size, indicates the development of site fidelity following successful reproduction, a common pattern in long-lived colonial species (Boulinier & Danchin, 1997).

The elevated daily distances traveled recorded for Aadi during breeding seasons reflect increased foraging effort associated with provisioning demands. Spot-billed pelicans are known to travel substantial distances between breeding colonies and foraging wetlands (Kannan & Manakadan, 2005), and the observed 35 to 42 km/day movements during reproduction align with central-place foraging constraints. The post-breeding decline in DDT suggests reduced energetic demands and potentially greater prey availability or accessibility during non-breeding periods.

From a conservation perspective, the identification of Ranganathittu and associated lakes as critical year-round habitats for Aadi, as well as the Shimsha River corridor, highlights the importance of protecting wetland networks rather than isolated sites. Connectivity between breeding colonies and foraging wetlands is essential for pelican persistence, particularly given the seasonal variation in water availability across India's wetlands (Kannan & Pandiyan, 2013). These findings underscore the need for landscape-level wetland management strategies that maintain hydrological connectivity, regulate disturbance during breeding seasons, and prioritize the protection of interconnected lake systems within the Bengaluru–Mysuru corridor. Such integrated conservation planning will be critical for sustaining breeding populations of spot-billed pelicans in human-dominated landscapes.

The successful post-release survival and breeding of Aadi over two consecutive seasons demonstrates the conservation value of rehabilitation and release programs for spot-billed pelicans. The confirmed breeding success at Ranganathittu indicates that rehabilitated adults can successfully reintegrate into wild populations and contribute at the population level. Similarly, Shimsha's apparent successful transition to independent foraging suggests that hand-raised juveniles, despite extended human exposure, can develop necessary survival skills.

This case report is limited by a small sample size (n = 2), precluding statistical generalization to broader populations. Individual variation in movement ecology can be substantial, and the rescued status of these pelicans may influence ranging behavior compared to colony-reared individuals. Future studies should track larger samples, including wild-caught individuals across multiple colonies, to establish population-level movement patterns and identify whether rescued individuals exhibit behavioral differences. Additionally, incorporating individual marking techniques such as color banding or wing tagging would facilitate long-term behavioral monitoring, site-fidelity assessments, and individual-based movement analyses. For tagged juveniles such as Shimsha, continued monitoring through sexual maturity would reveal whether juvenile spatial patterns predict adult home range establishment. Notably, wing-tagging of 14 pelicans was conducted during 2021-2023, and their resightings have been systematically monitored, providing complementary individual-level data. This study focused on spatial patterns without integrating data on habitat characteristics or prey availability. Future research should incorporate wetland productivity metrics, fish abundance data, and anthropogenic disturbance indices to model habitat selection and identify drivers of space use variation. The integration of accelerometer data could refine activity budgets and distinguish between foraging and non-foraging movements. Long-term tracking beyond two years would enable assessment of lifespan movement dynamics, breeding site fidelity over multiple seasons, and potential dispersal patterns.

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CONFLICT OF INTEREST

R. Suresh Kumar is an Academic Editor at the Journal of Wildlife Science. However, he did not participate in the peer review process of this article except as an author. The authors declare no other conflict of interest.

DATA AVAILABILITY

Data is available on request from the corresponding author.

AUTHOR CONTRIBUTIONS

All the authors contributed to the conception and design of the study. Material preparation and data collection were performed by Aksheeta Mahapatra. The analysis was performed by Aksheeta Mahapatra and Harindra L. Baraiya. The first draft of the manuscript was written by Aksheeta Mahapatra, and all the authors reviewed, edited, and approved the final manuscript.

ETHICS STATEMENT

All procedures involving animal handling were conducted in compliance with the Wildlife (Protection) Act, 1972 of India. Permission for rescue, rehabilitation, handling, and GPS tagging of Spot-billed Pelicans was granted by the Principal Chief Conservator of Forests (PCCF), Karnataka State Forest Department. All veterinary examination, treatment, and tagging were carried out by authorized veterinarians deputed by the Karnataka Forest Department. The study did not involve invasive sampling. The research adhered to national wildlife welfare regulations and ethical standards for the handling of protected species, and complied with the principles of the Convention on Biological Diversity and CITES.

DECLARATION OF THE USE OF GENERATIVE AI

The authors used Gemini 2 Pro for language improvement and paraphrasing during the preparation of this manuscript. The authors thoroughly reviewed and edited all content generated using this tool and take full responsibility for the accuracy, integrity, and originality of the content of the publications.

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TYPE Short Communication

Note on the distribution of *Parahyparrhenia khannae* (Poaceae: Andropogoneae): a rare and endemic taxon from India

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Abstract

In the present paper, we report *Parahyparrhenia khannae*, a rare and endemic grass, as a new distributional record for the state of Maharashtra. This discovery represents both a new species and a new genus record for the state's flora. This finding is particularly significant as population studies for this species are currently underway. To facilitate field identification, we provide a detailed description, a photoplate of the species, alongside images of its natural habitat. Furthermore, we present a comprehensive map of the species' known distributional range within India.

Keywords: Biodiversity conservation, grasses, Maharashtra flora, new record, range extension, taxonomy.

Parahyparrhenia A.Camus, a rare, relatively small Afro-Eurasian genus (Landge & Shinde, 2021), is classified within the tribe Andropogoneae Dumortier. Globally, this genus is represented by seven species distributed across Africa, India, and Thailand (Soreng *et al.*, 2017; Landge & Shinde, 2021, 2022). In India, only two species are known, *viz.*, *P. bellariensis* (Hack.) Clayton and *P. khannae* A.P. Tiwari & Chorghe, both of which are considered endemic to the country (Landge & Shinde, 2021). Taxonomically, the genus is generally considered polyphyletic. Morphologically, it is characterised by the presence of a protruding, pungent callus on the sessile spikelet; a detailed description of its distinguishing characters is provided in Landge & Shinde (2022).

During a phylogenomic study focused on Asian Andropogoneae, correspondence with the second and third authors (TAK and MS) brought attention to an important collection of an interesting grass specimen. This specimen originated from the northern drier regions of Maharashtra, specifically the Jalgaon district. The specimens were subsequently sent to the Blatter Herbarium (BLAT) and identified by the first author (SNKBL) as *Parahyparrhenia khannae* using the key provided by Landge & Shinde (2021, 2022) (Figures 1 & 2).

Prior to this finding, *Parahyparrhenia khannae* was known only from a few isolated localities in the Indian states of Madhya Pradesh and Gujarat (Tiwari *et al.*, 2020; Landge & Shinde, 2022). In this publication, we report the occurrence of *P. khannae* from Charmali village, Jalgaon District, establishing not only a new distributional record but also a new genus record for the grass flora of the state of Maharashtra (Figure 3).

Recent field studies conducted from 2024 to 2026 in the Marathwada and Vidarbha regions of Maharashtra revealed habitat similarities—specifically regarding aridity—to Asirgarh, Sailana, and Ratlam, where *P. khannae* is known to occur (pers. obs.). Based on these ecological parallels, we hypothesise that the species may also be present in the semi-arid districts of Aurangabad and Nagpur. Furthermore, targeted field surveys in Rajasthan, Haryana, and Chhattisgarh are recommended to further delineate the distribution of *P. khannae*.

Morphological description

Caespitose, ephemeral grass, ca. 350 mm high, with shallow roots and geniculately-ascending culms. Culms slender, unbranched, distinctly bicoloured (internodes pale yellow and sheaths green) with definite brown or purplish nodes, glabrous. A single tuft comprising up to 25 culms. Basal sheaths glabrous, somewhat reddish in colour, ca. 8.0 mm long, middle and upper sheaths 35–75 mm long. Internodes are longer than the sheaths, ribbed, prominently nerved, distinctly granulated between the nerves, and glabrous. The sheath mouth is constricted, leading to leaf blade abscission. Ligule membranous 0.9 mm, hairy on the dorsal surface, and the apex is ciliate. Blades linear, long-acuminate, apex acuminate; lamina initially flat, later convoluted; dorsal surface densely hairy, striated, slightly granulated between the nerves, glaucous; ventral surface of the blade is green, striated, prominently granulated with a distinct mid rib. The lowest blade is 8.0×0.5 mm, and the upper is 70×1.0 mm. Inflorescence terminal in a pedunculate fascicle (1–3 racemes each on a separate peduncle per fascicle) of racemes. Racemes 4.0 cm long (without awns) and 9.0 cm long (with awns), solitary, slender, possessing large awns. Spikelets disposed in a heteromorphic pair, lowest pair(s) homomorphic and sterile. Terminal spikelet pair constitutes a triad of one sessile and two pedicelled spikelets. Sessile spikelets, two flowered; lower floret epaleate, sterile; upper floret hermaphrodite, well-developed, and awned. Callus acicular, dorsally channelled, curved in the lower one-fourth, distinctly protruding, oblique at the base, profusely bearded, 2.0×0.2 mm, and honey-coloured. Sessile spikelet 7.0×0.7–1.0 mm, often farinaceous; lower glume coriaceous, dorsally convex, linear-elliptic, 5.0×0.8–1.0 mm, straw, green or greyish to leaden black in colour, setose in the upper half either side of the longitudinal median slit, 6–8-nerved, obscure, apex deeply notched (1.0 mm deep) with hyaline disintegrating membrane, both the margins rounded (except near the apex margins keeled, minutely winged and scabrid), evenly inflexed throughout the length, tightly and evenly clasping the edges of the upper glume. The ventral surface of the lower glume exhibits a median ridge throughout the length responsible for casting a longitudinal scar (channel) on the developed caryopsis. Upper glume coriaceous-membranous, linear-oblong, 4.8×1.0 mm (unopened), 3-nerved (mid nerve scabrid on the keel), apex tridentate (mid nerve excurrent as an arista); dorsally convex and upper portion flattened, margins evenly inflexed, upper margins slightly broader, glabrous, sometimes granulated. Lower floret, sterile and epaleate; lower lemma elliptic-lanceolate, 2.8×0.5–0.6 mm, hyaline-membranous, extremely fragile, nerves barely visible, apex obtuse or erose, puberulous or glabrescent, margins close to the apex puberulous, dorsally longitudinally depressed, closely appressed to the caryopses (in the mature fruiting specimens). Upper floret: hermaphrodite, epaleate: upper lemma with a geniculate awn, lemma body linear-stipitate, 4.0×0.3 mm, lower half hyaline-membranous, rupturable, prominently 3-nerved, glabrous, upper half tough, coriaceous, nerves not visible, husky-brown, bifid, lobes minute, linear (not persistent in fruiting specimens), caducous after anthesis; awn bigeniculate, first column 1.6 cm, second column 1.1 cm, bristle 3.6–4.0 cm; column hirtellus, hair 0.5–1.2 mm long, biseriately disposed on each margin of the twisted column. Stamens three, anthers ca. 0.8 mm, whitish. Lodicules two, scarious-membranous (in fruiting), subclavate-oblong, ciliate (only two on each lodicule), 0.8×0.3 mm, with two prominent cilia, 0.1–0.2 mm. Caryopsis deep purplish, linear-elliptic, 2.8–3.4×0.7–0.8 mm, longitudinally sulcate on the front side and bulged on the lower back because of the embryo; embryo more than half, almost two-thirds of the length, of the caryopsis. Rhachis internode yellowish, 2.1 mm long (before merging in the callus), laterally compressed, densely ciliate (hair white) on the margins, lower hair short ca. 0.5 mm and

Figure 1. Habit and habitats of *Parahyparrhenia khannae* near Charmalli, Jalgaon, Maharashtra, India. A. Closeup of the grass in the habitat. B. Tuft of a single specimen. C. Slope with intermittent basalt rocks. (Based on TAK 3168 at the Blatter Herbarium (BLAT)) (© Dr. Tanveer A. Khan)

Figure 2. Morphological characteristics of *Parahyparrhenia khannae* from Jalgaon, Maharashtra. A. Habit. B. Basal portion of the grass specimen. C. Leaf base, culm, and glabrous node. D–D1: Inflorescence. D. Raceme closeup. D1. Racemes in field showing all geniculate awns on one side. E–G: Sessile spikelet. E. Lateral view. F. Front view. G. Back side view. H & I: Geniculate awn closeup. J–L: Caryopsis. J. Front view (showing a median longitudinal groove/slit). K. Lateral view. L. Back side view. M. Leaf blade surface granulated. (Based on TAK 3168 at the Blatter Herbarium (BLAT)) (© Shahid Nawaz Khwaja Bhai Landge).

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Figure 3. Distribution map of *Parahyparrhenia khannae* A.P. Tiwari & Chorghe in India, prepared using ArcGIS PRO 3.6.1 (Legends: White dot=Type locality; Black dots=Already known localities; Green dot=recent collection locality).

upper hair 1.1 mm long, apex sharply oblique. Pedicel yellowish, shorter than the rhachis internode, 1.8 mm (before merging in the callus), laterally compressed except being angular towards the apex, densely ciliate on the margins, joint between pedicelled spikelet and pedicel scarcely visible. Pedicelled spikelet sterile without florets, equal or subequal to the sessile spikelet, often farinaceous, callus long, indistinct, 0.8–1.0 mm; lower glume elliptic-lanceolate, 7.0×1.0 mm, 7–8-nerved (of unequal lengths, four nerves reach to the apex and are somewhat excurrent), apex broadly bifid, submarginal nerves somewhat keeled and moderately winged all along the length except lower 2.0 mm, wings tend to curl inward, edges of the wing scabridulous, especially towards the apex becoming scabrid bearing processes; dorsal surface granulated on and between the nerves. Upper glume elliptic, 5.5×0.8 mm, subhyaline-membranous, 5-nerved, apex acute, margins hyaline, hairy in the lower two-thirds.

Parahyparrhenia khannae can be distinguished from another species of *Parahyparrhenia* found in India, *P. bellariensis*, based on morphological differences such as ligule, leaf blade size, anther length, *etc.* (Table 1).

Table 1. Morphological comparison of the key characters of two species of *Parahyparrhenia* from India.

Morphological characters	*Parahyparrhenia khannae*	*Parahyparrhenia bellariensis*
Habit	Ephemeral, 10–35 cm high.	Perennial, 50–65 (–90) cm high.
Basal leaf sheaths	Glabrous.	Appressed hairy indumentum.
Ligule	Membranous (only the apex is ciliolate).	Ciliate (biseriately ciliate).
Surface of the blades and sheaths	Granulated.	Non-granulated.
Leaf blade size	2.5–7.0 × 0.5–1.5 cm.	(5.0–) 10–45 × 0.1–0.4 cm.
Anther length	0.5–0.8 mm long.	2.8–3.1 cm long.
Geniculate awn length	4.5–6.7 cm long.	3.2 cm long.

Distribution: Gujarat state (Rajkot University Campus), Madhya Pradesh (Sailana Bird Sanctuary (also known as Sailana Lesser Florican Sanctuary) and Asirgarh fort hill) and Maharashtra (Jalgaon district) (Figure 3). Endemic to Peninsular India (Tiwari *et al.* 2020; Landge & Shinde, 2021, 2022).

Habitats: In Maharashtra, the species was observed growing on a slope among intermittent basalt rocks adjacent to a freshwater stream (Figure 1).

Specimens Examined: INDIA. Maharashtra state, Jalgaon District, 3 km away from Charmali village, 21.2993744, 75.8049824, 14 Sept. 2025, TAK 3168 (BLAT) 8 Preparations.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

All the information available to authors, have been provided.

AUTHOR CONTRIBUTIONS

The first author (SNKBL) conceptualised, designed, and prepared the manuscript; second (TAK) and third (MS) collected the specimens and provided the material for research work, reviewed the manuscript, and arranged the funding for the research work.

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TYPE Natural History Note

Spotting the difference: Sexual size dimorphism and individual identification in the Spot-billed Pelican *Pelecanus philippensis*

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Abstract

In the spot-billed pelican (*Pelecanus philippensis*), sexes are phenotypically monomorphic, though a slight size difference is suspected. This study aimed to determine the extent of sexual size dimorphism (SSD) by examining 10 morphometric characters in 41 adult pelican carcasses (18 males, 23 females) collected at the Kokkare-Bellur Community Reserve, India, between 2018 and 2022. The pelicans were surgically sexed for confirmation. Males were found to be significantly larger than females in nine of the 10 measurements. Notably, culmen length showed a clear distinction with no overlap; lengths less than 320 mm were classified as female and more than 337 mm as male. Comparison of wild pairs through digital photographs confirmed this dimorphism. Furthermore, unique spot patterns on the beak of each individual were discovered, which can facilitate non-invasive individual identification for future behavioral investigations.

Keywords: Beak spots, culmen length, digital photographs, Kokkare-Bellur, morphometrics, non-invasive monitoring, phenotypic monomorphism

In the avian world, over 50% of species are considered monomorphic, with sexes being indistinguishable in plumage (Griffiths *et al.*, 1998). However, sexual size dimorphism (SSD) often exists where reproductive roles are segregated, frequently associated with sex-specific behaviors and life-history strategies (Liker *et al.*, 2021; Fairbairn *et al.*, 2007). While males are often larger than females in birds, notable exceptions exist, such as Falconiformes, Strigiformes, and Charadriiformes (Fairbairn, 1997). The larger female may be advantageous for incubating larger clutches, defending nests, or competing with partners, like in Jacanas (Emlen & Wrege, 2004). In the family Pelecanidae, although sexes generally appear alike, male-biased SSD is known to occur. For instance, it has been determined in the American white pelican (*Pelecanus erythrorhynchos*) (Dorr *et al.*, 2005). In the case of Spot-billed pelican *P. philippensis*, sexes are again reported to be alike (Ali & Ripley, 1978), though males may be larger.

The Spot-billed pelican is among the smallest of the Old World pelicans and is a tree-nesting species. Its historical range across South Asia has contracted significantly, and it is now confined to smaller pockets in India, Sri Lanka, Thailand, Cambodia, and Sumatra (BirdLife International, 2017). Due to a declining population, the species is classified as Near Threatened (BirdLife International, 2017). Southern India hosts 21 known breeding colonies, primarily in coastal regions (Subramanya, 2006), though additional unreported breeding sites may exist. An exception is the inland pelicanry at Kokkare-Bellur in Karnataka, believed to be one of the oldest nesting sites in southern India, where pelicans have nested within the village for over 300 years (Manu & Jolly, 2000; Neginhal, 1977).

In 2017-18, this site witnessed a large-scale mortality of adult pelicans, which was potentially linked to gastrointestinal parasitic infections (Kumar *et al.*, 2019). This alarming event prompted the Karnataka State Forest Department to initiate a long-term monitoring project in 2018. Following this, over the course of four breeding seasons (2018-22), the pelicans that died were first measured for their morphometry, and then their sexes were identified through the surgical post-mortem. This note utilizes these specimens to provide the first detailed quantification of SSD in the spot-billed pelican using morphometric data. It further explores the reliability of using these findings, particularly culmen length, and digital photography to sex pelicans in the wild, thereby providing a valuable, non-invasive tool for conservation research on this Near Threatened species.

Morphological information was recorded from these dead pelicans for 10 characteristics, including head length, culmen length, culmen width between nares, culmen width maximum, culmen depth, tarsus length, tarsus width, mid-toe length, measured to the nearest 0.02 mm using Vernier caliper (Aerospace 300 mm). Tail and wing chord length were measured to the nearest 1 mm using a ruler (Figure 1).

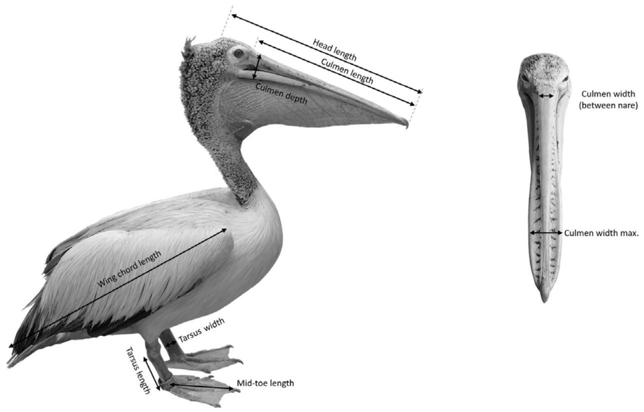

Figure 1. Linear morphological measurements of 10 characteristics were taken of adult spot-billed pelicans at the Kokkare-Bellur Community Reserve, India. Tail length is not marked in the image. It was measured as part of the total length by gently placing the base of the ruler against the base of the middle pair of tail feathers.

All specimens were confirmed to be breeding adults through surgical examination of the reproductive organs during post-mortem. Body mass was intentionally excluded from the analysis as the specimens were in poor physiological condition due to parasitic infections, which would have significantly skewed this variable. However, the skeletal and keratinized structures measured are inherently stable and not subject to the rapid atrophy seen in soft tissues. To assess field applicability, culmen lengths were compared using calibrated ratios derived from digital photographs of known breeding pairs. Digital photographs of wild pelican pairs were obtained using a Canon PowerShot SX60HS (zoom range: 3.8-247mm) after a pair's gender was determined following a mating event. The male mounts over the female and holds her neck for a brief period of time while they mate. This was an essential step since the spot-billed pelican builds its nests in clusters, which means that multiple nests will be joined to form a single platform, making it difficult to tell which sexes and pairings they belong to. To minimize measurement errors, we implemented the following controls: Only photographs where both individuals' beaks were in the same plane and at similar angles relative to the camera were selected; Only photographs showing both pair members in lateral profile with beaks parallel to the camera plane were used. A total of 36 photographs (from an initial pool of >80 images) met these stringent selection criteria for image processing in Adobe Photoshop CS6 to draw lines and measure line length in pixels. Sex-wise differences were evaluated using non-parametric statistics (Mann-Whitney U test), and sexual size dimorphism was quantified using a mean difference index as proposed by Delestrade (2001) to determine the degree of dimorphism in each morphological character.

Mean difference index (MDI)=

$$\frac{\text{(Mean character measurement for female)}}{\text{(Mean character measurement for male)}} \times 100$$

The comparison of morphological characters in 18 male and 23 female spot-billed pelicans showed significant differences in nine of the 10 characters measured. SSD ranged from 4-14% between sexes, with the mean difference index (MDI) exceeding 80% for all characters. Males were substantially larger than females, particularly in head and culmen length (14% larger) and tarsus width and length (10-13% larger) (Table 1).

Although the means for nine measurements were larger for males, there was overlap in the range of values for all characters except for culmen length (Table 1). The measurement of culmen length proved to be a definitive diagnostic tool; the culmen of males was consistently longer than 337 mm, while the culmen of females was always less than 320 mm (Figure 3).

The reliability of using culmen length to sex pelicans in the wild was tested by analyzing 36 digital photographs of known pairs (Figure 2). The ratio of male to female culmen length, calculated from these images, confirmed that males possess a longer beak, with an average ratio of 1.19 ± 0.09 (SD).

To enhance field identification methods, other physical attributes were compared. This investigation revealed no reliable differences between sexes in the presence of a crest, plumage coloration, or eye-patch color. Both sexes displayed a crest, over 90% of individuals had white plumage, and the majority of both males and females exhibited pale yellow eye-patches. However, the study revealed that the spot patterns on the beak were unique to each individual. These patterns, varying from triangular and alphabet-shaped spots to continuous lines formed by converging spots, serve as a natural marker (Figure 4). The variations in beak spot patterns could provide a method for identifying individual birds, subject to for further scientific investigation.

In the family Pelecanidae, which contains 8 species in the genus Pelecanus worldwide, information on SSD is scanty. Most of the available information on morphometry is based on a handful of museum specimens, which suggests that males are larger than females (Marchant & Higgins, 1990; Ali & Ripley, 1978). Our results clearly show that in spot-billed pelicans, males are larger. Male-biased SSD is a common attribute seen in waterfowl (Székely *et al.*, 2007). The advantages of males being larger have been explained with respect to contests over mates or resources, mate preferences by the opposite sex, and resilience to temporary food shortages (Székely *et al.*, 2007). However, the reasons for the male-biased SSD in spot-billed pelicans are still unclear, as there is no information available on the sex differences in breeding behavior and ecology.

Significant SSD was found in nine of the 10 morphological characters considered in this study (Table 1). However, culmen length alone showed clear distinction with no overlap, which can be used to determine the sex of adult spot-billed pelicans. A similar lack of overlap in culmen length was utilized to successfully determine the sex of the American white pelican (*P. erythrorhynchos*) (Dorr *et al.*, 2005). While our results provide a clear threshold for the Kokkare-Bellur population, it remains to be seen if this striking difference holds across other geographically separated populations or if these specific values are population-specific. Currently, no other studies have been conducted in India or other regions within the species' range to provide a comparative baseline. Simple linear measurement of the beak has been used to predict sex in many other waterbirds

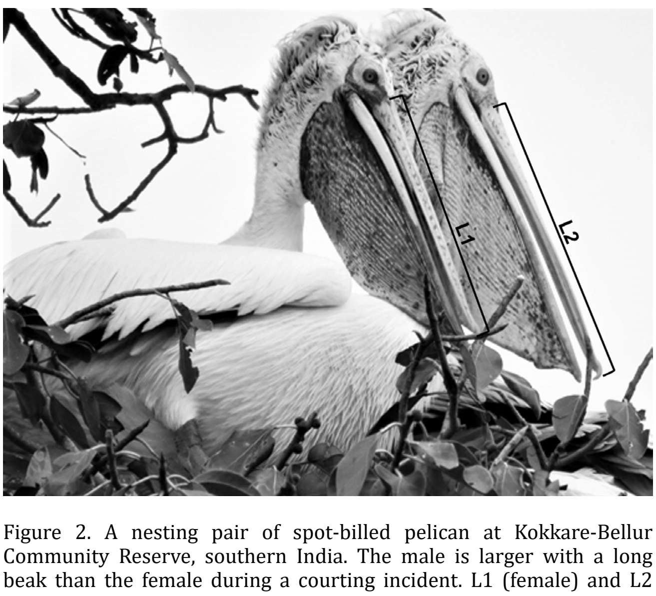

Figure 2. A nesting pair of spot-billed pelican at Kokkare-Bellur Community Reserve, southern India. The male is larger with a long beak than the female during a courting incident. L1 (female) and L2 (male) depict culmen length considered during measurement in Adobe Photoshop CS6.

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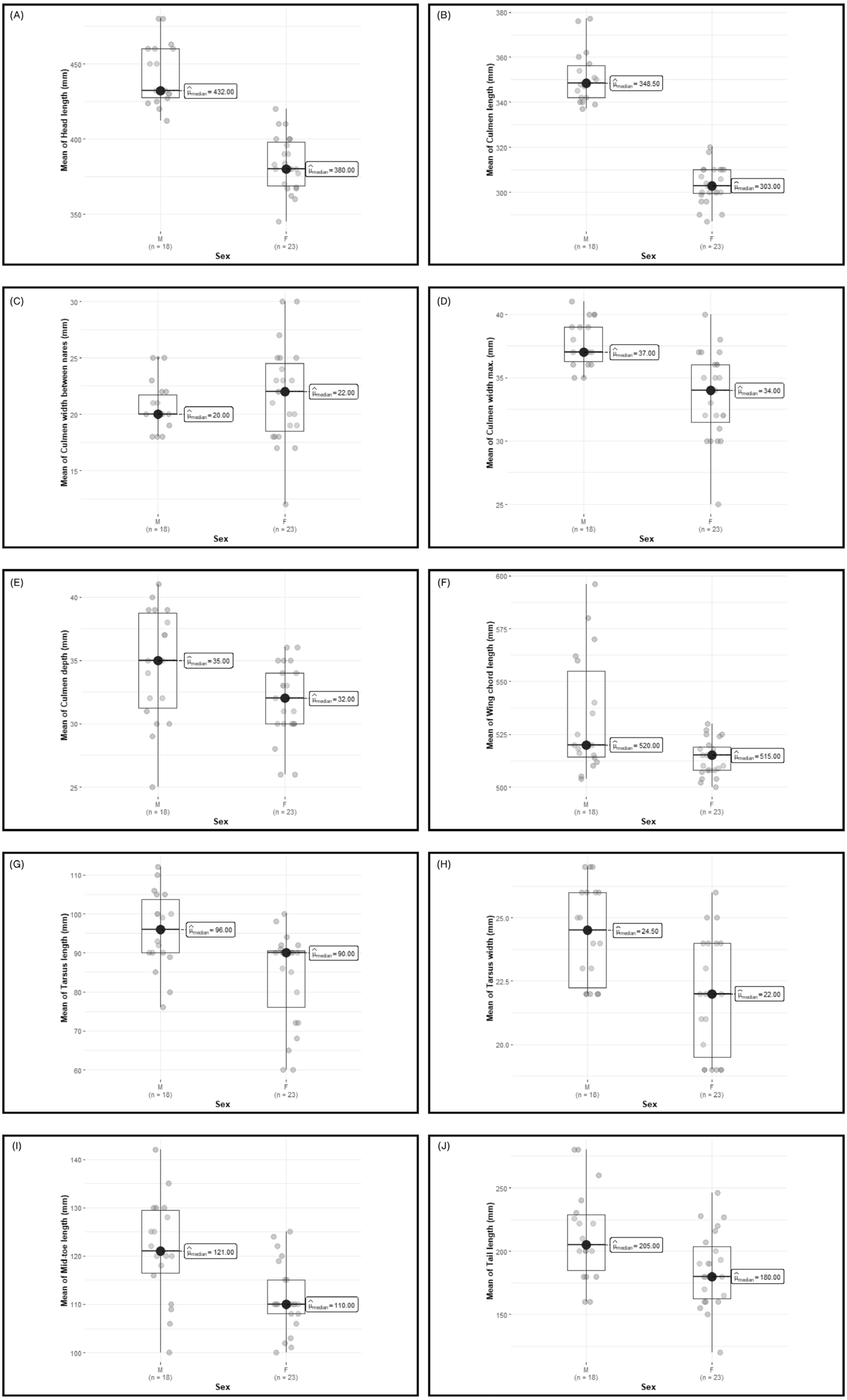

Figure 3. Box plots illustrating the variation in morphological characters between male and female spot-billed pelican. Panels represent: (A) head length, (B) culmen length, (C) culmen width between nares, (D) maximum culmen width, (E) culmen depth, (F) wing chord length, (G) tarsus length, (H) tarsus width, (I) middle toe length, and (J) tail length. The thick horizontal line inside each box indicates the median, the box represents the interquartile range (IQR), and the whiskers denote the standard deviation. Grey circles represent individual data points. Significant differences between sexes were observed for all morphological characters ($P < 0.05$), except for culmen width between nares, which did not show a significant difference ($P = 0.474$).

(*e.g.*, Riordan & Johnston, 2013; Devlin *et al.*, 2004; Murata *et al.*, 1988). The size of the culmen may be affected by both inter- and intrasexual selection (De Marchi *et al.*, 2012). The longer beak may allow males to produce loud clapping sounds to attract females or to threaten potential predators. While bill-clapping is a recognized display in the genus Pelecanus, the specific relationship between culmen dimensions and acoustic properties in spot-billed pelicans warrants further bioacoustic investigation. During mating, when the male mounts the female, males with longer beaks may be at an advantage when they use their beaks to grasp the female's neck (Gokula, 2011). Longer beaks in males may also be a result of greater fitness through sexual selection, as they allow males to more efficiently harvest food resources (Bildstein, 1987) or gather nesting material (Urfi & Kalam, 2006). The culmen is also likely to be more useful for identifying the sex of pelican carcasses, as it degrades more slowly than softer tissues (Dorr *et al.*, 2005).

Table 1. Comparison between male and female adult breeding spot-billed pelicans, based on 10 characteristics. Mean difference index (MDI) calculated as (mean characteristic measurement for female/mean characteristic measurement for male) × 100.

Characteristics	**Male n = 18 Mean ± SD(range)**	**Female n = 23 Mean ± SD(range)**	**Mann-Whitney U statistic**	**MDI (%)**	**p-value**
Head length (mm)	442.6 ± 20.6(412-480)	383.4 ± 18.2(345-420)	1.50	86.6	0.000
Culmen length (mm)	350.8 ± 11.7(337-377)	303.3 ± 8.4(287-320)	0.00	86.4	0.000
Culmen width between nares (mm)	20.6 ± 2.0(18-25)	21.6 ± 4.3(12-30)	234.00	95.3	0.474
Culmen width max. (mm)	37.7 ± 1.8(35-41)	33.6 ± 3.4(25-40)	62.00	89.1	0.000
Culmen depth (mm)	34.6 ± 4.5(25-41)	31.7 ± 2.8(26-36)	125.00	91.6	0.000
Tarsus length (mm)	95.6 ± 10.0(76-112)	84.1 ± 11.8(60-100)	102.50	87.9	0.000
Tarsus width (mm)	24.3 ± 1.9(22-27)	21.8 ± 2.2(19-26)	86.00	89.7	0.000
Mid-toe length (mm)	121.4 ± 10.6(100-142)	111.2 ± 7.0(100-125)	92.50	91.5	0.000
Tail length (mm)	212.7 ± 36.0(160-280)	185.5 ± 29.6(120-246)	118.00	87.2	0.000
Wing chord length (mm)	533.4 ± 28.0(504-596)	513.8 ± 8.5(500-530)	117.00	96.3	0.000

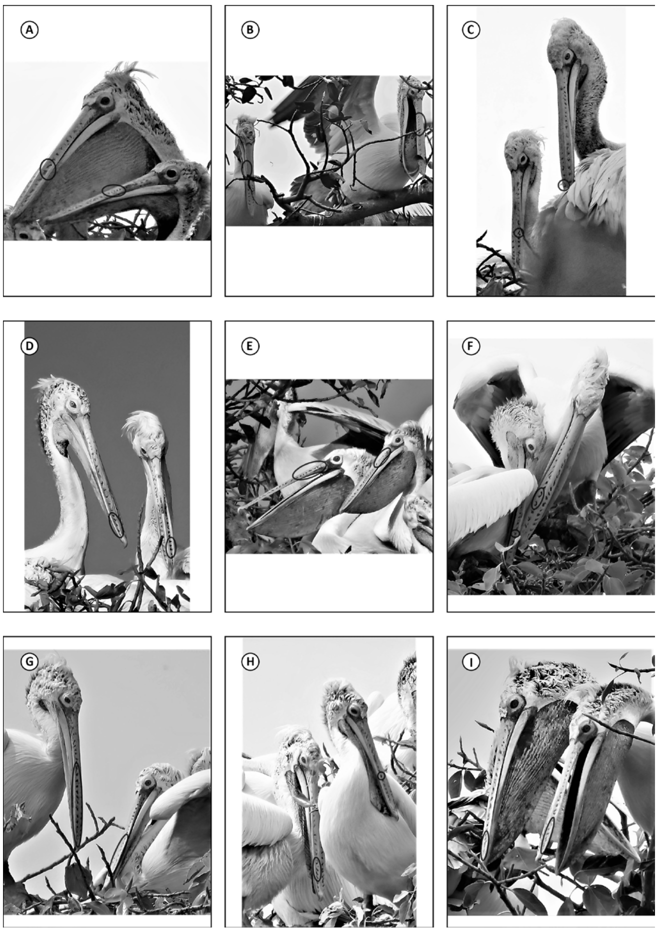

Figure 4. Variation in beak spot patterns of spot-billed pelican pairs photographed during breeding time at Kokkare-Bellur Community Reserve. A-I are 9 different pairs, and the black circles in the beak depict their unique spots.

Sexing birds using digital photographs has been tested before and proved to be a highly reliable, non-invasive method to sex individuals (Williams *et al.*, 2020; Weckauf & Handschuh, 2011; Urfi & Kalam, 2006; Cheong *et al.*, 2007). Such non-invasive techniques are particularly valuable for morphometric studies on wild, free-ranging animals on the Indian subcontinent, where capturing may not be feasible (Mahendiran *et al.*, 2018). This method has also helped to understand social interactions of species, such as larger painted stork (*Mycteria leucocephala*) males, which acquired better nesting sites over territorial winning from smaller conspecifics (Urfi & Kalam, 2006). Males of white ibis (*Eudocimus albus*) during nesting were found to be more agile in stealing prey than females as they were more efficient in intimidating others (Frederick, 1985). Foraging efficiency when compared between male and female Oriental white storks (*Ciconia boyciana*) revealed sex-based differences in foraging habitats and methods of foraging (Sung *et al.*, 2009).

Likewise, this study can be useful in a easier identification of sex in the field for studying sex-specific social, nesting, and foraging behaviors, understanding energetics, parental investments, and effects of differential sex ratio in the population. Future research should specifically leverage these sexing techniques to explore the ecological impacts on mortality across varying habitats. In particular, at sites like Kokkare Bellur, comparing the survival rates of spot-billed pelicans in man-made wetlands versus their natural habitats could reveal if sex-specific vulnerabilities exist. Understanding these mortality drivers is critical for the long-term conservation of the species.

Once a mating pair has been identified in the field, the male and female can be distinguished by the differences in their beak length. As the pairs are rarely observed together during the breeding season apart from the mating and nest-building events, researchers should develop methods to mark the individuals based on their unique beak spots. This method will aid in conducting detailed scientific investigations on their nesting behavior.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY

Data is available on online free public source at Figshare. (https://doi.org/10.6084/m9.figshare.31083748)

AUTHOR CONTRIBUTIONS

AM performed all roles, including conceptualization, investigation, analysis, and writing.

ETHICS STATEMENT

All procedures involving animal handling were conducted in compliance with the Wildlife (Protection) Act, 1972 of India. Permission for handling of Spot-billed Pelicans was granted by the Principal Chief Conservator of Forests (PCCF), Karnataka State Forest Department. All veterinary examinations and treatments were carried out by authorized veterinarians deputed by the Karnataka Forest Department. The study did not involve invasive sampling. The research adhered to national wildlife welfare regulations and ethical standards for the handling of protected species, and complied with the principles of the Convention on Biological Diversity and CITES.

DECLARATION OF THE USE OF GENERATIVE AI

The authors used Gemini 2 Pro for language improvement and paraphrasing during the preparation of this manuscript. The authors thoroughly reviewed and edited all content generated using this tool and take full responsibility for the accuracy, integrity, and originality of the content of the publications.

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Barn Swallows of the Imphal Valley – a potential case of past climatic events leading to year-round residency in the population in Northeast India

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Abstract

Birds have shown notable expansions and contractions of breeding ranges in response to climate change, land-use transformation, and the creation of novel human-made habitats. Synanthropic species, those closely associated with humans, are often at the forefront of such shifts. The Barn swallow (*Hirundo rustica*) is a widespread synanthrope that has successfully expanded its range across most continents. In India, two subspecies of barn swallows are reported to breed in the Himalaya, while one is believed to winter in parts of Northeast India. To ascertain their occurrence range, we conducted surveys in 2022 and 2023 in Manipur and recorded the presence of a resident breeding population of Barn Swallow for the first time. We captured 45 individuals and examined their plumage variation and morphometric characteristics. Mean wing length ranged from 111–123 mm in males and 111–122 mm in females. Comparisons with available museum records of other Indian subspecies showed overlapping morphometric measurements, preventing unambiguous subspecies-level identification. This record extends the known breeding distribution of the Barn Swallow in India and highlights unresolved questions regarding subspecies limits and breeding range dynamics in the eastern part of the subcontinent.

Keywords: Breeding range, colonization, hybridization, plumage variation, subspecies limits.

Introduction

What drives the occurrence of a species remains a fundamental question in natural history. Many argue that the species occurrence is the result of the combined influence of ecological and historical processes that shape niche availability, dispersal, and colonization (Parmesan *et al.*, 2005; Gaston & Fuller, 2009; Bridle & Hoffmann, 2022). But the global environment and anthropogenic changes, including climate, land-use modifications, add to this complexity sometimes leading to biotic homogenization. Owing to these changes, many species of birds have shown prominent shifts, both expansion and contraction, in their breeding ranges (Massimino *et al.*, 2015; Pigot *et al.*, 2010; Rodríguez, 2002). Interestingly, species that benefit by associating with humans – the commensals – exploit novel and widespread anthropogenic habitats and thereby show noticeable shifts in their occurrence range (Fawthrop *et al.*, 2025).

The barn swallow (*Hirundo rustica*) is one such human-commensal that is well known among the local people across its distribution range owing to its nature of building its cup-shaped mud nest in human-inhabited areas. As a consequence, it is the most widespread and abundant swallow species in the world, breeding in Eurasia and North America and migrating long-distances during winter to the global south; typically, from tropical Africa, northern Australia, to Central and South America (Turner, 2006). Large distributional range has resulted in different breeding populations, and phylogeographic studies have hypothesized the role of glacial-interglacial periods in shaping the population divergence primarily due to range expansions and contractions in response to climatic shifts (Turner & Rose, 2010).

Across the globe, six subspecies of barn swallows have been recognized, of which four are strict migrants, and two are residents (Dor *et al.*, 2010; Turner & Rose, 2010). The nominate, *H. r. rustica* (Europe, North Africa, and Western Asia), is the largest in body size, with a white to pale-buff vent and a moderately broad, complete breast band. The Asian subspecies, *H. r. gutturalis*, is small, buff-bellied, with a narrower and broken breast band. The Siberian subspecies, *H. r. tytleri*, is intermediate in body size, with a narrow, complete breast band and dark brown vent (Scordato & Safran, 2014). The American subspecies, *H. r. erythrogaster*, is similar to *H. r. gutturalis* with an extensively rufous throat, broken breast band, and rufous chestnut to orange underparts. There are two sedentary subspecies of barn swallows- *H. r. savignii* occurs in Egypt and has a smaller body size with rufous-chestnut underparts, while the Middle Eastern subspecies, *H. r. transitiva*, is similar in size to *H. r. rustica* but has a broader breast band and much darker rufous-buff vent (Scordato *et al.*, 2017). Except for *H. r. savignii* and *H. r. transitiva*, all others are migratory, occupying much of the southern hemisphere during the non-breeding season (Hobson *et al.*, 2015; Liechti *et al.*, 2015; Turner, 2006). Although subspecies vary in morphological traits (Figure 1, Dor *et al.*, 2010; Turner & Rose, 2010; Brown & Brown, 2020), considerable overlap in these characters often complicates subspecies identification, especially in contact zones and poorly sampled regions.

In the Indian subcontinent, three subspecies of Barn Swallow have been reported by Ali & Ripley, (1987), where two - *H. r. rustica* and *H. r. gutturalis* - are believed to breed in the Himalayan region. The nominate, *H. r. rustica*, is thought to breed from Baluchistan till Kathmandu valley, Nepal, while *H. r. gutturalis* is assumed to mix with rustica in Nepal and extend its breeding eastward to North Bengal, Sikkim, Bhutan, and Arunachal Pradesh in India. The subspecies *H. r. gutturalis* is also reported to breed in the Assam valley, south of the River Brahmaputra. While the third, *H. r. tytleri*, is considered a regular winter visitor to Northeast India (Ali & Ripley, 1987). Despite these assertions, the precise breeding limits of these subspecies in India remain speculative, largely owing to the lack of any ecological study on the species in the region.

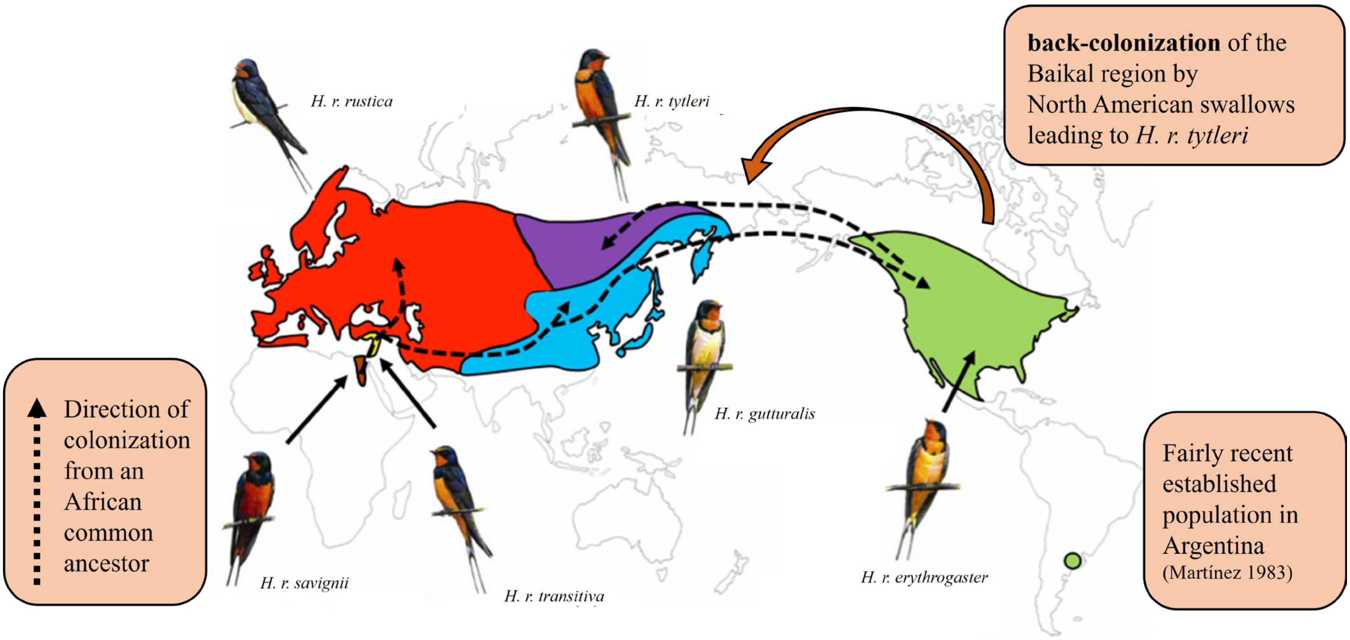

Figure 1. Range map of the six recognized subspecies of barn swallow depicting overall plumage variations in subspecies – color of underparts, breast band, and throat color. Dashed arrows show hypothesized directions of colonization of subspecies across the breeding distribution. The figure also depicts back-colonization by North American swallows (*H. r. erythrogaster*) to the Baikal region, which eventually separated as *H. r. tytleri*. (Figure adapted from Dor *et al.* (2010) and Scordato & Safran (2014). Barn Swallow illustrations by Hillary Burn.)

We, therefore, conducted sampling in the northeastern state of Manipur, which lies at the eastern extremity of the presumed occurrence range of the barn swallow in India. This region is geographically separated from the main Himalayan breeding areas and remains poorly studied, making it an important location for evaluating range limits and potential population differentiation. If breeding occurs in Manipur, the population may represent a peripheral or relatively isolated group compared to Himalayan breeding populations (presumably *H. r. gutturalis*). To evaluate the subspecies identity, we applied the traditional method of variations in morphometric traits (*e.g.*, wing length, tail streamer length) and plumage coloration. Specifically, we compared field-based morphometric measurements with published museum data from recognized subspecies to evaluate whether the Manipur population aligns with any of the existing subspecies descriptions or overlaps with multiple subspecies.

Study area and methods

This study was conducted in the Manipur state of Northeast India, between 2022 and 2023. Rapid surveys across the state confirmed the absence of barn swallows in the hilly region, and therefore, the subsequent surveys were carried out in the Imphal Valley, a low-lying basin (~750 m asl) in the center of Manipur. Imphal is an intermontane valley, spanning an area of approximately 1864.44 km^2, geographically located between 24°–25°N latitudes and 93.50°–94.25°E longitudes. The formation of this almost oval-shaped valley is a result of numerous small rivers, such as the Imphal River and its tributaries Iril, Thoubal, Khuga, and Sekmai, originating from the surrounding hills. The Imphal Valley largely falls within a subtropical monsoon-type (Köppen: Cwa) climate (Beck *et al.*, 2023), and experiences maximum summer temperatures ranging from 32 to 34°C, while winter temperatures can drop to a minimum of 1–2°C.

We conducted surveys radiating from the center of the valley towards its periphery, covering the districts of Imphal East, Imphal West, Bishnupur, and Thoubal. We consulted local people in locating the nests in small towns and villages, and recorded the presence of barn swallow nests associated with human structures and assessed breeding activity. During our surveys in 2023, we located barn swallow nests in approximately 50 properties, all confined to the central valley (Figure 2). At selected sites, we captured barn swallows using mist-nets and documented their plumage characteristics. We recorded standardized morphometric measurements, including body weight (in g), and length (in mm) of tarsus, head, bill, wing, and outer and inner tail length (Table 1). In discussions with local people of the valley, the Meitei, we were informed of the cultural significance of barn swallows. The Meitei community, a Tibeto-Burman ethnic group native to Manipur that largely follows the Hindu belief system (Devi & Devi, 2025), regards

Table 1. Morphometric measurements of adult Bbarn Sswallows captured in Imphal Valley, Manipur. Note: Tail streamer is the difference between outer and inner tail length and is a sexually selected trait with males having longer tail streamers than females.

Morphometric character	♂ (n = 26) Average ± SD(Range)	♀ (n = 19) Average ± SD(Range)	Overall (n =45) Average ± SD(Range)
Body weight (g)	15.67 ± 0.8 (14 – 18)	15.15 ± 0.8 (14 – 16.5)	15.45 ± 0.8 (14 – 18)
Tarsus length (mm)	10.95 ± 0.6 (8.5 – 12)	11.06 ± 0.3 (10.5 – 11.6)	11.00 ± 0.5 (8.5 – 12)
Head length (mm)	29.06 ± 0.7 (27.6 – 31.1)	29.02 ± 0.5 (28.4 – 30.5)	29.04 ± 0.6 (27.6 – 31.1)
Bill length (mm)	11.54 ± 0.4 (10.3 – 12.3)	11.55 ± 0.3 (10.8 – 12.3)	11.54 ± 0.4 (10.3 – 12.3)
Wing length (mm)	117.50 ± 3.2 (111 – 123)	115.16 ± 2.7 (111 – 122)	116.51 ± 3.2 (111 – 123)
Outer tail length (mm)	92.23 ± 10.1 (75 – 118)	81.74 ± 6.4 (65 – 92)	87.80 ± 10.1 (65 – 118)
Inner tail length (mm)	45.85 ± 1.1 (44 – 48)	45.58 ± 1.4 (43 – 48)	45.73 ± 1.3 (43 – 48)
Streamer length (mm)	46.38 ± 10.2 (30 – 71)	36.16 ± 6.2 (20 – 46)	42.07 ± 10.1 (20 – 71)

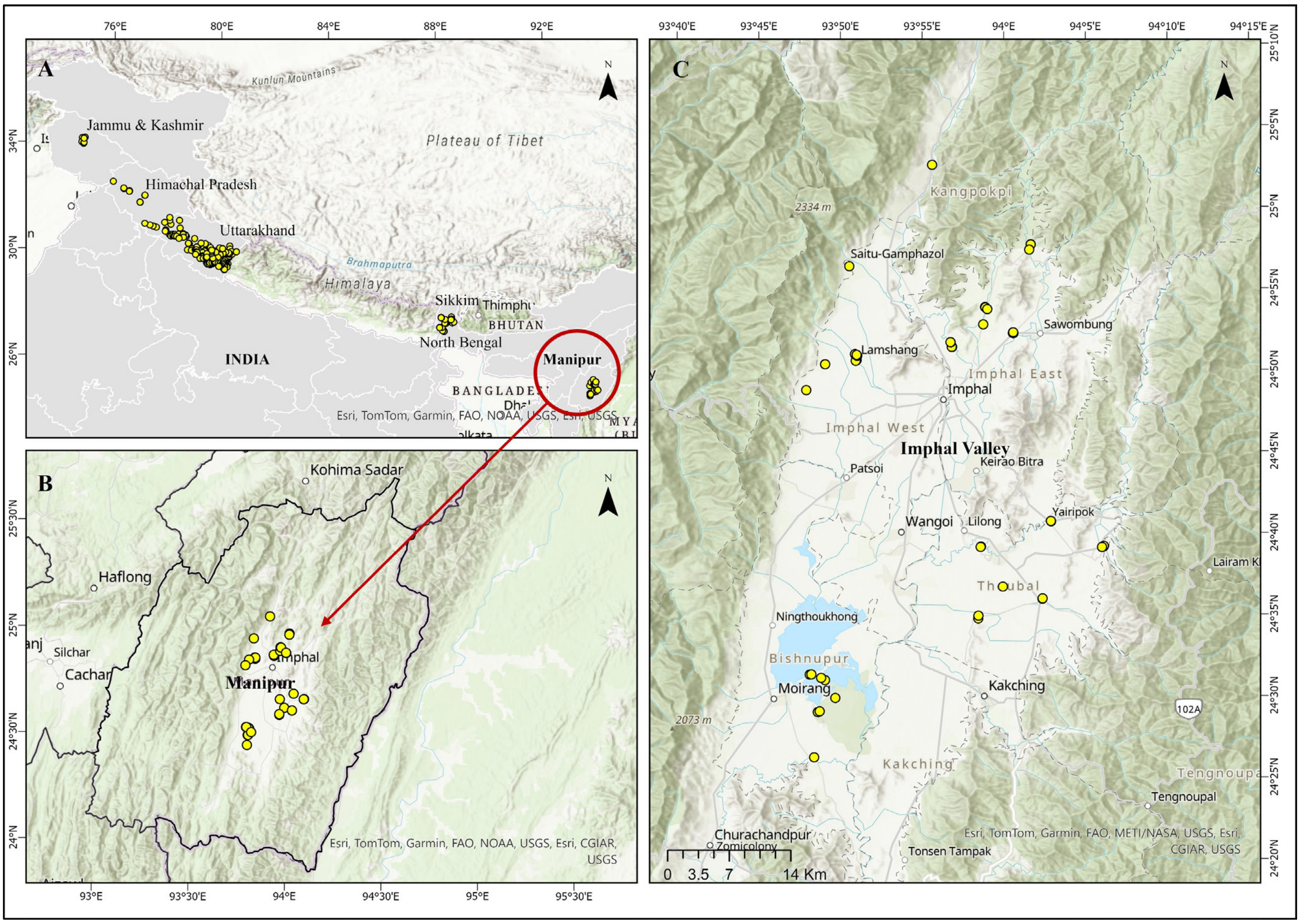

Figure 2. Distribution of barn swallow nest locations showing (A) breeding sites across the Himalayan region, (B) records from Manipur, and (C) a magnified view of nest locations within the Imphal Valley.

the barn swallow as a symbol of Goddess Lakshmi, prosperity, and good fortune. This belief translates into strong protection of nests and barn swallows within private properties, likely contributing to the persistence of breeding populations in densely inhabited areas in Imphal Valley.

Results and Discussion

During our surveys, we recorded the presence of a resident breeding population of barn swallows in Imphal Valley, reported for the first time in science. The population in Manipur was identified as year-round resident based on the continued presence of adults at nesting sites during both the breeding and non-breeding seasons observed during our field surveys, as well as information obtained from property owners where the swallows were nesting. This was further supported by our efforts of ringing adults with uniquely coded metal bands, which allowed us to confirm site fidelity over time. We captured a total of 45 adult barn swallows (26 males and 19 females) from the nests during the non-breeding season. Sex was determined using morphometric measurements, wherein males had longer tail streamers and bright colored plumage compared to females. Individuals captured in the Imphal Valley exhibited quite varying plumage color overall. The swallows were smaller-bodied, with an extensively rufous throat, with some having a broad and

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complete breast band, while some had a broken breast band, and rufous-chestnut to orange underparts extending to the vent (Figure 3).

The average body size (represented by wing length) was found to be 117.50 ± 3.2 mm (range: 111-123 mm) for males and 115.16 ± 2.7 mm (range: 111-122 mm) for females. The averaged outer tail length was found to be 92.23 ± 10.1 mm (range: 75-118 mm) for males, and 81.74 ± 6.4 mm (65-92 mm) for females. When comparing with the measurements of museum specimens of *H. r. rustica*, *H. r. gutturalis* and *H. r. tytleri* (Ali & Ripley, 1987), the measurements from Manipur's breeding population overlapped with all three subspecies preventing unambiguous subspecies identification (Table 2). Although plumage coloration was not quantitatively assessed, qualitative observations suggested that individuals from Manipur, particularly in throat and underpart coloration, resemble the American subspecies *H. r. erythrogaster* and the Siberian subspecies *H. r. tytleri*. However, whether the Manipur population represents an intermediate form between these subspecies can also not be determined, due to substantial overlap in morphological traits and the absence of quantitative plumage analyses. These preliminary observations highlight the need for more comprehensive studies on subspecies distributions in South and Southeast Asia, which may reveal a more complex biogeographic pattern than currently recognized.

Interestingly, populations from different subspecies are also known to intermix and form hybrid zones (Scordato *et al.*, 2017, 2020), exhibiting diverse migratory strategies. Birds from the rustica – gutturalis hybrid zone in western China migrate either westward to Africa or south across the Tibetan Plateau into India (Turbek *et al.*, 2022), and populations breeding in the Amur contact zone winter in Southeast Asia (Heim *et al.*, 2020). Yet uncertainties remain, particularly in Asia, where subspecies and hybrid populations exhibit diverse and poorly resolved migratory strategies. For instance, migration of the Siberian *H. r. tytleri* is poorly known, with only one geolocator-tracked individual suggesting a direct route into Southeast Asia (Anisimova *et al.*, 2026). These contrasting patterns highlight significant knowledge gaps in the migratory connectivity of Asian barn swallow populations, particularly those moving into or wintering within the Indian subcontinent.

Barn swallows are known for their exceptional dispersal ability and for repeatedly colonizing new regions through both natural movements and human-mediated habitat expansion (Hobson *et al.*, 2015; Scordato *et al.*, 2017). Phylogenetic studies indicate that the *H. rustica* complex is monophyletic and structured into two major clades: a Europe–Middle East clade and an Asia–America clade (Zink *et al.*, 2006; Dor *et al.*, 2010). European and West Asian populations differentiated around the onset of the Holocene (Smith *et al.*, 2018). The East and South Asian lineages colonized independently during the late Pleistocene, while the colonization of the Americas, a relatively recent event, likely occurred at least 50 thousand years ago (kya; Lombardo *et al.*, 2022).

Notably, a secondary dispersal event from North America back into Asia at approximately 27 kya has been proposed (Figure 1), explaining the close genetic affinity between *H. r. tytleri* and *H. r. erythrogaster* (Zink *et al.* 2006). Against this backdrop, we propose two non-mutually exclusive hypotheses to explain the origin of the Manipur population. First, a secondary colonization and admixture hypothesis – where the breeding population in Manipur may have originated from *H. r. tytleri*, with historical introgression from *H. r. erythrogaster* following back-colonization into Asia, resulting in the observed intermediate phenotypic traits. This can be tested via genome-wide analyses to look for admixture signatures, as well as broader sampling across putative contact zones in Central and East Asia.

Table 2. Morphometric measurement of traits - wing length and outer tail length (in mm) reported by Ali & Ripley (1987) of museum specimens of *H. r. rustica*, *H. r. gutturalis* and *H. r. tytleri* compared with Barn Swallows sampled in the present study from Imphal Valley, Manipur. Sample sizes are given wherever available as (n).

Subspecies	**Wing length (mm)**		**Outer Tail length (mm)**	
	♂ (n)	**♀ (n)**	**♂ (n)**	**♀ (n)**
H. r. rustica	120 – 129 (n = 26)	116 – 128 (n = 18)	93 – 122(n = 26)	76 – 107(n = 18)
H. r. gutturalis	110 – 123	108 – 113	72 – 96	67 – 73
H. r. tytleri	115 – 124	-	74 – 79	-
Barn Swallows from Manipur	111-123(n = 26)	111-122(n = 19)	75-118(n = 26)	65-92(n = 19)

Second, a shift in migratory strategy hypothesis - the wintering *H. r. tytleri* populations in Northeast India may have reduced or abandoned long-distance migration and become sedentary. Similar shifts have been documented in North American barn swallows (Winkler *et al.*, 2017), which began breeding within their former wintering range in South America during the 19th century. This scenario can be tested using tracking data (*e.g.*, geolocators or stable isotope analyses) to determine migratory connectivity, along with long-term demographic monitoring to assess residency and recruitment patterns.

In addition, the establishment of breeding populations in the Imphal Valley may have been facilitated by favorable climatic conditions and the availability of nesting sites; evaluating this possibility would require habitat suitability modelling and comparative ecological data from adjacent regions. If supported, either scenario would suggest a notable shift in range limits and/or migratory behavior, highlighting the ecological flexibility of the barn swallow. Furthermore, whether the Manipur breeding population is demographically or genetically connected to migratory *H. r. tytleri*, as suggested by Ali & Ripley (1987), remains unresolved and warrants further investigation.

Significance and future directions

This study provides the first documentation of a resident breeding population of barn swallows in Manipur, extending the known breeding range of the species in the Indian subcontinent. It highlights a critical ecological gap in our understanding of avian biogeography in this under-studied region and challenges long-standing assumptions about subspecies limits. Future work should integrate detailed breeding ecology, long-term monitoring, and climate niche modelling to evaluate the drivers of residency and range expansion. Comparative studies between resident populations in Manipur and migratory Himalayan populations could yield valuable insights into life-history flexibility under changing climatic regimes. More importantly, genomic analyses will be essential to resolve the subspecies identification, their evolutionary origins and divergence times, and to test hypotheses of admixture and secondary colonization. More broadly, our findings emphasize the importance of natural history observations, particularly in culturally diverse landscapes where human attitudes can profoundly shape the distribution and persistence of synanthropic species.

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Figure 3. Variation in plumage coloration in adult barn swallows sampled from the Imphal Valley, Manipur. Row A shows males with long tail streamers, and Row B shows females with shorter tail streamers. Underparts range from buff to rufous-chestnut to orange in both sexes (Row A & B). Variation is also evident in breast-band and throat characteristics (Row C), including narrow and broken breast bands (typical of *H. r. gutturalis*), narrow and complete breast bands (typical of *H. r. tytleri*), and broken breast bands diffused with rufous throat coloration (typical of *H. r. erythrogaster*).

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CONFLICT OF INTEREST

R. Suresh Kumar is an Academic Editor at the Journal of Wildlife Science. However, he did not participate in the peer review process of this article except as an author. The authors declare no other conflict of interest.

DATA AVAILABILITY

Data is available on request from the corresponding author.

AUTHOR CONTRIBUTIONS

AK and RSK conceived the idea. AK collected and analysed the data and wrote the first draft of the paper. Both AK and RSK revised the initial draft and approved the final draft of the manuscript for submission.

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Corrigendum to "Economic valuation of ecosystem services in the Kole wetlands, A Ramsar site in Kerala, India"

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In the published article, the author list inadvertantly ommitted Mannamparambath Krishnadas, Kunnath Chalil Ayyoob, and Mohan Shaji during the initial manuscript submission due to a submission oversight. The concerned authors have contributed to the research and analysis.

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Ms. Neha Vidyadhar Tamhankar: Conceptualization, methodology design, data collection, analysis, and manuscript drafting.
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This corrigendum has been issued following approval from all authors and in accordance with journal policies. The original article has been updated to reflect these changes, and the corrigendum is linked to maintain the integrity of the scholarly record. This correction does not affect the results, interpretation, or conclusions of the article.

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Corrigendum to "First photographic evidence of Indo-Pacific Humpback Dolphin (*Sousa chinensis* Osbeck, 1765) from the tidal river Rupnarayan, West Bengal, India"

Dona George[1], Gargi Roy Chowdhury[1], Kanad Roy[1], Pranay Bhatnagar[1], Shovana Ray[1], Qamar Qureshi[1] & Vishnupriya Kolipakam[1,2]*

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In the published article, an error occurred in the title where the district name was incorrectly stated. This oversight happened during the initial manuscript submission process and was unintentionally missed by the authors.

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The authors confirm that this correction does not affect the results, interpretation, or conclusions of the study. The authors apologize for any inconvenience caused.

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